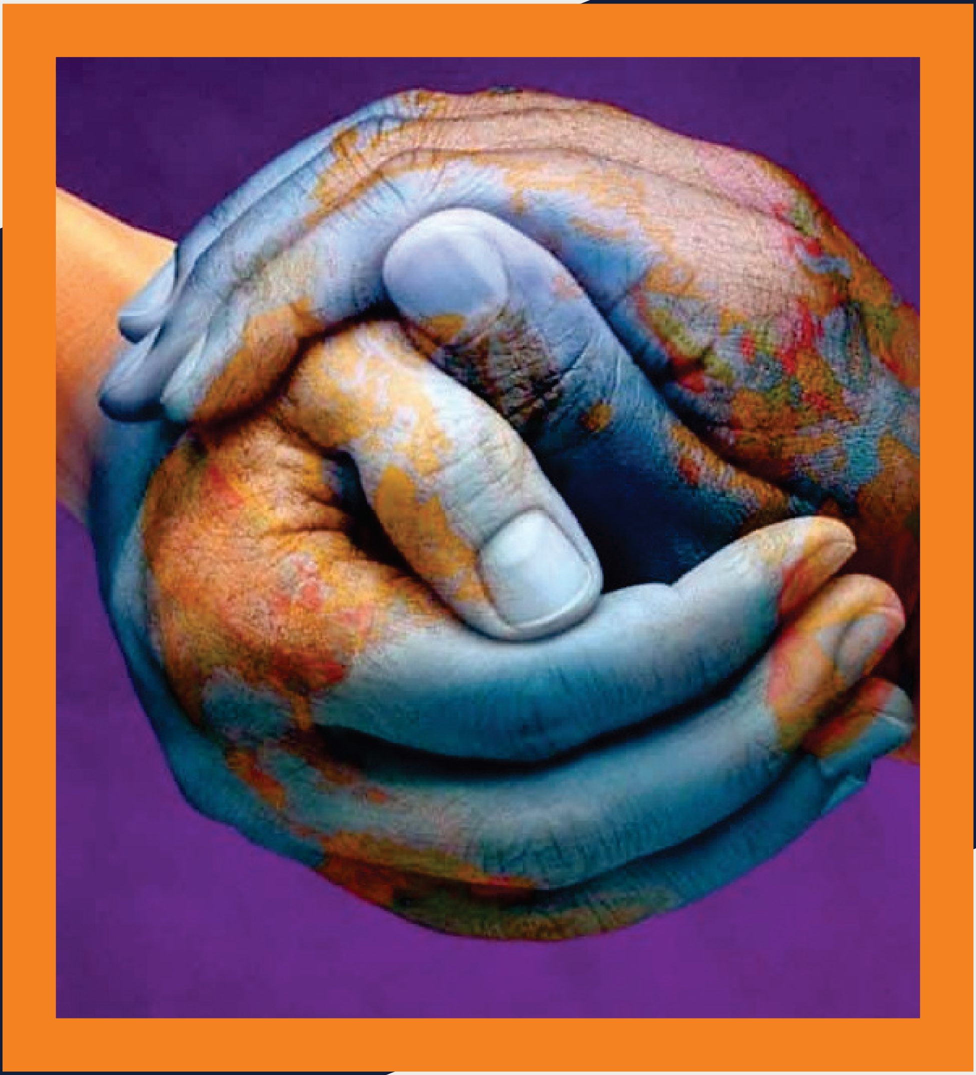
FOUNDATION COURSE IN HUMAN VALUES



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CHAPTER 1

A BRIEF DISCUSSION ON BROADBAND TECHNOLOGY

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ABSTRACT:

Broadband technology refers to the various technologies and systems used for high-speed internet access. The term "broadband" is used to describe the ability to transmit a large amount of data quickly, which is made possible by using a wider range of frequencies than traditional narrowband technologies. Broadband technology includes a variety of wired and wireless systems, including cable modems, digital subscriber line (DSL), fiber-optic cables, satellite, and cellular networks. Broadband technology has revolutionized the way people communicate, work, and access information. It has enabled high-quality video streaming, online gaming, cloud computing, and telecommuting. The development and deployment of broadband technology continue to play a crucial role in economic growth, education, healthcare, and social connectivity.

KEYWORDS:

Bandwidth, Cable Modems, Digital Subscriber Line (DSL). Fiber Optic, High-speed Internet.

INTRODUCTION

Despite the recent expansion of broadband technology, a sizable portion of the globe still lacks access to high-speed Internet. The additional costs of developing the required infrastructure to supply DSL or cable in many regions, particularly rural ones, are too high when contrasted with the very small number of clients Internet service providers would acquire. However, there would be no need for new infrastructure if broadband could be provided through power lines. Broadband service may be available everywhere there is power. In certain regions of the globe, high-speed data transport across the current electric power distribution network is possible thanks to technology. In order to provide users with high-speed internet access, Voice over Internet Protocol, and other broadband services, Broadband over Powerline will use electric power lines to connect to their homes and places of business. Up to 3 megabits per second of data may be sent over power lines and into houses using a combination of radio, wireless networking, and modem technology. The BPL developers might collaborate with power companies and Internet service providers to offer broadband to everyone with access to electricity by changing the present power grids with specialized equipment [1].

Customers may get high-speed internet connections via their electrical outlets thanks to broadband over powerlines. A power line modem does not need any additional wiring or installation and can be plugged into any electrical outlet around the property. The use of PLC technology to provide broadband Internet access over regular power lines is known as "broadband over power lines." For high-speed Internet connectivity, a computer just has to plug a

BPL modem into any outlet in a facility that is set up for it.BPL may have advantages over traditional cable or DSL connections because of the enormous infrastructure that is already in place, which enables isolated residents to access the Internet with just a little outlay of equipment on the part of the utility. It would also be considerably simpler to connect other equipment, such TVs or sound systems, with such widespread availability.The delivery of the service is far from being a consistent, repeatable procedure due to variations in the physical features of the power network and the existing absence of standards. Furthermore, it's not entirely clear how much bandwidth a BPL system can offer in comparison to cable and wireless.

The main issue is that electricity lines are intrinsically a highly loud environment, which has been highlighted by the deployment of BPL. The system has to be built to handle and get over these normal signaling hiccups. Because power system design philosophies have historically differed between Europe and the United States, broadband over power lines has advanced more quickly in Europe. Step-down transformers are used in power distribution to lower the voltage for consumer usage. Transformers, however, are unable to easily pass BPL signals because of their large inductance, which causes them to function as low-pass filters that block high-frequency signals. Repetizers must thus be connected to the transformers. A single home or a small group of homes may be served by a tiny transformer that is mounted on a utility pole in the US. A somewhat bigger transformer often serves 10 or 100 homes in Europe. This change in architecture doesn't significantly affect electricity distribution for consumers. However, a typical American city needs an order of magnitude more repeaters to deliver BPL over the power grid than a comparable European city does. On the other side, since there would be less traffic on the available bandwidth to the transformer, each family will be able to connect faster. Using BPL as the backhaul for wireless communications, such as by mounting Wi-Fi access points or cell phone base stations on utility poles, is one potential option. This would let end users within a certain range to connect using the equipment they currently own.

Signal strength and operational frequency are the second important problem. The system is anticipated to employ frequencies between 10 and 30 MHz, which have long been used by amateur radio operators, international shortwave broadcasters, and a number of communications systems. Unshielded power lines will serve as antennas for the signals they transport and may obstruct short-wave radio communications.The many technologies that are utilized to offer broadband to end users, the actual design and operation of BPL systems, the BPL business model, and the regulatory obstacles that BPL must overcome in order to be profitable will all be covered in this course. Let's look at the state of broadband service in the United States right now to get things started.

DISCUSSION

Current Status of Broadband Delivery

A range of technologies, network designs, and transmission techniques are used to give broadband access and services. The most important broadband technologies are as follows:

1. Subscriber Digital Line
2. Technology Fiber
3. Wi-Fi Coaxial Cable BPL

Over the past few years, there has been a sharp increase in the use of fast Internet connections. Coaxial Cable and Asymmetric Digital Subscriber Line now rule the market. A comparison of the different access technology alternatives.

Subscriber Digital Line

DSL is a high-speed Internet connection that makes use of the same cables as a standard phone line. Two copper wires make up a typical telephone installation in the United States. This pair of copper wires has enough capacity to support both voice and data traffic. Only a small portion of the wires' capacity is used by voice signals. DSL takes use of this residual capacity to transmit data across the connection without interfering with voice communication.

The frequencies that switches, telephones, and other equipment may convey are restricted by standard phone service. Human voices may be heard in the 400–3,400 Hz range while speaking in natural conversational tones. The majority of the time, the cables themselves are capable of handling frequencies up to several million Hertz. The capacity of the telephone line may now be securely used by much more modern technology that transmits digital data, and DSL accomplishes precisely that[2], [3].

Benefits of DSL

1. Use of a phone line for both voice calls and an Internet connection simultaneously is possible.
2. a speed that is far faster than a standard modem.
3. uses the existing phone line rather than installing new wiring.
4. In most cases, providers supply a modem with the installation.
5. DSL's limitations
6. The closer you are to the provider's headquarters, the higher the connection quality.
7. Over the internet, receiving data is quicker than sending it.
8. DSL is not universally accessible.

The DSL technology comes in a number of different forms. When referring to DSL in general, the phrase "xDSL" is often used, where "x" is a variable. The descriptions of eight distinct DSL iterations are provided here.

Disparate DSL

Because the download speed is higher than the upload speed, it is referred to as "asymmetric". Due to the fact that the majority of Internet users view or download significantly more data than they send or upload, ADSL operates in this way.

High-speed DSL

offering transfer rates similar to those of a T1 line HDSL needs two lines that are distinct from a typical phone connection and transmits and receives data at the same pace.

ASDL ISDN

With a fixed rate of 144 Kbps in both directions and a focus on Integrated Services Digital Network consumers, ISDL is slower than most other types of DSL. Customers of ISDL benefit from the ability to utilize their current hardware, although the actual speed increase is often just 16 Kbps.

Multi-Rate Diagonal DSL

This is symmetric DSL, which supports multiple transmission rates. The service provider determines the transfer rate, usually depending on the service level.

Rate Adjustable DSL

This common ADSL variant enables the modem to modify the connection speed according on the length and caliber of the line.

Diagonal DSL

This variant transmits and receives data at the same rate, much as HDSL. Although SDSL only uses one line as opposed to HDSL's two, it still needs a separate line from the phone.DSL with a high bit rate VDSL is an asymmetric connection that is very fast, but it can only be used across a small area using conventional copper phone cable. VoDSL, a kind of IP Telephony, enables the consolidation of many phone lines into a single phone line with data-transmission capabilities.

The majority of DSL connections in households and small businesses are asymmetrical. On the basis of the premise that the majority of Internet users consume much more data than they transmit or upload, ADSL splits up the available frequencies in a line. According to this presumption, the user will profit the most if the connection speed from the Internet to the user is three to four times quicker than the connection from the user back to the Internet.

How much of a benefit a user will experience will depend on how far away they are from the provider of the ADSL service. The signal quality and connection speed diminish with increased connection length since ADSL is a distance-sensitive technology. Although many ADSL providers set a lower limit due to speed and service quality concerns, the maximum distance for ADSL service is 18,000 feet. While customers closer to the central office have faster connections, ADSL customers at the extremes of the distance limits may experience speeds well below the promised maximums.

Upstream rates of up to 640 kilobits per second and downstream speeds of up to 8 megabits per second are both possible with ADSL technology over a maximum distance of around 6,000 feet. In reality, the fastest rates currently being commonly provided are 1.5 Mbps downstream and 64–640 Kbps upstream.DSL is restricted by distance, while voice calls are not. This is because loading coils are used to amplify the speech signals. A voice coil in the loop between a phone and the phone company's central office will prevent a user from using ADSL since these loading coils conflict with ADSL signals. Additional elements that could prevent a user from receiving ADSL include:

Bridge taps are connections that provide service to additional consumers between the user and the central office. In a typical phone system, consumers would not be aware of these bridge taps, but they may cause the circuit's overall length to exceed the service provider's permitted distance.Fiber-optic cables - If a component of a telephone circuit uses fiber-optic cables, ADSL signals cannot pass through the conversion from analog to digital and back to analog that takes place.

Two sets of equipment are used by ADSL, one at the provider's end and one at the consumer end:There is a DSL transceiver at the customer's location, which could also provide additional services. DSL transceivers are often referred to as DSL modems by residential consumers. ATU-

R, which stands for ADSL Transceiver Unit - Remote, is the right word, nonetheless. Whatever name it has, the transceiver is the device that connects the user's computer or network to the DSL line. There are numerous ways the transceiver may connect to a customer's equipment, but 10BaseT Ethernet or Universal Serial Bus connections are used in most home setups. The majority of ADSL transceivers are only transceivers, however some of the devices may also include network switches, routers, or other networking hardware[4]–[6].

To accept client connections, the DSL service provider has a DSL Access Multiplexer. The equipment that makes DSL possible is the DSLAM at the access provider. A DSLAM combines connections from several users into a single, high-capacity Internet connection. DSLAMs are often adaptable and capable of supporting several DSL types as well as offering extra services like routing and dynamic IP address assignment for users. Many consider VDSL to be the next step in offering a whole home communications and entertainment bundle.Although there are a few differences, VDSL and ADSL both use copper wires to transmit data. VDSL is capable of astounding speeds of up to 16 Mbps in the upstream and 52 Mbps in the downstream. Compared to ADSL, which offers up to 8 Mbps downstream and 800 Kbps upstream, this is much quicker. VDSL, however, is distance-sensitive. It can only function for a few hundred feet, or 4,000 feet, above the copper wire.

It is obvious that the switch from current broadband technology to VDSL might be as important as the switch from a 56K modem to broadband considering the highest speed for ADSL or cable modem is 8 Mbps. The fact that many of the telephone companies' primary feeds are being replaced with fiber-optic cable is the key to VDSL, however. Some phone companies have plans to replace all current copper lines up to the point where a phone line branches off to a house, a practice known as fiber to the curb. The majority of businesses anticipate implementing Fiber to the Neighborhood. With FTTN, fiber is connected to the neighborhood's main junction box rather than being installed down each street.

The distance restriction is removed by installing a VDSL transceiver in a residence and a VDSL gateway in the junction box. The ADSL over fiber-optic connections issue with analog-digital-analog conversion is fixed by the gateway. It transforms the information obtained from the transceiver into light pulses that may be sent across the fiber-optic network to the central office, where the information is then sent to the proper network to reach its target. The VDSL gateway transforms the signal from the fiber-optic connection and transmits it to the transceiver when data has to be transferred back to the computer.

Coiled Cable

Subscribers may use cable modems to access high-speed data services using cable networks, which are often built using a hybrid fiber-coaxial architecture. Although primarily used for homes, cable modem service may also offer some small business services.

Technologies like asymmetrical digital subscriber lines compete with cable modems. The operation of a cable modem and the transfer of cable television channels and websites via a single coaxial cable are discussed in the sections that follow. Signals from the different channels in a cable TV system are each assigned a 6-MHz slice of the cable's available bandwidth before being routed to the residence. Cable television uses coaxial cable, which has the capacity to transport hundreds of megahertz of signals and consequently many channels. Coaxial cable is the sole medium utilized for signal distribution in certain systems. In other systems, fiber-optic cable travels from the cable provider to various communities or regions. The fiber is then cut, and the signals are transferred to coaxial cable for delivery to specific homes.

Because the cable modem system sends downstream data—data sent from the Internet to a specific computer—into a 6-MHz channel, when a cable company provides Internet access over the cable, Internet information can use the same cables. The data appears just like a TV channel on the cable. Thus, the amount of cable space required by Internet downstream data is equal to that required by a single channel of programming. Since it is assumed that most people download far more data than they upload, upstream data information sent from an individual back to the Internet—only uses 2 MHz of the cable's bandwidth.A cable modem on the customer's end and a cable modem termination system on the cable provider's end are needed in order to transmit both upstream and downstream data through the cable television network. All computer networking, security, and administration for Internet access through cable television are implemented between these two pieces of technology.

Virtually the entire bandwidth of a cable channel is made available to the first users who connect to the Internet through it. However, the drawback of coaxial cable is that as more users, particularly those with heavy access, are connected to the channel, all users will have to share bandwidth, which may result in performance degradation. It's likely that performance will be significantly below the theoretical maximums during periods of high use with lots of people connecting. The cable provider may fix this specific performance problem by dividing the customer base and creating a new channel. The performance of the cable modem for Internet connection does not rely on the distance from the central cable office, in contrast to ADSL, which is another advantage. A digital CATV system is designed to provide digital signals to client homes at a certain quality. The burst modulator in cable modems, which is located upstream, is configured with the head-end's location and gives the right signal strength for precise transmission.More than 90% of residences served by cable networks now have access to broadband services, thanks to the cable sector. The cable industry anticipates that industry-wide facility modifications necessary to provide residential consumers broadband Internet access will be finished soon.

Technology Fiber

In recent years, carriers have started building transmission facilities made solely of fiber optic cable that connect the loop demarcation point at an end-user customer premise to a distribution frame in the central office of an incumbent local exchange carrier. Fiber-to-the-home loops are the name given to these loops. More capacity is available with FTTH technology than with any copper-based technology. One instance is a business that now uses a FTTH system that distributes transmission rates up to 500 Mbps among a maximum of 16 customers using commercially available equipment. If needed, this system can symmetrically provide up to 500 Mbps to a single customer. The amount of people online and the time of day also affect how fast a user will actually experience things. A typical FTTH system may supply current and next-generation data services at rates exceeding 100 Mbps, multiple telephone lines, and up to 870 MHz of cable television video services or IP video services.

To deliver FTTH, three different styles of architecture are often employed. The technique of passive optical networks is the most widely utilized architecture. Multiple homes can share a passive fiber network thanks to this technology. This form of network uses only passive components in the field; no electronics are required between the client location and the head-end at the central office. The other designs in use are hybrid PONs, which combine home run and PON architecture. In home run fiber or point-to-point fiber, subscribers have a dedicated fiber strand, and active or powered nodes are employed to handle signal dispersion.

FTTH technology is still in its infancy, yet FTTH implementation is rapidly expanding. Additionally, FTTH equipment costs have dropped significantly. In addition to FTTH technology, some carriers are building fiber-to-the-curb facilities, which only extend 500 feet from the subscriber premises to a pedestal rather than all the way to the customer's house. The pedestal is then connected to the network interface device at the customer's location via copper cables. FTTC technologies enable carriers to provide high-speed data in addition to high definition video services due to the restricted usage of copper[7]–[10].Unlicensed wireless options like WiFi and WiMax, fixed wireless options like MMDS and LMDS, and satellite delivery systems are all examples of wireless broadband alternatives.

CONCLUSION

The way we interact, work, study, and have fun has been changed by broadband, which has become a necessary technology. Broadband has made it possible for consumers and companies to access massive quantities of information, interact with people across the globe, and take part in the global digital economy by being able to offer high-speed internet connection. Broadband has evolved into a necessary tool for contemporary life, enabling everything from online schooling and video conferencing to streaming music and movies. Even though broadband technology has advanced significantly in recent years, there are still many areas that require improvement. There are still many areas of the globe with little or no access to broadband, and there are continuous discussions regarding the price and quality of broadband services in various nations.

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CHAPTER 2

A BRIEF DISCUSSION ON WIRELESS TECHNOLOGY

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ABSTRACT:

Wireless technology has become an integral part of modern life, providing people with access to information, entertainment, and communication from anywhere and at any time. This technology has evolved rapidly over the years, from the first cellular networks to the latest 5G technology, offering higher speeds, lower latency, and greater coverage than ever before.Wireless technology has transformed the way we work, learn, and play, enabling us to be more productive, efficient, and connected. It has also paved the way for new innovations, such as the Internet of Things (IoT) and smart cities, which have the potential to revolutionize entire industries and sectors.

KEYWORDS:

Bluetooth, Cellular Networks, Frequency Bands, Global System,Radio Frequency.

INTRODUCTION

There has been an increasingly fast proliferation of goods and businesses in bands designated for unlicensed use ever since the FCC initially made spectrum in the 902-928 MHz range available for unlicensed use. The widespread deployment of gadgets like cordless phones, security alarms, wireless bar code scanners, and data collecting systems initially happened in the Industrial, Scientific, and Medical band. Many original equipment manufacturers still offer point-to-point and point-to-multipoint system hardware for uses like data acquisition and supervisory control. Additionally, there are numerous suppliers of wireless LAN hardware in this band[1].

The abbreviation Wi-Fi, which stands for Wireless Fidelity, is a catch-all word for any product or service that adheres to the IEEE 802.11 family of specifications for wireless local area network connections. These standards were created by the Institute of Electrical and Electronics Engineers. Wi-Fi networks deliver numerous data speeds up to a maximum of 74 Mbps and operate on an unlicensed basis in the 2.4 and 5 GHz radio bands. The users split the available bandwidth. Any location within signal range of a Wi-Fi equipped base station or access point can send and receive data using Wi-Fi enabled wireless devices, such as laptop computers and smart phones. Mobile devices must typically be 300 feet or less away from a base station.

The "wireless cloud" that is created by Wi-Fi technology encompasses the hotspot area. Depending on the climate and power requirements for the equipment being used, the coverage area's precise dimensions change. The typical coverage radius is between 300 and 500 feet.Reaching potential clients may be hampered by environmental factors like the weather and line of sight.Hotspots have multiplied quickly as Wi-Fi access to the Internet has increased. Hotspot networks with several access points have been built to span bigger spaces, including airports.

Because IEEE 802.11 or Wi-Fi-based wireless local area networks have been so successful, the emphasis in wireless is shifting to the wide area. Although WiFi predominates in the neighborhood, there is still a sizable untapped market in the wide area. With their 2.5G/3G data services, cellular carriers entered this market first, but they were set up to provide basically add-on telephony services. WiMax, a new data-oriented technology, may be the actual threat to cellular data services. Any broadband wireless access network built on the IEEE 802.16 standards is known as WiMax, or Worldwide Interoperability for Microwave Access. Fixed systems using a point-to-multipoint architecture and operating between 2 GHz and 66 GHz are included in WiMax. Broadband wireless access based on WiMax, commonly referred to as wireless DSL, will provide data speeds of 512 Kbps to 1 Mbps. Delivering low-cost, user-installable, indoor premises equipment that does not need to be in line with the base station—i.e., having the antenna in the premises equipment integrated with the radio modem—will be crucial.

WiMax is intended to provide a broadband wireless access service for urban areas. BWA aims to compete with cable modems and DSL by offering a fixed location wireless Internet access service. WiMax systems are designed to serve as the foundation of a carrier service and could support users at distances of up to 30 miles.

To meet the needs of carriers worldwide, the WiMax specifications allow a significantly larger spectrum of possible implementation. When the 802.16 standard was first published, it targeted devices using the 10 GHz to 66 GHz frequency range. Such high frequency systems are more expensive and have a smaller client base since they need line-of-sight to the base station. Additionally, in LOS systems, when a new cell is added to the network, customer antennas need to be realigned. The 802.16a standard has altered the playing field since its first introduction. Systems that operate between 2 GHz and 11 GHz are covered by the 802.16a standard. The non-line-of-sight capability offered by these lower frequency bands eliminates the need for base station and customer unit alignment. A list of WiMax radio connections is shown in 4.

Unlicensed frequency bands are used in Wi-Fi deployments. On the other hand, WiMax can function in both licensed and unlicensed spectrum. There are four bands in the 802.16a frequency range that are very desirable: Multichannel Multipoint Distribution Service (MMDS) at licensed 2.5 GHz has been given 200 MHz of licensed radio spectrum between 2.5 and 2.7 GHz. Licensed 3.5 GHz Band: In the majority of the globe, a licensed spectrum band that is roughly equivalent to MMDS has been assigned in the 3.4 to 3.7 GHz range. Unlicensed 3.5 GHz Band: For fixed site wireless services, the FCC has made an additional 50 MHz of unlicensed spectrum in the 3.65 to 3.7 GHz band available. Unlicensed 5 GHz U-NII Band: In the United States, the 5.15 to 5.35 GHz and 5.47 to 5.825 GHz bands have each been given 555 MHz of unlicensed spectrum. The frequency utilized for 802.11a wireless LANs is known as the Unlicensed National Information Infrastructure band[2]–[4].

Wireless applications are represented by Wi-Fi and WiMax from two very distinct angles. A local network technology called Wi-Fi was created to provide private wired LANs more mobility. Contrarily, WiMax is intended to provide a metro area broadband wireless access service. BWA aims to compete with cable modems and DSL by offering a fixed location wireless Internet access service. WiMax systems might support users at ranges up to 30 miles, but Wi-Fi only supports transmission ranges of a few hundred feet. WiMax is meant to serve as the foundation of a carrier service, while Wi-Fi is aimed at the end user. WiMax and Wi-Fi are distinguished from one another by a number of advancements in radio connection technology in addition to the difference in broadcast range. A comparison between Wi-Fi and WiMax technologies.

DISCUSSION

Fixed Wireless Technologies

In the backhaul networks of phone companies, cable TV providers, utilities, and government organizations, point-to-point microwave links have a long history. Higher frequencies and smaller antennas are now possible because to recent technological advancements. As a consequence, carriers are now able to sell lower cost solutions for the final mile of communications.

Initially used to distribute cable television service, multi-channel multipoint distribution service operates at a frequency of 2.5GHz. For household Internet service, MMDS is currently being developed. With throughputs ranging from 64 kbps to 10Mbps, "two-way" service may be provided using MMDS wireless technology. However, line of sight between the transmitter and receiver is necessary for MMDS systems. The lower MMDS frequencies do not attenuate very rapidly, allowing services to be delivered up to 30 miles from the hub, or 2,800 square miles, of coverage. One of the widest coverage areas of any point-to-multipoint communication technology now on the market is offered by this one.

Local multipoint distribution service is utilized for point-to-multipoint applications including Internet access and telephony in the ranges of 27.5GHz to 28.35GHz, 29.1GHz to 29.25GHz, and 31GHz to 31.3GHz. However, LMDS uses TDMA and has a 3-mile coverage area, allowing multiple users to share a single radio channel.

To supply fixed services, namely phone, video, and Internet access, the system employs a cellular-like network architecture of microwave radios located at the client's location and at the business' base station. With the use of time-division multiple access and frequency-division multiple access technology, numerous users may share a single radio channel within a range of three to five miles. Customers may get data at speeds ranging from 64kbps to 155Mbps.

In an LMDS system, there are four components:

1. The network management system hardware that oversees significant portions of the client network is kept in the network operations center.
2. Diverse NOCs are connected by a fiber-based infrastructure.
3. The base station is where the transition from fiber infrastructure to wireless infrastructure takes place. It is often found on a cell tower.
4. The customer premises equipment normally consists of both inside-the-building equipment that performs modulation, demodulation, control, and interface functions as well as microwave equipment positioned on the outside of a consumer's residence or place of business.

The following are LMDS benefits:

Low entry and deployment costs - The operator is able to plan capital expenditures progressively with new customer acquisition since a major portion of the cost of a wireless network is not spent until the CPE is deployed.

Rapid deployment - A network without fiber simply needs a radio at the customer's location and another one on a tower in the middle of the network. This makes it possible for deployment to happen faster than with typical broadband providers.

Demand-based build out: To guarantee that service may be increased as customer demand rises, LMDS utilizes a scalable design in conjunction with industry standards.

Variable component cost - The infrastructure component of wireline networks often requires a significant capital expenditure. Because LMDS systems shift the cost to the CPE, the operator only incurs costs when a customer signs up for a revenue-paying service.

The system needs line-of-site between the CPE and base station hub, which is one of LMDS's drawbacks. To forward signals across obstructions, repeaters can be needed.

Moisture has an impact on LMDS signals, which may cause "rain fade," or signal degradation as a consequence of heavy rain. In most cases, rain fade issues may be resolved by boosting the signal's transmission power.

Systems for Satellite Delivery

For rural Internet customers who seek broadband access, satellite Internet connectivity is suitable. Satellite Internet employs a satellite dish for two-way data connections rather than phone lines or cable networks. The 500 kbps download speed is about one-tenth of the upload speed.A two-by-three-foot dish, two modems, and coaxial cables connecting the dish and modem are required for two-way satellite Internet. Since the orbiting satellites are over the equator, a clear view to the south is a crucial installation planning requirement. Additionally, just like with satellite TV, trees and heavy rains can interfere with receiving Internet signals.

Due to the usage of Internet Protocol multicasting in two-way satellite Internet, a single satellite may support up to 5,000 channels of communication at once. Data is compressed and sent from one point to many via IP multicasting. The size of the data and the bandwidth are both reduced through compression. The bandwidth constraints of conventional dial-up land-based terrestrial networks hinder large-scale multicasting.The satellite data downlink is identical to the typical terrestrial connection, with the exception that the satellite sends the user's data through the same TV receiver dish. In 1, a satellite delivery system is shown as an example. As you can see in this, the data link to the Internet is provided by a second satellite.

Internet over Powerline Technology (BPL) is also known as Power-line Communications (PLC) or PLC, and PLC and BPL are sometimes used interchangeably. For consumer uses, the FCC has opted to use the phrase "broadband over power line". The customer just has to install a modem that plugs into a standard wall socket and pay a monthly fee comparable to those for other forms of Internet service in order to utilize BPL.

In order to transport data through power lines and into homes at speeds comparable to those of DSL and cable, engineers have combined the technology concepts of radio, wireless networking, and modems. The BPL developers might collaborate with power companies and Internet service providers to offer broadband to everyone with access to electricity by changing the present power grids with specialized equipment.Electric power lines might act as a "third wire" into homes thanks to BPL technology, which would put cable television and copper telephone lines in competition. BPL may be classified as Access BPL or In-Home BPL, and they are each defined as: Through the use of BPL technology, broadband access is made possible over medium voltage power lines.

A home networking solution called in-house BPL makes advantage of the HomePlug Alliance's transmission standards. Because they connect directly to the low voltage electric lines inside a home or office, in-house BPL products can comply with the radiated emissions limits in the FCC's Rules fairly easily. The "middle mile" and "last mile" of a communications line are utilized with Access BPL. This area of the network links households and businesses to high-speed services and the Internet. The drop wire connecting the interface on a house to the cable company network and the wire from the interface connecting to the wall plates in the home, for example, would all be considered part of the last mile for residential broadband service customers who get cable modem service[5]–[7].

Similar to how cable and DSL modems transport messages over cable and telephone lines, BPL modems employ devices built to convey signals over electric power lines. New BPL modems can now transport communications signals across the electric power lines despite their previous challenges because to advancements in processing power.A powerline telecom network may be broken down into three major sections: the backbone, the middle mile, and the final mile. BPL technology transmits high-speed data into the customer's house across medium- or low-voltage power lines, from the viewpoint of the end user. The signal travels via the network's medium and low voltage lines using either transformers or couplers or bridges to bypass the transformer. The system delivers data, audio, and video to the end user's connection at broadband rates. A simple electrical wire from the "BPL modem" must be plugged into any available outlet, and the user must then connect a USB or Ethernet cable to the Ethernet card or USB interface on their PC. The data signal may also link to other wireless, fiber, or other media for last-mile completion and backhaul. Although the actual hardware used for the deployment varies depending on the manufacturer, it usually has some common features.

The Internet is a vast global network of networks linked by cables, computers, and other wired and wireless devices. To move data across the Internet and ultimately to another medium, such a phone, DSL, or cable line, into the houses, big Internet service providers often lease fiber-optic connections from the phone company. Fiber-optic connections are used to send trillions of bytes of data every day because they allow data to be sent without interfering with other forms of communications.The concept of transferring data while utilizing AC power is not new. Data may be sent without a separate data line by combining radio frequency energy and an electric current on the same line. Electric current and RF do not interact with one another since they vibrate at distinct frequencies. Electric companies have been keeping an eye on the efficiency of the power networks with this technology for years. Even networking solutions that use a building's electrical cabling to convey data are now readily accessible. However, the data is not complicated, and the transmission speed is not fast.

The challenges posed by transferring data across electrical lines may be overcome in a variety of ways. The grids used by electric firms include many different parts, including the power wires. Power grids employ transformers, substations, and generators in addition to wires to transport energy from the power plant all the way to a plug in the wall. After leaving the power plant, electricity is distributed to high-voltage transmission lines by way of a transmission substation. These high-voltage wires are the first obstacle in transmitting broadband.

These voltages, which vary from 100,000 to 765,000 volts, are used for transmission. It is not advisable to transmit data at this voltage level. It's much too "noisy." Data must have a defined radio spectrum frequency at which to vibrate without external interference in order to transmit smoothly from point to point.Electricity at a voltage of hundreds of thousands of volts vibrates at several frequencies. The spectrum is completely covered by that level of power. It generates many forms of interference as it spikes and hums along. If it spikes at the same frequency as the RF being used to transfer data, it will cancel out that signal, resulting in the loss or destruction of the data transmission.

By eliminating all high-voltage power cables, BPL gets around this issue. The technology transfers data from conventional fiber-optic cables downstream to 7,200/12,470 volt medium-voltage power lines, which are significantly easier to handle. The data can only be dumped into the medium-voltage cables for a short distance before it starts to deteriorate. Devices that operate as repeaters are put on the wires to combat this. The data is ingested by the repeaters, who then amplify it for the next leg of the trip and repeat it in a new broadcast.Two additional devices are mounted on the electrical poles of one BPL variant to distribute Internet traffic. The Bridge, a device that makes it easier to transport the signal into the residences, and the Extractor, which enables the data on the line to bypass transformers. The transformer's responsibility is to lower the 7,200 volts to the regular 120/240 volts used in typical domestic electrical service. A coupler is required to provide a data channel around the transformer since low-power data signals have trouble passing through a transformer. Data may transfer smoothly and without any degradation from the 7,200-volt line to the 120/240-volt line and into the home using the coupler[8], [9].

The last mile is the final step that carries Internet into the subscriber's home or office.In the various last-mile approaches for BPL, some businesses send the signal into homes along with the electricity on the power line, while others install wireless links on the poles. A bridge gadget makes both possible.A powerline modem that connects into the wall picks up the signal. The signal is sent to the electrical appliances within the house via the modem. Silicon chipsets that are specifically designed to manage the workload of extracting data from an electric current are used in BPL modems. BPL modems are equipped with adaptive algorithms and specifically designed modulation methods to handle powerline noise over a broad spectrum. A plug-and-play BPL modem is about the size of a typical power adapter. It attaches to a standard wall outlet, and the connection is completed by an Ethernet wire that runs to the computer. There are additional wireless variations available.

Access to BPL Architecture Extractors, repeaters, and injectors make up BPL equipment. BPL injectors interact with the medium voltage power lines supplying the BPL service region and are connected to the Internet backbone through fiber optic or T1 lines. Both overhead and subterranean medium-voltage power lines are possible. Overhead wire is fastened to utility poles, which are normally 35 feet above the ground. These wires may be physically placed on the utility pole in a variety of configurations for three phase wiring, which typically consists of a medium voltage distribution circuit going from a substation. From one pole to the next, this physical orientation could shift. The three phase lines may split into one or more phase lines to service different clients. A grounded neutral wire often runs between distribution transformers that provide low voltage electricity to customers and is situated below the phase conductors. It is possible to theoretically inject BPL signals into medium-voltage power lines between two phase conductors, between a phase conductor and the neutral conductor, or onto a single phase or neutral conductor.

A list of some of the tools used to provide BPL is shown below.

BPL modems are connected to the medium voltage power lines via inductive couplers. See 5. Without physically attaching to the wire, an inductive coupler wraps around it to transmit the communications signal onto the power line. How to transfer the signal from the medium voltage line to the low voltage line that enters the home presents a significant issue since the transformer, which reduces the electric power from 7,200 volts to 120/240 volts, may act as a barrier to the broadband signal.

A router is a device that manages networks and serves as an interface between two networks. In a network, a repeater is a physical-layer hardware device that is used to increase the physical medium's length, topology, or interconnectivity beyond the limits set by a single segment. The device that collects end-user CPE data into the medium voltage grid is called a concentrator/injector. Injectors interact with the medium voltage power lines supplying the BPL service area and are connected to the Internet backbone through fiber or T1 lines.

The medium voltage power lines delivering BPL signals and the homes in the service area are connected by extractors. Typically, BPL extractors are situated at each low-voltage distribution transformer that supplies a community of houses. Some extractors strengthen the BPL signal enough to enable transmission via low-voltage transformers, while others use couplers on nearby medium- and low-voltage power lines to relay the BPL signal around the transformers. A different class of extractors connects to non-BPL gadgets to expand the BPL network to the consumers' locations.

Different BPL system types employ various methodologies and architectural designs. All of them are carrier-current systems, which is a phrase for devices that purposefully transmit signals across power lines or electrical wire.Interference problems between unlicensed equipment, such as BPL modems, and other electronic devices are governed by Part 15 of the FCC's Rules. Radio frequency emissions standards set by the FCC must be met by all electronic devices marketed in the US. The communications signal is insulated by the conduit and the earth when BPL modems are put on underground power lines, making it unlikely to interfere with other communications services. The FCC is especially worried about the possibility of interference from BPL signals sent over exposed, overhead medium voltage power lines.

In order to maintain the needed BPL signal strength and fidelity over long runs of power lines, BPL service providers may use repeaters. Signal attenuation or distortion across the power line may cause this. The fundamental BPL system, which may be installed in a cell-like configuration across a considerable area supplied by current medium voltage power lines, is shown in figure 8. Power is delivered to a residential area from an electrical substation using medium voltage lines, which normally carry voltages between 7,200 and 34,500 volts. For residential application, low voltage distribution transformers reduce the line voltage to 240/120 volts. Vendors of BPL devices employ one of three network designs. Below is a description of these architectures.

Architectural Type 1: OFDM

This design uses a large number of narrow-band sub-carriers and orthogonal frequency division multiplexing to spread the BPL signal across a broad bandwidth. Data from the Internet backbone is transformed into the format of an OFDM signal at the BPL injector before being coupled into one phase of a medium voltage power line. Additionally, an injector on the medium voltage power converts BPL signalslines to the format used in the backbone connection of the Internet. Using BPL extractors to avoid the low-voltage distribution transformers, the two-way data are transported to and from the low-voltage lines, each of which supplies a group of houses. The extractor transforms between access and internal BPL signal formats and routes data. The subscribers utilize internal BPL devices to access this BPL signal. Repeaters may be used to cover great distances between a BPL injector and the extractors it serves. On the medium voltage power lines, the injectors and extractors operate in a separate frequency range than the subscriber's internal BPL devices, which operate on the low voltage power lines. Carrier Sense Multiple Access is used with Collision Avoidance enhancements to reduce channel congestion. Since all devices on medium voltage lines operate in the same frequency range, this type of system is made to tolerate some co-channel interference between quasi-independent BPL cells without the use of isolation filters on the power lines. The BPL signal could be resistant enough to co-channel BPL interference to allow the independent installation of two or three of these devices on nearby medium voltage power lines. One phase line is used in this system to link BPL signals.

Architecture 2 - Wi-Fi and OFDM

The OFDM/WiFi model is similar to the previous model in that it employs OFDM as its modulation method, but it varies from it in the manner that it transmits the BPL signal to customers' houses. This approach pulls the BPL signal from the medium voltage power line and turns it into an IEEE 802.11 WiFi signal for a wireless interface to subscribers' home PCs as well as local workplace computers instead of utilizing a device that utilizes low-voltage power lines. The crucial thing to remember is that BPL is not utilized on low-voltage power lines, despite the possibility of using technologies other than WiFi to interface subscribers' devices with the BPL network. To distinguish between upstream and downstream BPL signals and to reduce co-channel interference with other adjacent access BPL devices, this system makes use of several radio frequency bands. Repeaters may be used to cover great distances between a BPL injector and the extractors it serves.BPL repeaters utilize distinct frequencies than injectors and other adjacent repeaters, and they broadcast and receive on various frequencies as well. When equipped with a WiFi transceiver, repeaters may also function as extractors. The medium voltage power line's first phase receives BPL signals thanks to this model.

Structure 3: DSSS

In this arrangement, the BPL data is sent via the medium voltage power lines using Direct Sequence Spread Spectrum. A BPL cell's users all use the same frequency band. Carrier Sense Multiple Access is used to reduce channel congestion,As all devices use the same frequency band, this type of system, like the first, is made to tolerate some co-channel interference between cells. Each cell in the system is made up of a concentrator, which acts as a bridge between the user's computer and the electrical wiring carrying the BPL signal, a number of repeaters, which compensate for signal losses in the electric power line and through the distribution transformers feeding clusters of homes, and customer premises BPL equipment. The BPL terminals and repeaters of the customers may connect with the concentrator that provides the optimal communication channel at any moment since adjacent cells often overlap. A pair of couplers on a phase and neutral line are used in this system to couple the BPL signal onto the power line.

Upcoming Systems

Manufacturers and service providers of BPL plan to provide their users a broad variety of apps. On-line gaming applications, high definition, multi-channel video, audio, and speech over Internet Protocol, as well as their need for more bandwidth, are predicted to rise quickly. BPL systems are anticipated to function at rates of 100 Mbps or more over the medium voltage power lines in the future in order to sustain the average subscriber at 1 Mbps.

BPL suppliers from several companies have proposed using frequencies up to 50 MHz. At least one manufacturer is contemplating using the range of frequencies from 4 MHz to 130 MHz, except those that are already being used by licensed services. One suggestion made in an effort to minimize interference with licensed services is to "notch" or reduce BPL transmissions in frequency areas where licensed services are being used close by. Future BPL systems could be able to carry out this task without the need for system operator assistance. BPL systems are anticipated to employ new modulations that can handle more subcarriers that are more precisely spaced in order to execute this solution and increase the usable bandwidth at the same time. The BPL systems may need to operate at higher transmission power levels, albeit not necessarily with higher power density than is now employed, as data rates and bandwidth needs increase. While limiting emissions to levels compliant with FCC Part 15 regulations, BPL may use techniques to dynamically adjust the power level in order to maintain a minimum signal-to-noise ratio across the entire BPL spectrum. One suggestion is to modify the transmitted power with a hard restriction based on Part 15 regulations in order to maintain a consistent SNR across the BPL spectrum. Creating a control system that can optimize transmitted power while also minimizing radiated emissions would be difficult; maybe frequency agility can help. Blocking filters, when used properly, may split BPL networks into cells of varying sizes with little conducted co-channel interference from other cells. This will make it possible to reuse frequencies at a higher level than what is now possible[10].

CONCLUSION

Despite these difficulties, wireless technology continues to be an important and developing aspect of contemporary life, with new developments and innovations appearing frequently. The future of wireless technology is bright and has the promise of revolutionizing society as the need for fast, dependable wireless communication grows. Wireless technology can present certain difficulties, however. The possible health effects of exposure to radiofrequency radiation are still up for dispute, and security issues like hacking and data breaches remain a persistent danger. Another problem is wireless technology's accessibility and price, especially in rural and distant places.

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CHAPTER 3

A BRIEF DISCUSSION ON BPL BUSINESS MODEL

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ABSTRACT:

The BPL (Broadband over Power Line) business model is an innovative approach to providing high-speed internet access through existing power lines. This technology enables internet service providers (ISPs) to use the existing infrastructure to deliver broadband services to homes and businesses, without the need for new cables or infrastructure.The BPL business model works by using the electric power lines to transmit data signals, which are then converted into usable internet data by specialized equipment. This technology offers a cost-effective solution for delivering broadband services, especially in areas where laying new cables or building new infrastructure is not feasible.

KEYWORDS:

Distribution Network, Government Regulations, Initial Investment, Operational Expenditure, Revenue Streams.

INTRODUCTION

Most electric utilities are now concentrating on developing an intelligent electric distribution grid utilizing BPL. To monitor and manage the equipment in the power grid, power companies often utilize low-speed power line communication for internal purposes. This may lead to decreased electricity prices, improved dependability, and higher security.Some electric utilities have thought about getting into the end-user BPL communications market, either independently or in partnership with a telecommunications provider like an ISP, a Competitive Local Exchange Carrier, or a long-distance provider looking for a different last mile route to their customers.

Each utility is required to evaluate BPL in accordance with its own business goals, risk appetite, and processes. Cost, market size, pricing, distinguishing BPL characteristics, bundled services, average revenue per user, and utility applications are the variables to be considered. While the primary application driving the deployment of BPL networks may be broadband Internet access, there are a huge number of other potential uses for such a communications network that must be taken into account as the business model is created. Although providers may operate in one or more segments, the broadband market is typically split into the following categories:

This part of the network links end customers, such as residences and businesses, to high-speed services and the Internet. The drop wire connecting the interface on a home to the cable company's network and the wire from the interface connecting to the wall plates in the home, for example, would all be a component of the last mile for residential broadband service customers who get cable modem service.The middle mile is the section of the network that is made up of high-speed fiber backbones and other "middle-mile pipes" that transport data between ISPs, content providers, online service providers, and other clients as well as between networks and computers.Internet service providers are businesses that receive, translate, and assist users in locating online information on the Internet. Content providers are the businesses that make information, products, and services accessible to customers over the Internet.Based on network functioning and the fact that each of these groups has unique economic features and regulatory concerns, these characteristics and distinctions are made. Since there is currently little competition in the middle-mile service market, existing providers are free to treat their customers unfairly. The capacity or desire of content producers to enter into exclusive contracts for the carrying of their material raises competitive difficulties, and they can pose problems for free expression and consumer protection[1], [2].

Because they relate to the wires portion of the electricity network, which is the sector's simplest entry into the broadband industry, the last mile and the middle mile are of particular importance to utilities. Because each party can concentrate on what it does best, a partnership between a utility and an external third-party service provider has strategic value. While adept at creating infrastructure, utilities lack experience operating in a market that is competitive. ISPs work in a very competitive atmosphere, on the other hand. Effective customer marketing, low-cost client acquisition, and top-notch customer service are essential success components.With cable modem and DSL providers actively promoting their services and other alternative providers considering joining the market, the current broadband climate is competitive. Most customers seem to see customer service as a major distinction. Key advantages of a utility partnership with an ISP or CLEC include: The utility might concentrate on network administration while the ISP could concentrate on sales. The possibility of collaboration can also include joint investment.

When it comes to providing broadband services to households and businesses, BPL may have a lot of important advantages. This innovation may make broadband more widely available and make the market for broadband services more competitive. Access BPL might make broadband services more widely accessible, introduce customers to useful new services, boost economic activity, raise productivity on a national level, and expand economic opportunity. BPL's very nature should make it possible to provide fresh, cutting-edge services to just about any place with electrical outlets. The National Telecommunications and Information Administration claims that "BPL holds great promise as a new source of innovation and competition in the broadband marketplace". It thinks that BPL has the potential to open up new channels for Internet access, to make it possible for utility companies to provide new and extended services, and to build a new foundation for subsequent developments in communications technology.

DISCUSSION

Consumer Benefits

Supporters of BPL anticipate it will increase the market's level of competition for broadband services. It provides the third wire that has been long needed for last-mile broadband communication service delivery to homes and small enterprises. BPL will boost competition in the regions currently covered by other broadband providers, improving performance and lowering costs for customers. BPL is likely to cost the customer a little more than more conventional services like coaxial cable, DSL, or even wireless. However, based on expected relative cost comparisons between the various technologies, it should be considerably less expensive than either satellite or FTTH systems. Every electric appliance in BPL is linked to the electrical distribution network, which is an intriguing feature. BPL could enable communication between the electronics of all electric devices. Of course, any appliance might include a Wi-Fi, Bluetooth, or other wireless gadget. BPL, however, could be a superior remedy. People who owned PCs before the Internet took off can recall the functional differences between a standalone PC and a networked PC. Every electric device could be networked over the power lines, potentially boosting convenience and productivity in both the home and workplace[3]–[5].For BPL, a number of different models have been put forward. Some utilities could allow a third party to install BPL equipment by opening up their lines to them. Some people could want to provide broadband directly. The three basic business models that are accessible to electric utilities are the landlord, developer, and service provider models.

The Tenant Model

The Landlord Model places a strong emphasis on joining forces with an established communications firm, which would provide an electric business rapid access to operations and marketing experience and employees without requiring an investment in either the costs or the personnel. Of course, the electric business's network of power lines would represent the value it delivered to the corporation. Conscious utilities will want to join into such partnership agreements as part of a landlord strategy in order to reduce capital or operational risk. If properly positioned, the landlord business model is a fairly safe framework. This paradigm permits modest rewards for modest expenditures of time and effort. For an electric utility, the landlord model has many advantages, includingThere is no need to spend money constructing the broadband network.The BPL system does not have to be run by the utility, and regulations may be handled to let the utility to continue to create value without mandating that all profits be distributed to the ratepayer base.

The Creator Model

The infrastructure is built as part of the developer model, and wholesale access is provided. This approach will be used by utilities looking to make the most of their core strengths in creating and maintaining networks. Electric firms that are hesitant to pay the marketing expenses necessary to provide retail broadband services may want to think about marketing to a more specialized market—traditional broadband providers. Traditional broadband providers are those that offer communications services, including broadband, as their main or only business. Many businesses that already have personnel with experience in the promotion and sale of broadband services have struggled to succeed as a result of the high costs of constructing networks. In reality, a large number of these businesses are dependent on ILECs to provide broadband connectivity to their clients.

BPL gives power providers the chance to offer these businesses internet services. Electric firms might provide ready-made last-mile broadband networks for competitive broadband providers who wish to stop their reliance on ILECs, which are their direct rivals for consumers, by upgrading their power networks to incorporate internet capabilities. Regulations do not prohibit possibilities to take use of the utility's position in the market, which is one of the advantages of the developer model for an electric utility.To build a BPL network that can economically compete with other participants, internal talents are available.There are viable options on the market that can act as the BPL service provider.There is no aptitude or interest in managing the network and operations, and there are lucrative market sectors that make certain construction chances possible.

The Model for Service Providers

The utility interacts with the client under the service provider model. The service provider model may be taken into consideration by aggressive utilities looking to provide retail broadband services. The service provider business model has the most risk, but it also has the greatest potential for success. Given that they already own the poles and lines that virtually every residential and commercial customer in the US uses to access electricity, electric utilities are well-positioned to offer this service.

These customers could get broadband service by simply adding equipment to their wires. BPL consumers would instantly have in-house networks without having to buy and install extra wire in their homes, which would make it more appealing than DSL or cable modem.The problem with offering retail services, however, is that there are marketing expenses that some businesses may be unable or unable to cover. It may be quite expensive to advertise in order to gain market share. When choosing to enter this retail market, an electric company would also need to hire or retrain personnel with experience in marketing broadband services. Any utility that wants to follow the service provider model must deal with market, operational, and network construction issues. The Service Provider Model has many advantages, including: Regulations permit cooperative marketing, allowing better predicted market penetration performance;Internal resources are available to build and maintain a BPL network during operations,The industry is alluring and provides significant promise for financial returns, and the skills required to support marketing, operations, and network administration are already in place.

Competitors

The primary rivals of BPL, or maybe those with whom BPL will compete, are cable TV providers, ILEC DSL services, and cellular services offered by either a CLEC or an ILEC.

Cable as an adversary

Each subscriber from the Head-End shares the available bandwidth since cable is a shared media. Since many cable networks have been upgraded to Hybrid Fiber Co-axial networks, many goods and services, including voice, data, and video, can be bundled through cable.Cable companies are looking for strategies to strengthen their position as the leading suppliers of internet connectivity. Tiered service levels are one trend that is still being used to attract lower-value prospective consumers while maintaining profits on higher-value clients. VoIP and digital cable are two of the services provided by cable providers.

More than 90% of residences served by cable companies now have access to broadband services. The cable industry anticipates that the industry-wide facility modifications necessary to provide residential consumers broadband Internet access will be finished shortly.Cable providers have raised download transmission rates from 200 kbps to over 30 Mbps in addition to extending the range of enhanced broadband services. The technology used to supply internet services has continued to be upgraded by cable companies as well. The essential interface specifications for cable modems and cable modem termination systems used for high-speed data transfer and connectivity to the Internet have continued to be developed by the Data over Cable Service Interface Specification, or DOCSIS.

The cable industry is also working on Next Generation Network Architecture, which is partly a competitive reaction to wireline internet providers and partly a response to the Digital Video

Recorder technology used by Direct Broadcast satellite. A next-generation all-digital cable network's characteristics are being defined by the NGNA project, which might have significant effects on both functionality and cost. The effort entails completely transitioning cable service from analog-to-digital transmission so that all services could be delivered using IP. This involves rethinking cable's fundamental technologies, including everything from encryption strategies to set-top boxes that can be dramatically upgraded via software uploads[6]–[8].

The price floor for cable providers is really formed by a combination of cost variables. These include the following: Programming and labor costs have been steadily increasing and exceeding inflation rates; Cable companies have invested more than $75 billion, or over $1,000 per customer, in network upgrades; and Cable companies view satellite providers rather than DSL providers as their main pricing rivals.

As a Competitor, DSL

The majority of the current phone networks may be configured to use DSL technology, which is available in a variety of configurations. The most prevalent DSL configuration being used by service providers is ADSL. DSL rollouts have trailed behind cable modem installations. The market penetration of DSL, which had been anticipated to surpass that of cable modem, is now only around 50% of its broadband equivalent. The main issues are:ILECs effectively controlled the provisioning process and prevented data local exchange carriers from being able to effectively serve customers. ILECs have been relatively slow to aggressively deploy DSL for fear of cannibalizing their T1 business. DSL is slow with 1.5 Mbps to 3.0 Mbps in most areas.

Wireless as an adversary

Hot spot coverage is sharply expanding, and this pattern is anticipated to remain. The sector will have potential to profit from economies of scale as a result of this sustained expansion, since already low equipment prices will continue to decline. While the Wi-Fi application is developing, a number of issues are also being addressed: Comparing simplicity and convenience vs. network safety Typically, radio signals travel beyond the actual boundaries as part of their intended signal propagation. When users didn't use Wired Equivalent Privacy, network security breaches have happened frequently.

Short range limits market reach - Developers are worried that the business's ability to expand beyond a single hot spot may be constrained by the reach of its customers. New technologies, however, are anticipated to expand reach and provide more opportunities to create a broadcast access market play.An effective long-term expansion plan requires the establishment of a format to create IP roaming, which has not yet been done. Although a growth strategy necessitates roaming agreements, a pure hot spot market approach does not necessarily require them. High deployment levels may result in interference in the Industrial, Scientific, and Medical spectrum band.

Regulation Concerns

Broadband service might benefit from actual competition because to BPL technology. Given the applications and services it may provide, authorities must enact a consistent set of laws and policies that will enable the delivery of BPL services across the United States while guaranteeing the protection of public interest issues. The FCC and the states are developing and implementing a regulatory framework that eliminates unnecessary obstacles to market entry and enables electric firms to compete in the marketplace in order to deliver internet access to all residents.

Despite the fact that the Telecommunications Act of 1996 required that broadband service be widely accessible in the United States, the market for that service is currently dominated by two companies: either the incumbent local exchange carrier, which offers broadband service through digital subscriber lines, or the local cable operator, which offers the service through a cable modem. Many consumers are increasingly turning to electric companies as a third competitive source of internet since duopoly does not always provide them the option to receive the greatest mix of pricing and services.

In 2004, the Federal Communications Commission published regulations that lay out legal requirements for the provision of BPL. The FCC has spelled out the requirements in this decision, which some claim shows that the FCC supports BPL. In a market dominated by digital subscriber line and cable modem service, the FCC and others have lauded BPL as a possible "third wire" that may assist expand the accessibility and cost of broadband services. The government Communications Commission (FCC) modified Part 15 regulations to include steps to reduce radio interference brought on by broadband over powerline as part of the government effort to eliminate obstacles to BPL adoption. In essence, the FCC's 2004 decision would help prevent BPL's ability to interfere with radio and telecommunications transmissions.Many jurisdictional and classificational questions are still unresolved, though. For instance, are the broadband services provided by BPL considered telecommunications or information services? This has consequences since the Telecommunications Act of 1996 imposes rules on telecommunications services, most notably the common carrier obligations.

The primary issues for state commissions are the safety and dependability of the electricity supply system and the provision of high-quality services. Cross subsidization difficulties and affiliate transaction restrictions are also significant concerns. State Commissions are required to stop an asset created with ratepayer money from being used unfairly for the advantage of shareholders. Additionally, they must make sure that electric utilities do not have an unfair advantage over rivals. Thus, a number of options, including the establishment of unregulated BPL subsidiaries or the adoption of accounting regulations that prevent cross-subsidization, may be taken into account.

Rights of way and difficulties with access to poles will also need to be addressed by the state regulators. As an instance, some communities could try to impose taxes for BPL rights of way. Due to possible interference issues, pole attachment regulations may also need to be revised.In this decision, the FCC acknowledged the valid concerns of licensed radio services and specified additional technical specifications for BPL devices, including the need for BPL to stay away from certain frequency bands and frequency exclusion zones.

According to the FCC, the regulations would call for the device to reduce disturbance by either notching, changing the operating frequency, or remotely shutting down. It's a feature that many BPL technologies already have. In order to safeguard certain permitted activities that are vital to life and safety, the FCC will also prevent BPL from using specific frequencies locally or nationally. The FCC will also only demand a minimal amount of disclosure of BPL activities for a publicly available database to notify licensees who suffer interference and give contact information for the BPL operator. Finally, there will be "consistent and repeatable" new measurement guidelines, and the authorization of BPL equipment will be subject to a certification procedure rather than merely manufacturer verification. The FCC claims that these regulations eliminate ambiguity and guarantee the safety of licensed services.

The FCC is confident that the updated Part 15 regulations will safeguard already licensed operations from harmful interference while also fostering the development of BPL technology and its attendant advantages.

Radio Wave Spectrum

Let's quickly examine the frequency range where BPL operates and potential conflict areas. BPL suppliers from several companies have proposed using frequencies up to 50 MHz. While excluding frequencies that are currently in use by specific licensed services, at least one vendor is considering using the range from 4 MHz to 130 MHz. One suggestion made in an effort to minimize interference with licensed services is to "notch" or reduce BPL transmissions in frequency areas where licensed services are being used close by. Future BPL systems could be able to carry out this task without the need for system operator assistance. BPL systems are anticipated to employ new modulations that can handle more sub-carriers with more precise spacing in order to execute this solution and increase the usable bandwidth at the same time.

Unlicensed channels at 2.4 GHz and 5.8 GHz are used by another BPL technology. The idea of transmitting data across medium-voltage power lines at speeds more than 200 Mbps has been demonstrated with an implementation using several IEEE 802.11b/g WiFi chipsets.The frequency band is currently divided as follows: 535 kHz to 1.7 MHz on AM radio5.9 to 26.1 MHz on shortwave radio. Long-distance, intercontinental radio communication is only supported by this region of the radio spectrum. International broadcasting, aviation, marine, disaster relief, and other agencies, including the military, utilise the short waves.Public-access radio 26.96 to 27.41 MHz Channels 2 through VHF are broadcast on 54 to 88 MHz by television stations: Volunteer police and fire departments as well as other first responders often utilize the "low-band VHF" frequency spectrum.

Incompatibility and Radio Static

Electric utility companies have historically employed powerline systems, a kind of carrier current system, for protective relaying and telemetry. Although today many utilities rely on the 1-30 MHz bandwidth for BPL transmission, they still operate between 10 kHz and 490 kHz. A receiver receives radio frequency energy from a carrier current system via conduction across an electric power line. BPL functions as an inadvertent carrier-current emitter in accordance with Part 15 of the FCC's requirements for unlicensed devices. The power levels generally employed by BPL systems are around 30 to 40 dB higher than the FCC restrictions for other unintended emitters, even though carrier-current devices satisfy radiated emissions standards rather than conducted limits like other broadband technologies. It is not unexpected that BPL offers a substantially greater hazard from interference than practically all other categories of unauthorized RF noise emitters[9], [10].

Both carrier current systems and powerline carrier systems are subject to various emission restrictions under Part 15 of the FCC's current regulations. The FCC also imposes restrictions on the amount of radio frequency energy that may be conveyed by RF devices that are powered by commercial power sources, including carrier current systems that link RF energy onto the AC wire for communications.

There are two ways that this conducted energy could interfere with radio transmissions. First, other devices connected to the electrical wiring may receive the RF energy through electrical wiring. Second, large sections of electrical wire may function as an antenna for frequencies below 30 MHz when wavelengths are more than 10 meters, allowing the RF energy to be broadcast across the airways. Such emitted energy may interfere with other services across great distances because to the low transmission loss at these frequencies.

An unlicensed equipment, such as a cordless phone or a garage door opener, is what a BPL modem is. Part 15 regulations set out by the FCC apply to all unlicensed devices. All electronic products sold in the US must adhere to FCC-mandated radio-frequency emission standards. These restrictions are in place to guard against disruption of crucial broadcasts including government channels, air traffic control, and CB communications.

All of the cables used by cable TV providers are shielded, which solves the interference issue. The signal wire in coaxial cable used in cable TV operations is encased in a braided metal shield. Additionally shielded are telephone cables. On the other side, there is no protection on power cables. A power line is often made of bare wire or wire that has been covered in plastic. Because electric power lines are not shielded, interference is a concern.

Internal use of BPL for electric utility operations is likely to involve the low end of the 1-30 MHz range, reducing stress on Federal emissions limits. From a regulatory perspective, Limits are stricter for Class B settings than for Class A. Emissions above 30 MHz are under stricter control than those below 30 MHz.The FCC is taking a cautious approach that would permit deployment under current emission limits but which proposes additional safeguards to mitigate interference that may occur from BPL operations in order to promote BPL deployment while preventing harmful interference to authorized radio operators[11], [12].

CONCLUSION

In comparison to conventional broadband distribution techniques, BPL technology provides a number of benefits. First off, since the electricity lines are already there, it is easily accessible and affordable. Second, it may provide high-speed internet to places that might have previously lacked access or weren't covered by conventional broadband providers. Finally, since power lines are less prone to interference and signal loss than wireless technologies, it can provide more dependable connectivity.

The BPL business model, however, also faces a number of difficulties. These include legal concerns, the requirement for specialized tools, and the possibility of power line device interference. Despite these difficulties, the BPL business model is developing because to new ideas and technological advancements. BPL technology is anticipated to play an increasingly significant role in supplying dependable and cheap broadband services to households and companies throughout the globe as demand for high-speed internet access keeps growing.

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CHAPTER 4

A BRIEF DISCUSSION ON ARRL'S POSITION ON INTERFERENCE

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ABSTRACT:

The American Radio Relay League (ARRL) is the national association for amateur radio operators in the United States, and it has a clear position on interference. The ARRL believes that all radio services must coexist peacefully and avoid interference to one another.The ARRL's position on interference is rooted in the fundamental principles of radio communication. Radio spectrum is a finite resource, and every radio service has the responsibility to use it efficiently and without causing interference to other services. Therefore, the ARRL advocates for responsible use of radio frequencies and encourages radio operators to be aware of their surroundings and potential sources of interference.

KEYWORDS:

Frequency Allocation, Interference Mitigation, Radio Frequency, Spectrum Management, Technical Standards, Wireless Communications.

INTRODUCTION

American Radio Relay League has vociferously stated its worry that Access BPL may interfere with amateur operations if it is not carefully limited. Amateurs, according to ARRL, employ very sensitive receivers and outdoor antennas with high gain that may be situated near to power lines.According to ARRL, if an Access BPL system were to be implemented, the city-wide coverage of the power lines as an effective antenna would significantly impede amateur radio activities. The ARRL thinks that Access BPL's potential interference would be so severe that it should be banned from all frequencies designated for amateur usage. BPL gives an almost unprecedented opportunity for meddling. Other kinds of broadband, such as fiber to the house, DSL, and different forms of wireless broadband, have far lesser potential for interference than BPL[1]–[3].

Power lines are a major potential source of interference for all radio services operating in this frequency range since they are not intended to block the emission of RF energy. Residential wiring and overhead electrical power lines serve as antennas, while the latter transmit broadband communications as radio waves into whole neighborhoods and beside roadsides. Nearly a mile away from the closest access BPL source, interference has reportedly been seen, according to ARRL.

Due to BPL's ability to produce 10,000 times more interference than conventional devices, its electromagnetic compatibility requires special consideration. BPL must not utilize spectrum that is close to another system or device that is being used in order to prevent interference. This includes using the Amateur Radio Service, the Citizens Band Radio Service, receiving international shortwave broadcasts, and using other radio services like receiving government time signals, etc. in residential areas. Additionally, broadcast television may experience interference from BPL devices that operate above 54 MHz.

Despite having a high potential for interference, BPL can be successfully implemented in ways that help prevent common RFI issues. In order to minimize BPL noise in the amateur bands to a level similar to other devices, BPL systems and devices must thus have adequate filtering.On all HF and VHF amateur channels, certain access BPL providers have installed devices that apply spectrum masks. The most recent spectral notching technology for amateur bands offers an excellent all-around solution that avoids the majority of interference issues, according to ARRL's evaluation of many of these notched access BPL systems. All access BPL systems that did not notch the amateur bands have shown significant interference.Unlicensed emitters, like BPL systems, are required by the Communications Act of 1934 and the FCC Rules to shield licensed radio services from interference and to tolerate any interference to their operation that results from the regular operation of licensed radio services. However, in actuality, it is frequently challenging to address such interference issues in the field.

The likelihood of interference from a BPL system operating at the FCC radiated emission limit on the same frequency as a typical two-way radio station is nearly 100% for distances of 600 to 1,200 feet from the power line, depending on the frequency, according to studies by the National Telecommunications and Information Administration. This implies that BPL system operators will need to spend money on costly measures to rectify interference on a case-by-case basis unless BPL manufacturers willingly design their systems for decreased emissions. Depending on the situation, it could not be feasible until they switch off their systems. Of course, they'll fight tooth and nail to avoid having to. Radio operators are worried about this, which is why BPL users cannot be confident they will get dependable internet connection unless all BPL implementers accept notching of the amateur bands and include it into their legislation.

BPL signals "unintentionally radiate" from power lines, according an NTIA study. The NTIA also said that "interference risks are high under existing FCC Part 15 rules" and that the measuring methods used at the time for FCC Part 15 might "significantly underestimate" peak BPL field strength. These issues have only been partly addressed by the FCC ruling.Although the ARRL claims that the current FCC BPL rules have not sufficiently protected licensed radio services from interference, interference can be avoided if BPL systems and their designs avoid the use of locally used spectrum. Because amateur stations, with few exceptions, are situated in residential or rural areas and use sensitive receivers and effective antennas, this necessitates the use of permanent notches in the amateur bands for the Amateur Radio Service. Many people in the BPL sector are aware of this crucial idea.

DISCUSSION

Pole Attachments

Access, rates, modifications, and surveys are just a few of the special problems BPL offers for regulating pole attachments. These difficulties may all have an influence on BPL operating costs. Investor-owned utilities are subject to FCC regulation, while neither municipal power grids nor electric cooperatives are.Pole attachments have been a problem ever since BPL technology first appeared. After the Telecom Act was passed, any company requesting access to an electric utility's poles had to be granted access if the utility used the poles for any kind of communications, including its own. The fees, terms, and conditions of access must be administered consistently to all telecommunications carriers and cable operators that have access or seek access under FCC regulations in cases where access is required. Access may be denied by utilities due to issues with inadequate capacity, safety, reliability, and other technical requirements[4]–[6].

By not placing any form of communications equipment on their poles, several electric companies have avoided the administrative expenses of setting up a system for controlling access to and usage of their poles. But if they wanted to offer BPL service, they would no longer be able to avoid it. Unless the FCC could be persuaded to establish a BPL exemption as a motivation for electric companies to build and install BPL networks, these administrative expenses would thus have to be taken into account when calculating the price of delivering broadband services.

Concerning BPL, there are still open issues:

1. Issues with open access, safety, capacity, and compatibility
2. Issues with imputation and occupied space
3. Cost-sharing and concerns with notification
4. Cost-sharing and market competition
5. constraints on local zoning, franchise costs, and right of way
6. State control over private easements

In view of interference concerns, pole attachment duties must also be addressed. The FCC admitted that there may be an issue here: Cable television service and high-speed digital transmission services, such as DSL, may not operate as intended due to BPL equipment being located so near to these services on utility poles. Interestingly, despite the fact that the FCC has authority over both service delivery models, the regulatory paradigm for incumbent local exchange carriers and the neighborhood cable provider has been different.

Title II of the Communications Act of 1934 regulates telephone companies that provide DSL service and contains common carrier requirements that cable operators do not share. These rules, which were created in response to the ILECs' historical monopolistic control over their separate service regions, oblige them to provide rivals nondiscriminatory, cost-based access to their networks. Currently, it is difficult for federal and state regulators to determine how much market share an ILEC must lose before those obligations are lifted. Given the number of competitors who have siphoned off their potential customers, many ILECs think the requirements are no longer necessary. Contrarily, cable modem broadband service is exempt from open access requirements since the FCC only recognized cable as an information service. This categorization has been contested in court, and if it is upheld, cable companies may be subject to the same regulations as ILECs. Since there is little competition in the delivery of cable services in many American cities and towns, many people believe that the cable industry's exemption from open access requirements has been unfair and has given cable companies an unfair competitive advantage over ILECs.

Standards

The Institute of Electrical and Electronics Engineers created Standard P1675, "Standard for Broadband over Power Line Hardware," in an effort to assist in realizing BPL's potential.

Electric utilities now have a detailed standard for deploying the necessary hardware on overhead and subterranean distribution lines that serve as the backbone for broadband-over-power-line systems in IEEE P1675. It will also contain installation specifications for the safety of persons who operate with BPL equipment and to guarantee that such systems don't endanger the general public.

Electrical Wire Communications

The demand for broadband multimedia applications has grown dramatically over the last several years and is still expanding quickly. For example, broadband Internet connectivity is in high demand and is quickly becoming a must for families and companies. Currently, a variety of technologies are used to connect broadband to and within homes and offices.Power line communications, one of these communication technologies, is the subject of intense study and offers a highly alluring multimedia connection solution to the last-mile issue. To offer high-speed broadband communications, PLC makes use of already-existing electrical networks. PLC uses the in-building electrical wiring as a local area network to provide high-speed networking, including broadband Internet access, voice over IP, and home entertainment services to virtually every power socket in residential or commercial premises, in addition to resolving the last-mile connectivity issue. The main benefit of PLC is that it does not need new wiring since it employs an infrastructure that is far more common than any other connected architecture.

It has been around for a while to use electricity lines for communication services. About a century ago, analog communications were used for remote metering and home automation, which were the first PLC applications. To keep the high-voltage PLs operating, it was also crucial for power supply utilities to have a functional communication channel. However, in the last ten years or so, the focus has been on using PLC for broadband multimedia services, including fast Internet access.PLC provides a competitive and affordable solution for LAN applications and Internet connectivity. However, the lack of a widely accepted standard published by an internationally renowned standardization body has so far prevented this technology from being widely expanded and adopted. The HomePlug Standard and its variation provide the foundation for the majority of PLC devices now on the market. The long-awaited standard is scheduled to be published in February 2011 after the first IEEE standard for broadband over power line networks was recently accepted. The release of the IEEE standard 1901-2010 is anticipated to mark a critical turning point in the history of PLCs and will significantly influence the creation and uptake of PLC applications.Despite the benefits that PLC offers, this technology transmits communication signals through a medium that was never intended to be used for telecommunications. Power lines are structurally and physically quite different from common communication channels like fiber optic and coaxial cables. For the design of PLC systems, it is crucial to comprehend their qualities.

Attenuation, multipath fading, and noise are the three most significant issues that effect communications via power lines. For long-distance communications, PL cables have significant frequency-dependent attenuation that worsens with high frequencies. In addition, impedance mismatching often occurs in PL networks, resulting in significant signal reflections and multipath fading.The noise produced by internal and external sources that are either linked to or nearby the PLC transmission medium is another ongoing problem for PLC systems. Any power outlet's noise is the result of the background noise on the line, as well as the noises made by all connected appliances. Colored background noise, narrowband noise, periodic impulsive noise asynchronous to the mains frequency, periodic impulsive noise synchronous to the mains frequency, and asynchronous impulsive noise are five forms of noise that are often present in PL channels. The first three forms, which are categorized as background noise, are essentially stationary. The latter two forms are often categorized as impulsive noise because of their time-varying random nature.

For PLC systems, impulsive noise is one of the main obstacles. It often happens as a consequence of power appliance switching transients. These impulses often have extremely high amplitudes and short durations, ranging from a few microseconds to a few milliseconds. The power spectral density of this sort of noise may be up to 50 dB greater than the background noise when impulsive noise is present.

High-speed PLC must choose a modulation strategy that can withstand such anomalies due to the existence of impulsive noise and other unfavorable PL grid characteristics. PLC engineers and researchers are interested in a variety of modulation schemes, including single-carrier, multi-carrier, and spread spectrum. Orthogonal frequency division multiplexing stands out as a strong contender for PLC among them. The fundamental idea of OFDM is to divide fast data symbols into slow data streams, which concurrently modulate a number of narrowband orthogonal subcarriers. By lengthening the symbol duration, this lessens the impact of multipath by ensuring that, depending on the channel delay spread, only a small fraction of the sign is impacted. Multipath in OFDM can be totally solved with the inclusion of a cyclic time guard. Additionally, because the discrete Fourier transform operation is used in the receiver to divide the received OFDM signal by the number of subchannels in addition to the added noise, the impact of impulsive noise is reduced. The resilience and ease of implementation that OFDM provides make it a popular choice for PLC[7].

Adaptive modulation systems, which enable individual subcarriers to have varied constellation sizes, trans-mit powers, instantaneous Bit-error rates, channel codes, and other characteristics, may be successfully integrated with OFDM. This resolves the PLC network's frequency selectivity problem. Subchannels that are hampered by fading or narrowband interference may carry fewer bits or, under severe circumstances or if the sub-bands are used by wireless operators, may even be zeroed. Adaptive loading algorithms that may effectively leverage the available spectrum and maximize performance must be devised in order to allow high-speed PLC via power lines.

The use of forward error correction techniques may increase the dependability of PLC systems under challenging channel circumstances. Because PL channels frequently experience bursty impulsive noise, interleaving must be used to decrease channel memory and aid coding schemes intended to combat single errors in handling errors brought on by burst disturbances. The use of PLC technology to connect workplaces and residences to the Internet and enable local area networking through in-building wiring has grown in popularity in recent years. Without the need for additional wires, PLC technology offers the ability to provide high-speed broadband communications across the most widely used wired network. Power line networks, however, are unfriendly to high-speed data communications since they were originally intended for the distribution and transmission of energy signals at 50 or 60 Hz. High attenuation, multipath fading, and noise with erratic time-varying impulsive behavior are some of the most unfavorable properties of power line channels.

The preferred technique for PLC systems is OFDM. The inter-symbol interference brought on by multipath propagation is mitigated and may even be completely avoided employing a cyclic time guard in OFDM because of the lengthy symbol duration. Due to the discrete Fourier transform operation in the receiver, OFDM effectively handles impulsive noise by dividing noise impulses among all the OFDM subcarriers.Practical measurements demonstrate that impulsive noise has a substantially higher power than other types of noise in PLC contexts. High-power impulsive noise may significantly reduce performance in a PLC that uses OFDM. Therefore, it is crucial to look into how it affects data communications and to present strategies for reducing its harm and improving PLC performance in such a harsh environment.

The purpose of this thesis is to improve the performance of existing and upcoming OFDM-based broadband PLC systems. This goal is accomplished by first addressing the issue of impulsive noise and outlining novel strategies for limiting the impact of this noise on communication signals. Second, this thesis introduces novel techniques for adaptive modulation that aim to maximize the data throughput while also improving the power efficiency of PLC systems.

Utilizing existing electrical power line networks for communication purposes is the fundamental tenet of power line communications. Power line networks have been used for transmission and distribution of electrical signals across time. Up until recently, communication across power lines was only used for low-speed tasks that aided power supply companies, such remote metering and operations management. The very high demand for high-speed broadband multimedia communications lately caused a shift in the previously restricted range of power line functions. In this chapter, a review of PLC-related literature is presented. Undoubtedly, the analysis and development of new PLC techniques and products depend heavily on understanding of the structure and characteristics of power line networks. The PLC technology's historical evolution and recent advancements are described. Additionally provided are specifics on competing modulation techniques and channel modeling approaches. This acts as a knowledge base that will be utilized later in the dissertation to research current strategies and create new ones with the intention of improving the performance of PLC systems[8]–[10].

CONCLUSION

The ARRL is in favor of using technology to reduce interference, including the creation of filters and other tools to block harmful signals. In order to avoid interference and encourage effective use of the radio spectrum, the organization also promotes improved coordination amongst radio services. The ARRL urges radio operators to collaborate to address interference concerns in a cooperative and polite way since it acknowledges that interference may still happen despite best efforts.

In order to reduce interference and raise the general standard of radio communication, the organization also encourages the adoption of correct protocol and manners in communication. The installation of a "third wire" or alternative, such as internet across power lines, into millions of American homes holds potential. According to tests, BPL is functional and capable of delivering internet through power lines, and BPL systems produce interference that has to be controlled. Since the turn of the century, there has been a slight decline in interest in BPL, but businesses are still considering its potential for use. To make this a competitive alternative to DSL, CATV, and satellite broadband transmission, several technological and legislative challenges must be addressed.

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CHAPTER 5

A BRIEF DISCUSSION ON ELECTRICAL NETWORKS AND THEIR PROPERTIES

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ABSTRACT:

Electrical networks are fundamental components of modern society, providing the infrastructure for the generation, transmission, and distribution of electrical energy. These networks are complex systems that consist of numerous components, including generators, transformers, transmission lines, and distribution systems.One of the primary properties of electrical networks is their ability to transmit energy over long distances with minimal loss. This is achieved through the use of high-voltage transmission lines that reduce the resistance and impedance of the system, allowing for efficient transmission of power.

KEYWORDS:

AC circuits, Capacitance, Circuit Analysis, Conductance, Electrical Power.

INTRODUCTION

Utilizing the current electrical grid infrastructure, power line communication technologies transmit communication signals delivering various broadband services. However, the primary function of electric power lines is the transmission and distribution of 50 Hz or 60 Hz AC power signals from the power plants to the final consumer. As a result, power line networks are quite different from traditional communication channels like twisted pair, Ethernet cables, coaxial cables, optical fibers, and so on in terms of topology, structure, and physical features. To determine if power lines are a viable option for high-speed data connections, it is crucial to first research and comprehend their structure and properties[1]–[3].

The high-voltage level, the medium voltage level, and the low voltage level are the three categories into which electrical networks are divided based on voltage levels. Transform-ers link these three electrical network components together. The transformer works as a barrier, preventing high frequency electric impulses from passing through power lines where data signals are being transferred. A typical structure of an electric power system is shown in Figure 2.1.

Maximum Voltage

The transfer of electrical energy produced at the power plant to several substations across vast geographic areas of up to several hundred kilometers takes place through high-voltage power lines. The backbone of the electric grid for the electric utility is made up of high-voltage power networks. For the transmission of HV electricity, three phase structures in the form of overhead conductors are employed.

High voltage levels are used to transmit electric power in order to virtually minimize energy loss during long distance transmission. The heat loss resulting from the resistance of the power line material and leakage losses are the two primary losses in high-voltage lines. The nominal voltage may be increased to reduce heat losses. However, increasing the voltage causes the leakage losses to increase.

Heat losses may be kept at acceptable levels by carefully choosing the wire material and dimensioning the power lines. Due to stimulation of discharge activities in the surrounding environment by the strong electric field at the high-voltage level, additional corona losses result. If thinner wires are utilized for high-voltage energy transmission, this discharge effect will be more pronounced. Corona discharge may produce powerful high-frequency impulses that interfere with radio communications utilizing the low and medium frequency bands in addition to the energy losses. Corona losses and related interference may be reduced by properly arranging the high-voltage cables geometrically.

Another barrier to dependable communication via high-voltage cables is interference at high frequencies. In high-voltage overhead lines, there are primarily two types of high-frequency interference: the first type is periodic short-duration impulsive interference, which is brought on by switching events and atmospheric discharges. The frequency domain spectrum of this kind of interference is vast. The generated impulses are characterized by extremely high amplitudes that cause harmful peaks at the receiving end because of the high voltage levels. A persistently present broad-band interference with a moderately high power spectral density is the second form of interference that may be seen in high-voltage electric lines. It is possible to describe this interference, which is brought on by discharge activities, as white gaussian noise with a PSD that is highly dependent on weather conditions and increases considerably in the presence of rain, frost, or fog.

HV power lines are not suitable for data transmission due to the extreme interference and attenuation at high voltages. Instead, fiber optic cables are often deployed along high-voltage channels for monitoring and control reasons. Because of their great capacity, these cables may also be used for data transfer[4].

DISCUSSION

Medium-Voltage Level

Electricity is often provided to rural regions, small towns, and individual industrial businesses using medium-voltage networks. Medium-voltage power lines typically range in length from 5 to 25 km and carry voltages between 10 kV and 30 kV. For electricity transmission and distribution at the medium-voltage level, both overhead lines and underground cables are employed. However, only underground cables are utilized in densely populated urban areas. In comparison to high-voltage transmission lines, medium-voltage overhead wires require relatively few poles and smaller wire cross sections. This is because medium-voltage power cables only carry lower voltage levels. In terms of their physical composition, medium-voltage wires are mostly constructed of copper and aluminum and come in a variety of cross-sectional geometries, including round, oval, and sector-shaped. In medium-voltage wires, polyvinyl chloride and vulcanized polyethylene are often employed as insulating materials. Medium-voltage lines are the foundation of electric utility data communications through power lines in terms of data transmission.

Low Voltage Range

The last section of the electrical network, known as low-voltage level, delivers electricity to the final user at voltages between 100 and 400 volts. In this voltage range, underground cables are typically used in Europe. In Australia, though, LV overhead wires are still visible in populated areas. Low-voltage lines are made of copper or aluminum with PVC or VPE insulation and share a physical construction with medium-voltage lines. From the MV/LV transformer station to the consumer's meter, LV power lines typically run for up to 500 meters. PLC technologies employ low-voltage power networks to develop in-building networking and provide communications services to the home or workplace.

Power lines' characteristics

In PLC systems, power lines serve as the transmission medium. These lines were originally intended to carry electric signals at 50 or 60 Hz, and their design did not account for the possibility of carrying data at higher frequencies. To better understand how useful electrical wiring is for data exchange, this section gives an outline of its technical properties.

Inductance and Capacitance

Different devices connected to the network receive electrical power from the power line network. Based on the current flowing through its circuits, each of these devices has a certain inductance and capacitance.An electric circuit's inductance is a measurement of the magnetic flux that the circuit's current causes. The inductance's value will determine if it has a limit inside the circuit or whether it interferes with other circuits. When two adjacent conductive surfaces with opposing charges are brought together, a potential is formed that may be measured as the capacitance of an electric circuit.

Impedance

The impedance of alternating current circuits measures the total resistance to the passage of electricity. Components that are resistive, capacitive, and inductive make up a cable's impedance.The impedance is equal to a pure resistance if a direct current flows through the circuit. Devices are continuously linked to and removed from electrical networks. As a result, a PLC device linked to the network may experience changing input impedance. Modeling the power network for the transmission of communication signals is challenging due to this fluctuation. Refractions from the loads back to the cable may happen if the loads in the electrical network are not appropriately matched to the characteristic impedance of the cable. The reflections may be strong and may restrict how far the communication signal can travel over the power line, depending on the output impedances of the loads. The performance of PLC systems must use adaptive strategies to account for channel variance caused by electrical appliance plugging and unplugging. These techniques will be covered in more depth in chapters 5 and 6 of this article[5], [6].

Power lines making noise

Electric networks' vulnerability to various signals is a key characteristic, especially in the "last mile" and within buildings. It is crucial to research and comprehend the many interference circumstances present in the electric network in order to employ power lines for dependable high-speed PLC data transfer. Electrical equipment connected to the network or nearby tends to cause interference in power lines. The regular use of various electrical equipment and gadgets might cause interference. Additionally, when electrical appliances are switched on and off, impulsive voltage and current peaks propagate along the electrical wiring. Electrical appliances that often produce noise include light dimmers, fluorescent and halogen bulbs, universal motors, and more.

Broadband power line communications are also subject to electromagnetic interference, which is caused by the electromagnetic compatibility of the power lines. Radio services using the same radio frequency band might cause electrical cables to become radioactive. The frequency band is primarily used by BPL devices. An illustration of a radio service Amateur radio, which has been utilizing parts of the medium-frequency and high-frequency bands for decades, is using frequencies in this range.

Power line channel noise scenario.

As a result, unlike the majority of other communication channels, power line noise cannot be well characterized by the traditional method of additive white Gaussian noise. Power line noise is often divided into several types. Three major categories—colored background noise, narrowband interference, and impulsive noise—are used to characterize the noise at a wall outlet in. According to, there are five different forms of noise: asynchronous impulsive noise, colorful background noise, narrowband noise, periodic impulsive noise asynchronous to the mains frequency, and periodic impulsive noise synchronous to the mains frequency. the PLC transmission encountered the noise situation. The channel transfer function H expresses the PLC channel via which the sent signal x travels. Then, before reaching the receiver, x is mixed with various kinds of noise. The many sorts of noise that are ed are further described in the sections that follow.

Background noise that is colored is thought to represent the accumulation of several sources of white noise that have varied noise amplitudes at various frequencies. A somewhat low power spectral density often identifies colored background noise. With an increase in frequency, the PSD level falls. Its peak value is in the frequency range up to roughly 20 kHz that is close to the electrical signal frequency.

Noise that is limited to a small portion of the frequency spectrum yet has a high PSD is referred to as narrow-band noise. In the frequency domain, strong noise amplitude peaks represent narrowband interference. It frequently happens as a consequence of radio stations transmitting their signals at frequencies that are normally between 1 and 22 MHz. However, at lower frequencies, narrowband interference might occur. The switching of electrical equipment like televisions, power supply, fluorescent lights, or computer displays is the main source of interference at such low frequencies.

Periodic impulsive noise that is synchronous to the mains frequency is mostly caused by the phase control in electric devices like light dimmers and the switching of rectifiers in DC power supply, which occur synchronously with the frequency of the electric signal. Every time the mains signal crosses its zero line, impulsive periodic voltage peaks are created, causing repetition rates to be multiples of the mains frequency. This type of impulses are distinguished by brief durations and a decreasing PSD with frequency.Impulsive noise that is periodic and asynchronous to the mains frequency; this interference repeats at frequencies between 50 and 200 kHz. This kind of impulse is brought on by power supply changes.

Asynchronous impulsive noise is mostly caused by switching transients, which happen across the electric network at various locations. According to experiments, this sort of impulse typically lasts between a few microseconds to a few milliseconds. The serious impact this form of noise may have on high-speed communications employing PLC technology is shown by the fact that it exhibits unpredictable behavior and can emerge in bursts. It also emphasizes the need of strong channel coding methods, which will be studied, as well as resilient modulation strategies, which will be covered in section.

The first three categories of noise mentioned above may be categorized as background noise since they often stay motionless for extended periods of time. The latter two forms, which may be categorized as impulsive noise, are random in character and change over time. Section 2.5 will provide an overview of the various modeling techniques for impulsive noise. Historical Development of Communications Over Power Lines

The initial purpose of electrical power networks was to transmit and distribute energy from power plants to end customers. However, soon after full-coverage electrification, this infrastructure was used for data communication. The need for a communication connection to maintain the functionality of HV transmission networks served as the impetus behind the first creation of communication systems that utilize the electric network. Power supply utilities needed to set up a quick, bidirectional information flow between power plants, transformer stations, switching equipment, and coupling points in order to control operations, monitor performance, and locate and fix faults. Given that telephone lines weren't always available where communication was needed, it made sense to use the HV lines for both the transmission of electric energy and the fulfillment of the communication task. Additionally, it was discovered that telephone lines were unreliable and frequently resulted in serious interruptions during crucial communications. The applications for remote meter readings were also among the first to use power line networks for data transfer. An overview of the historical evolution and some of the traditional uses of power line communications are given in this section. CTP has been the primary method for transmitting data via HV power lines, whereas RCS was used in MV and LV networks.

Transmission over Power Lines by Carriers Beginning in 1914, carrier transmission via telephone lines underwent development. The method became commercially accessible in the US four years later under the moniker "wired wireless". The first country to use this method on electricity lines was Japan that same year, 1918. Power companies have to employ CTP for their operations management in order to optimize the distribution of power because to the quick expansion of high-voltage cables bringing electricity to new locations. The majority of early communications between the various electric network components used voice transmission. Later, non-voice data transmission was necessary due to the increasing importance of automatic tele-metering and remote monitoring. When compared to telephone lines, the use of CTP by PSUs for communications purposes yielded many benefits. These benefits include the following:

The optimal distribution of energy is one of the key duties carried out by the data communications network of power providers. Therefore, it's crucial to set aside enough energy for peak loads while also making sure that no extra energy is present. Monitoring in power networks, which gives data on energy needs, voltage levels, and frequency, is another crucial role accomplished by data lines. Data communications via HV power lines are a crucial tool in the event of breakdowns in addition to these two functions. A prompt and dependable communication path must be established between power plants, transformer stations, and coupling sites under such circumstances. HV power lines serve as a conduit for sui data transfer. HV power lines provide a broad spectrum due to their excellent transmission qualities, and only small transmit powers are required for secure data transfer across HV lines.

With only 10 Watts of transmit power, CTP can travel up to 900 km over very long distances in ideal circumstances. It can go roughly 300 kilometers under unfavorable circumstances. The frequency range used by CTP is 15 kHz to 500 kHz. The expense of the necessary capacitors is the major reason why frequencies at 15 kHz are not suitable. On the other hand, communication signals find it challenging to travel across long distances at frequencies exceeding 500 kHz due to high attenuation.

Radio users in the long-wave and medium-wave channels could also use some of this frequency spectrum. Power lines are not effectively shielded against radio operator interference at higher frequencies since they are built primarily for power transmission at low frequencies. Contrarily, the transmission of higher frequency communication signals across HV lines only slightly interferes with nearby radio receivers. Avoiding any frequency bands utilized by radio stations that could be sending their signals from nearby sites is crucial for the frequency allocation of CTP. Amplitude modulation was employed to transport the speech signal across power lines since the first types of communications over HV lines were voice communications utilizing carrier-wave telephony. For both the transmitting and receiving sides, AM represented a reliable and economical signal modulation scheme[7], [8].

Ripple Carrier Signalling

High-voltage power lines weren't the only ones that might be used for data transfer. The power network's medium-voltage and low-voltage levels need similar communication lines. The communication link's main responsibility in the MV and LV networks is managing energy distribution to guarantee the best possible use of the power capacity provided by HV power lines. MV and LV power lines have worse data transmission capabilities as compared to HV power lines, necessitating high transmit power levels for communication signals. This is because the MV and LV electric networks have a lot more junctions than HV networks do. Since around 1930, ripple carrier signalling has utilized MV and LV power grids for communication. Only extremely low frequencies close to the power signal frequency are utilized in RCS in order to allow communication signals to flow through the transformers between the MV and LV levels and prevent the need for extra expensive coupling equipment. However, this leads to low data rates that are insufficient for information to flow in both directions. Because of this, RCS can only be used for unidirectional communications from the PSU to the power consumer. Additionally, this technique cannot be used for remote metering because it can only communicate in one direction.

RCS transmitted information signals using time division multiplexing in its early implementations, modulating the mains voltage based on amplitude modulation. TDM-based single-frequency systems were first deployed later in 1935. RCS has mostly been used to convey on/off orders from the electricity provider to the user, which is essentially digital data. Digital modulation methods, including on-off keying, are the logical option for RCS nowadays and are often used in practice. ASK is the predominate modulation strategy for RCS communications because to the ease of its receivers.

Modeling of Power Line Channels

A thorough understanding of the properties of the transmission medium is necessary for the creation of novel communication systems. Based on the channel transfer characteristics and the capacity the channel offers, the transmission method and other design factors are chosen. Sui models that can accurately characterize the transmission behavior via the communication channel are needed in this situation. Modeling the power line channel is a highly challenging undertaking and is one of the main technological obstacles since the power line channel was not intended for high-speed data transfer connections. Power lines exhibit substantial branching owing to their complex distribution structures, which results in a major reduction of transmission quality in addition to the impulsive noise issue that was covered in the previous section. There is more than one way for a signal to get from the transmitter to the receiver while it is traveling via a power line. The sent signal is received in numerous delayed forms as a result of reflections from load locations. The literature contains many efforts to simulate the power line. However, the two main methodologies of time domain and frequency domain are the foundation of the existing models for the transfer function of power lines. Time domain models often rely on averaging the outcomes of measurement attempts. On the other hand, deterministic methods are used in frequency domain models. The next two sections provide a quick overview of the two methods.

Time-domain methodology Multiple Path Model Power line grids have a distinct topology and structure than telecommunications networks. In contrast to communications networks like telephone local loops, the link between a substation and the customer's home in power line networks is not portrayed via a point-to-point connection. As previously shown, the link from a transformer substation is made up of home connections with varied lengths representing branches from the distributor cable and a distribution link creating a bus topology. Numerous branches in the in-house wiring follow the house connection's termination at the house connection box. Power line network branching and impedance mismatches result in multiple reflections, which provide a multipath propagation situation with frequency selectivity. Additionally, when modeling the power line channel, frequency-dependent attenuation must be taken into account. Coupling losses, which rely on the PLC transmitter design, and line losses, which depend on the length of the cable, are the causes of signal attenuation in power lines. Along with being frequency-dependent, the channel transfer function is both time-varying and location-dependent since various appliances are continually being turned on and off, changing the transfer function. Philipps, Zimmermann, and Dostert,, have suggested models of the power line channel transfer function that explain the multipath propagation effects.

Transmission line models using a frequency domain approach

If the communication relationship between the transmitter and the receiver is well understood, the power line channel may be described using a deterministic technique. This involves being aware of the cable's topology, physical characteristics, load impedances, and other things. The models based on the multi-conductor and two-conductor transmission line theories are briefly explored in the sections that follow.

Models of two-conductor transmission lines

The literature contains many efforts to simulate the power line channel using the two-conductor transmission line theory. Either scattering or transmission matrices are used in these models.

Four different signal transmission modes are supported by a two-conductor transmission line, with earth acting as the second conductor. Two spatial modes, each with two propagation directions, carry the signal down the line. The differential and common modes are the two spatial modes. The differential mode is the dominant mode that carries the data signal along the transmission line in the desired direction. Differential signaling may be used to maximize propagation in the differential mode, which is the mode that is often stimulated by external noise, and to reduce propagation in the common mode. The two conductors must be carefully balanced in order to accomplish excellent rejection of undesired external signals since any imbalance between them stimulates common mode propagation. The impact of wiring and grounding procedures on transmission behavior were not taken into account by the two-conductor model. The model also failed to account for electromagnetic compatibility problems when estimating common mode currents. Furthermore, an MTL situation results from the two-conductor model failing to account for propagation in the presence of a third conductor, as is seen in single-phase power lines. In light of this, efforts to describe the power line channel using a two-conductor transmission line method could not adequately account for the behavior of propagation over power lines[9].

CONCLUSION

Another characteristic of electrical networks is their capacity to control voltage and frequency, which is crucial for maintaining a steady and dependable power supply. Voltage regulators, reactive power compensation, and frequency control systems, which guarantee that the power provided to customers is of a constant quality, are used to do this. Electrical networks' adaptability and resilience to shifting circumstances in demand and supply are significant characteristics as well.

This is accomplished with the use of dispatch and load balancing systems, which may modify the flow of electricity to meet shifting supply or demand situations, such as blackouts or severe weather, as needed. In general, electrical networks are essential parts of contemporary civilization because they provide the groundwork for the dependable and effective transmission of electrical energy. The development of new technologies and the optimization of current systems will be crucial for ensuring that electrical networks remain dependable, effective, and sustainable for years to come as energy consumption increases.

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CHAPTER 6

A BRIEF DISCUSSION ON MULTI-CONDUCTOR TRANSMISSION LINE MODELS

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ABSTRACT:

Multi-conductor transmission lines are a fundamental component of modern electrical networks, enabling the transmission of electrical energy over long distances. To accurately model the behavior of multi-conductor transmission lines, engineers use mathematical models that take into account the physical properties of the transmission lines, such as capacitance, inductance, and resistance.One of the most common models used for multi-conductor transmission lines is the distributed parameter model, which represents the transmission line as a series of interconnected segments. This model takes into account the capacitance and inductance of each segment and the resistance of the conductors, allowing for accurate predictions of the transmission line's behavior.

KEYWORDS:

Coupling, Distributed Parameters, Electromagnetic Field, Inductance, Line Parameters, Mutual Inductance.

INTRODUCTION

The three- or four-conductor power wire used in single-phase connections restricts the usefulness of the two-conductor transmission line model to understanding the propagation situation. Therefore, MTL theory should be used instead when modeling the power line channel when a third or fourth conductor is present. A transmission line with N conductors and a ground is divided into N simple TLs in MTL, each of which represents a different propagation mode. As a result, the signal entering an MTL is divided into N modal components, each of which travels via a different modal TL. At the output ports, the signal's modal components are recombined. The weighting elements in the voltage and current transformation matrices are used to determine the coupling between each port and each modal TL[1]–[3].

Six propagation modes occur in the line as a consequence of three spatial modes when a three-conductor power connection is employed. There are two paths of propagation for each of the three spatial modes. In the differential mode, the intended signal current often moves. While the signal in the common mode of propagation corresponds to the overall imbalance between the modes and is directly related to the cable installation practices, the signal in the pair-mode corresponds to the current flowing from the ground wire and the other two wires. In indoor PLC systems, the propagation modes are often out of balance, which causes coupling between the modes.

The advantage of low computational complexity that is virtually independent of the power line connection architecture is provided by frequency-domain channel models based on TL theory. However, comprehensive and in-depth knowledge of the transmission link must be known beforehand. The topology, characteristics of the cables utilized, and impedance values at the ends of every branch included in the model must all be specified. If precise information of these parameters is not accessible, it may significantly impair the model's accuracy. It is very hard to represent the power line channel using frequency-domain models based on TL theory in a real-world situation because of this lack of understanding about the power line network. However, the time-domain method described does not call for such network-specific information. To simulate the communication situation in power lines, this thesis uses the time-domain multipath model, which is recommended over frequency-domain models.

Simulation of Impulsive Noise

One of the primary obstacles to high-speed communications via power lines is asynchronous impulsive noise. Practice demonstrates that this sort of noise may have enormous energy, which can significantly impair the performance of PLC systems. Researchers and PLC device and system designers are concerned by the possibility that impulsive noise may regularly sweep whole data symbols. The normal intensity of a single impulse is more than 10 dB above the background noise level and may surpass 40 dB, according to measurements made in real power lines in. According to measurement findings, throughout the majority of the frequency range between 0.2 and 20 MHz, the PSD of impulsive noise is typically at least 10–15 dB higher than the PSD of background noise. They found that at some points in the band, this disparity might increase to more than 50 dB.

a sample impulse with a duration of around 50 microseconds. The impul- sive noise that occurs in power lines and other communication media is characterized in the time domain by three random variables. These are the inter-arrival time, amplitude, and width of the impulse. The literature contains many efforts to determine the probability distribution statistics of these three parameters based on actual measurements made in power line networks. The energy of a single impulse is determined by the impulse breadth and am- plitude. The strength of impulsive noise is described by the frequency and energy of the impulses. There are several statistical methods used in the literature to represent impulsive noise. On the other hand, background noise is often modeled as white Gaussian noise. To better understand the characteristics of impulsive noise, we examine several of these models in this section[4]–[6].

DISCUSSION

Middleton Class A Noise

Middleton divides electromagnetic interference or noise into three broad categories: Class A, Class B, and Class C. For explaining the statistical properties of impulsive noise in PLC contexts as well as other communication systems, many researchers believe that the Middleton Class A noise model is appropriate. The model takes into account both impulsive and background sounds. The overall noise, according to the Middleton Class A model, is composed of a series of independent, identically distributed complex random variables.The Middleton Class A noise model was first created to explain how impulsive behavior is affected by man-made EM interference. Despite the fact that many studies have studied this approach to represent impulsive noise, it is unclear if it can be used to describe impulsive noise in power line networks.

Model of Binary States

A binary-state model may be used to simulate impulsive noise. According to 2.5, there are two states in the model. The absence of impulsive noise is the initial state, S0. The model creates samples with 0 value in this state. The "on" state, which is represented by the second state S1, on the other hand, corresponds to the appearance of impulsive noise. In this condition, the model generates impulse bursts with unpredictable amplitude and duration. Aij represents the likelihood of a change from state Si to state Sj. demonstrates a simple binary-state model with no memory, where the transition probability is independent on the current state. This implies that when modeling impulsive noise, whether an impulse occurs at time t or time t + 1 is unrelated to whether an impulse occurs at time t.

The Markov chain model is a more extensive, all-encompassing version of the binary-state model. With a variable number of states, the Markov chain model has the property that the behavior in the future depends only on the process's state right now. The partitioned Markov chain, in which there are two sets of states, is a unique variation of the Markov chain. To simulate the duration and IAT of impulsive noise in power line networks, Zimmermann and Dostert suggested the partitioned Markov chain model. Several studies of impulsive noise in power line communications then used the model. A variable number of states, n, may be used in the partitioned Markov model. These states are divided into two clusters: impulse, which includes v states, and impulse-free, which includes w states. The earlier cluster is when impulsive noise occurs, while the latter cluster is when there are no impulses present in the channel. There are two distinct transition probability matrices that may be used to describe the two groups. The transition probabilities for the impulse group of states and the impulse-free group, respectively, are shown in the next two matrices.

Model of Bernoulli and Gauss

The Bernoulli-Gaussian model is often used to simulate impulsive noise in power line networks and other communication channels due to its simplicity. In a Bernoulli-Gaussian model of impulsive noise, the magnitude of the impulses is represented in accordance with the Gaussian distribution n, while the occurrence of the impulses is described in accordance with the Bernoulli process b. An i.i.d. sequence of ones and zeros, known as a Bernoulli process, has a probability that the process will take the value J1J = 1) = ; as a result, the process will most likely take the value J0J with a probability of 1 . A Bernoulli process' probability mass function

Gaussian Poisson Model

The Poisson-Gaussian model, which is often used to simulate impulsive noise, is straightforward and effective. According to measurement data in residential power line networks, impulsive noise arrives according to a Poisson distribution. In the Poisson-Gaussian model, the impulsive noise amplitudes are modeled using the Gaussian process, which has a mean of zero and a variance of two, while the arrival of impulses is modeled using the Poisson process. This indicates that impulsive noise will occur at a rate of units per second according to a Poisson distribution, and the chance of an event having m arrivals in one unit of time is:

Contrarily, as in the preceding section, the amplitude of impulsive noise follows a Gaussian distribution with a mean of 0 and variance of 2. The background noise wk is often taken into account to be an AWGN in order to mimic the overall noise that happens in PLC transmission in the discrete-time domain. The Poisson-Gaussian model may be used to characterize the impulsive noise ik as:

bkgk = ik

where gk is a white Gaussian process that represents the amplitudes of the im- pulses and bk represents the arrival of impulses according to the Poisson process. According to this concept, each transmitted symbol is physically imagined as being separately impacted by an impulse with probability bk and random Gaussian amplitude gk. The Poisson-Gaussian model is used as the impulsive noise model in all of the experiments examined in this thesis due to its ease of use and effective depiction of impulsive noise in real-world power line networks. In addition to impulsive noise, background sounds that are simply described as an AWGN make up the overall noise present in power lines.

Reduction of Impulsive Noise's Effect

Power line networks may have a variety of noise kinds. The section went into depth on some of each noise type's features and typical causes. Impulsive noise is the most harmful sort of noise among them, and it significantly restricts high-speed communication across power lines. Other high-speed communication technologies, such as digital subscriber line and digital video transmission, are also significantly hampered by this kind of noise. Impulsive noise in DSL systems is often brought on by a variety of factors, including lightning surges, engine and ignition noise from moving vehicles, electromagnetic discharge, and transmission and switching gear. In, a study of impulsive noise's impact on ADSL was provided. Similar to ADSL, impulsive noise sources such as household electrical appliances, light switches, ignition systems, and central heating thermostats are the origin of noise in DVB systems. Impulsive noise in terrestrial DVB systems has been measured and statistically analyzed[7]–[9].

Since the widely-used AWGN model is inapplicable in power line networks due to the presence of impulsive noise, modeling the noise scenario in this channel is challenging. The PSD of impulsive noise may be 50 dB greater than the background sounds.For high-speed PLC systems, a wise choice of modulation technology is essential. OFDM and multicarrier modulation methods often outperform single-carrier systems in the presence of impulsive noise, as will be detailed. This is a result of the receiver's discrete Fourier transform process, which spreads the impact of impulsive noise over many subcarriers. However, impulsive noise will affect all of the OFDM sub-carriers if its power exceeds a certain level, which will result in worse performance than in the case of single-carrier modulation. This emphasizes how crucial it is to use specific techniques to lessen the negative effects of impulsive noise in high-speed PLC applications.

The literature contains a variety of research on impulsive noise and strategies to lessen its impact on communication systems. The time domain memoryless nonlinearity is a straightforward technique that is often used in practice to lessen the impact of impulsive noise. In OFDM systems, this method is used to the received time-domain signal before the DFT operation. Samples that go above a specific limit are trimmed or blanked. To reduce impulsive noise, several studies suggested using frequency domain-based methods, After the DFT block at the OFDM receiver, these techniques counteract the impact of impulsive noise in the frequency domain. Using robust error-correcting codes that take impulsive noise into account is another method of reducing impulsive noise in communication networks. An overview of the current techniques for reducing the impact of impulsive noise in communication systems, and PLC systems in particular, is provided in this portion of the dissertation.

Time-domain Approaches

By pre-processing the time-domain signal at the front end of the receiver using a memoryless nonlinearity -, it is possible to lessen the impact of impulsive noise in multicarrier transmissions. Nonlinear methods like clipping, blanking, and clipping/blanking are often utilized in practical applications because to their simplicity. The purpose of these techniques is predicated on the idea that impulsive noise amplitudes are often noticeably bigger than signal amplitudes. As a result, a threshold is established, and signal samples with amplitudes over the threshold are presumptively influenced by impulsive noise and then adjusted in accordance with the used nonlinearity. a streamlined block diagram of an OFDM system using a nonlinear method to reduce impulsive noise. The demonstrates that the memory nonlinearity not only recognizes the incoming signal's amplitude and phase, but also alters simply the amplitude while maintaining the signal's phase.

Methods in the Frequency Domain

Prior to demonstration utilizing the discrete Fourier transform, the impulsive noise reduction methods covered in the preceding section act on the received OFDM signal in the time domain. Treating the impact of impulsive noise in the frequency domain is an alternative strategy, These methods are used at the OFDM receiver after the DFT signal demonstration. After demodulation and channel equalization of the received signal, Zhidkov suggested a frequency-domain approach to suppress impulsive noise based on early estimations of the broadcast signal that are then used to estimate the noise in the received signal. Prior to ultimate demodulation using the DFT operation, the derived estimate of the impulsive noise element is removed from the initial received signal. Because impulsive noise appears random in the frequency domain while the signal is well-structured, as opposed to the opposite being true in the time domain, frequency-domain techniques can be effective in reducing the impulsive noise effect.

Codes for Correcting Errors

For high-speed data transmission, the power line channel is regarded as a hostile medium since it is primarily affected by multipath fading, attenuation, and different types of noise, particularly high-amplitude impulsive noise. Despite this, research on the channel's capacity predicts extremely high data rates. When used as a transmission method, OFDM not only addresses impulsive noise but also some of the channel limitations like frequency selectivity. In fact, one of the main reasons for the revived interest in adopting multicarrier modulations for digital communications was their tolerance to impulsive noise. OFDM is suitable for broadband applications because it makes use of a large number of narrowband subcarriers that may be considered to have a flat frequency response. When impulsive noise occurs, OFDM divides its impact across all of the subcarriers throughout the receiver's demodulation operation. Even with OFDM, it is vital to adopt efficient channel coding techniques that can counteract impulsive noise and other channel impairments in order for the PLC channel to fully exploit its capacity and offer broadband high-speed data rates. In order to perform forward error correction, redundant bits are added to the relevant data bits. At the expense of a reduced effective data rate, the receiver may then utilize these redundant bits to identify and perhaps fix transmission faults.

For PLC systems, many coding techniques may be appropriate. Block coding is one of the most well-known types of coding. In this kind of coding, the data is broken up into smaller blocks of k data bits, and then each block is connected with the necessary redundancy bits to create bigger blocks of n bits. Next, the code is indicated. The ratio k/n between the data bits and the total number of bits per block is defined by the coding rate.Hamming codes are a popular basic type of block codes. Such codes are ideal for indoor, low-speed PLCs. Hamming codes are able to identify combinations of two or fewer faults in a single block and repair all single errors. Syndrome decoding may be used to crack hamming codes.

The BCH code is a popular class of block codes. BCH codes are essentially an extension of Hamming codes that allow for multiple error repairs. They have a wider range of block lengths, coding rates, alphabet sizes, and error-correcting capabilities, and they are more powerful. When using a block length of a few hundred, BCH codes outperform all other block codes with the same block length and code rate.Numerous publications have touched on coding for impulsive noise reduction. In and, researchers looked at the basic performance constraints of single-carrier and multicarrier communication systems in the presence of impulsive noise in terms of possible information rates. Consideration was given to low-density parity-check coding and decoding for impulsive noise reduction in and. In order to improve PLC systems that are affected by both AWGN and impulsive noise, the authors in suggest a coding scheme that makes use of erratic LDPC codes and bit-interleaved coded modulation. In, it was investigated how well LDPC-coded OFDM performed in channels that had impulsive noise problems. Based on the fact that OFDM as a multicarrier system may be seen in the complex field as a Reed-Solomon code, several coding techniques were created to tackle impulsive noise in OFDM systems. For channels influenced by impulsive noise, block codes over complex numbers are presented as a decoding approach in. The authors demonstrate how a complex number code using the discrete Fourier transform as the generating matrix may be used to represent an OFDM system. Therefore, for OFDM systems that are affected by impulsive noise, a suboptimal iterative decoding algorithm was proposed.

Numerous studies on impulsive noise in power line networks make the assumption that impulsive noise manifests as independently distributed complex random variables with the same distribution. Impulsive noise, however, may come in bursts whose lengths may exceed the length of transmission symbols. Since coding schemes that are created for individual errors do not effectively correct burst errors, this burstiness of impulsive noise needs to be taken into account when designing PLC systems. Interleaving may be used to overcome this issue. The interleaver minimizes the channel memory and spreads mistakes among the sent data by reordering the data bits. As a result, the decoder views the mistakes brought on by impulsive noise bursts as separate and simpler to manage issues. In Chapter 4 of this dissertation, the use of interleaving in conjunction with convolutional codes in power line channels impacted by impulsive noise will be examined. It will be investigated how well a bit-interleaved convolutionally coded OFDM system performs under various coding rates and impulsive noise situations.

Schemes for PLC Systems' Modulation

The properties of the power line as a communication channel for broadband applications were described in earlier parts of this document. As we have shown, PLC systems must contend with adverse channel characteristics that are uncommon in other well-known communication channels. The characteristics of power line networks and their susceptibility to different forms of noise need careful consideration when choosing the modulation techniques to be used in PLC systems. When choosing a modulation scheme for PLC, the following three important considerations must be made:

1. A person's vulnerability to various noise kinds, such as impulsive noise with relatively high noise power and lower SNR.
2. The PLC channel is a frequency-selective time-varying channel.
3. The transmission power in PLC systems is limited to modest levels due to electromagnetic compatibility problems.
4. Some of the potential modulation schemes for PLC systems are discussed in this section of the thesis.

Modulation using a single carrier

The data signal modifies a single carrier with frequency f0 in single-carrier modulation. The carrier's amplitude, phase, or frequency is used to encode the information. In ASK, the message signal modulates the carrier signal's amplitude without changing its frequency or phase, whereas in FSK, the carrier signal's frequency is modulated. By adjusting the carrier signal's phase in accordance with the information bits, PSK is obtained. QAM is created by combining PSK with ASK. In 2.10, a demonstration of QAM modulation using Gray coding is shown. The constellation diagram for rectangular 4-QAM is shown at the top, and the rectangular 16-QAM and 32-QAM are shown, respectively, in the middle and bottom plots. The simplicity of single-carrier modulation methods makes them desirable PLC system choices. Single-carrier modulation is a realistic solution and has been used in actual implementations for PLC's narrowband uses. These plans, however, have been shown to be inadequate for high-speed communications across power line channels in broadband PLC.

This is due to a number of issues connected to the power line channel's transmission characteristics. The multipath effect in this channel first creates deep notches in the frequency domain of the transfer function showing frequency-selective fading as well as severe inter-symbol interference. Depending on the characteristics and layout of the power line network being utilized, the impacted frequencies may change across time and space. The performance of single-carrier modulation might be extremely subpar in the face of such unpredictable frequency-selective fading. Strong detection and equalization methods must be used in order to improve performance and reduce the impact of ISI, which negates the simplicity benefit of single-carrier systems. Secondly, wide bands cannot be assumed to be sufficiently flat for high-data-rate communications because the channel attenuation typically rises with frequency. Thirdly, broadband PLC solutions need to achieve great spectral efficiency in a noisy environment like power lines. The spectrum effectiveness of simple single carrier modulation schemes is, regrettably, limited to 1 bit/s per 1 Hz.

Spread Spectrum Techniques

In the beginning, spread spectrum technologies were created for military applications with the goal of improving resilience against deliberate interference by dispersing a narrowband signal across a broad frequency spectrum. Due to its resistance to frequency-selective fading brought on by the multipath effect and robustness against all forms of narrowband interference, SST is appealing for PLC applications. Additionally, SST is a desirable alternative for PLC due to the low power spectral density of the transmitted signal, which complies with EMC restrictions.

Direct-sequence spread spectrum, frequency hopping, time hopping, chirp, and hybrid approaches are only a few of the SST variations. Code division multiple access may be used in SST to provide media access without the requirement for international coordination and synchronization.

In SST, a single carrier at frequency f0 is initially modulated with the information using traditional modulation techniques, resulting in a bandwidth that is about twice that of the message. As seen in the center graphic of Figure 2.9, a high-speed pseudo-random sequence is then used to accomplish a second step of modulation. After this modulation, a band-width that is roughly twice the pseudo-random sequence's clock frequency is obtained. The identical sequence utilized in the transmitter must be recognized and synced with the received signal on the receiving side. The message signal is then obtained by ordinary demodulation of the resultant signal.

The very broad bandwidth of SST is a crucial component that gives it the ability to fight narrowband interference. The high redundancy required for SST may dramatically lower the data flow via the transmission channel for a given transmission bandwidth. Therefore, SST requires a very large bandwidth that might not be present in the power line channel in order to provide high-speed communications over power lines. By using multicarrier modulation techniques such orthogonal frequency division multiplexing, which will be covered in the next section, spectral efficiency in PLC may be increased.

Multiplexing using orthogonal frequency division

A well-established multicarrier method, OFDM, has been successfully used in a number of high-speed wired and wireless applications. Examples of its applications include Wi-Max, asymmetric digital subscriber lines, digital audio broadcasting, and digital video broadcasting. Given its increased spectral efficiency and resistance to impulsive noise, narrowband interference, and selective fading, OFDM is a strong candidate for high-speed communication systems. Single-carrier systems are particularly vulnerable to frequency selective attenuation and interference since even a little amount of fading or interference may cause the whole connection to fail. In the case of OFDM, however, the same interference or attenuation may only harm a small number of subcarriers. Due to the orthogonality property, it is possible for the subcarriers to partially overlap without interfering with one another and still achieve the efficiency of OFDM. compares the spectral efficiency of OFDM to that of traditional frequency-division multiplexing and illustrates the difference.

The fundamental idea behind OFDM is to divide a single high-speed serial data stream into a number of parallel, low-speed streams that may all be sent at once via a number of orthogonal subchannels. Parallel trans- mission is not a brand-new concept. Early versions of this technology were really created in the 1950s and 1960s of the previous century. In 1970, the first patent was submitted. Military communications systems saw the earliest OFDM uses. By lengthening each low-speed symbol, parallel transmission is able to reduce intersymbol interference brought on by multipath delay. A cyclically prolonged time guard is added at the start of every OFDM symbol in order to totally remove ISI. Furthermore, a single-tap equalizer can be used in the receiver, simplifying the equalization process, and narrowband subcarriers have roughly flat frequency response when a sufficient number of subcarriers are used.

Four subcarriers that might make up an OFDM signal are used as an example to show the orthogonality attribute of the technology. This shows that the time interval for all four subcarriers is an integer number of cycles, and that neighboring subcarriers are separated by a complete cycle. Due to this orthogonality property, the integration over T yields the QAM symbols that were used to modulate a particular subcarrier when demodulating for that subcarrier. The outcome of the integration is 0 for all other subcarriers.

As a result, the channel's delay spread is significantly reduced in relation to the length of the symbol. By doing this, the receiver's exposure to ISI is reduced. Every OFDM symbol has a time guard connected to it in order to entirely remove ISI. This time guard is a little bit longer than the channel's anticipated delay spread. The time guard must be filled with a cyclic extension of the same OFDM symbol since it is crucial that it does not compromise the orthogonality of the subcarriers. This so-called cyclic prefix makes sure that the information bits are not impacted by the delay spread and that orthogonality is maintained, resulting in a signal that is free of ISI and ICI. At the receiver, the CP is eliminated before demodulating with FFT. The channel dispersion in the delayed route will be present in the FFT interval if the CP is less than the multipath delay spread, resulting in loss of orthogonality and ISI and ICI. The selection of the various parameters and the trade-offs between them is a crucial step in the design of OFDM systems. The three requirements of bandwidth, bit rate, and delay spread are of utmost significance. The selection of the CP length requires knowledge of the delay spread. Nee et al. state that an appropriate CP length should be between two and four times the root-mean-squared delay spread. Since higher order modulation is more susceptible to ISI and ICI, the choice of this value depends on the modulation and coding techniques used.

The less SNR loss caused by the CP, the longer the symbol duration in relation to the CP length. This results in more subcarriers with tighter spacing for a given bandwidth, which increases implementation complexity and creates issues with frequency and phase offset. When more subcarriers are used, a new issue involving the high peak-to-average power ratio of the OFDM signal arises. an example of an OFDM system that might work for PLC applications. Before being translated into PSK or QAM symbols at the transmitter side, the information bits first go through channel coding and interleaving. To identify the features of the channel transfer, pilots are injected into the data. The data stream is then divided into N parallel streams that use IFFT to modulate N subcarriers. All OFDM symbols include the CP before the signal is ready for transmission. In addition to the necessary synchronization and channel equalization utilizing the data given by the pilot symbols, more or less the reverse occurs at the receiver side.

The top contender for high-speed broadband PLC systems is currently thought to be OFDM. The following list of benefits highlights the main benefits this method offers:For wide-band communications across a channel with extremely little spectral resources, like the power line channel, OFDM gives a high spectral efficiency.OFDM's extended symbol period offers the method an edge over ISI and multipath propagation. Although the addition of a cyclic prefix lowers the system's useful data rate, it eliminates any ISI or ICI that might arise from multipath when designed to last longer than the PLC channel's delay spread.The IDFT/DFT process is the fundamental component of OFDM. The FFT method may be used to do this in reality in a manner that is both efficient and economical.

The frequency band is occupied by the subcarriers when a high number of subcarriers are utilized in OFDM. For each subcarrier, the channel may thus be considered to be flat. This results in a single-tap equalizer equalization process that is quite straightforward.When it comes to wide-band, high-speed communications, the power line network is a hostile channel. The existence of random time-varying impulsive noise, one of this channel's most important characteristics impacting high-speed communications, is essential. In the presence of impulsive noise, OFDM performs better than single-carrier modulation approaches, the influence of impulsive noise is significantly reduced in the receiver portion of OFDM by dividing the received signal, which includes impulsive noise, by the number of subcarriers.

The versatility of OFDM is a key feature. Each of the several subchannels in an OFDM signal may have a varied data rate, coding rate, constellation size, and transmit power depending on the PLC channel circumstances. Using adaptive modulation algorithms, these parameters can be changed to optimize system performance based on channel fading conditions. Additionally, by zeroing the subcarriers that fall in frequency bands that are prohibited from use in PLC systems due to regulations, these bands can be easily excluded[10], [11].

CONCLUSION

In general, multi-conductor transmission line models are essential to the planning and management of contemporary electrical networks. The creation of new and better models will be crucial for assuring the efficiency and stability of these crucial systems as technology advances and electrical networks grow more complicated. The T-model, which describes the transmission line as a collection of lumped components, is another popular model for multi-conductor transmission lines.

Despite being more straightforward than the distributed parameter model, this model is still effective in many situations. In recent years, new models have been created to accommodate the contemporary electrical networks' growing complexity. For instance, multi-conductor transmission lines with complicated geometries and material characteristics may be modeled using the finite element method (FEM), allowing for more precise predictions of the transmission line's behavior.

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CHAPTER 7

A BRIEF DISCUSSION ON ADAPTIVE MODULATION

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ABSTRACT:

Adaptive modulation is a technique used in wireless communication systems to adjust the modulation scheme and transmit power of a communication signal based on the channel conditions. The goal of adaptive modulation is to optimize the use of available resources and improve the reliability and quality of communication over wireless links.Adaptive modulation works by continuously monitoring the quality of the communication channel, which can be affected by factors such as distance, interference, and fading. Based on this information, the modulation scheme and transmit power of the signal can be adjusted in real-time to maintain a reliable and efficient communication link.

KEYWORDS:

Constellation Mapping, Error Correction Coding (ECC), Fade Margin, Modulation Schemes, Quadrature Amplitude Modulation (QAM).

INTRODUCTION

Its ability to efficiently transform a broadband frequency-selective channel into narrowband flat-fading subchannels is one of the main advantages of employing OFDM in PLC and different wired and wireless systems. As a result, the receiver's channel equalization complexity may be kept to a minimum. In addition to the frequency-selectivity feature introduced by branching and impedance mismatches, PLC systems are susceptible to narrowband interferences produced by AM broadcasters and other sources. All subcarriers in traditional OFDM systems are given the same constellation size and transmit power level. As a consequence, a subchannel or set of subchannels that are substantially faded would dominate the system's overall bit error rate, significantly degrading performance. High-speed OFDM-based PLC systems may perform better by using adaptive modulation techniques that allow each subchannel to have a varied constellation size and/or transmit power depending on its fading circumstances. The fundamental idea behind adaptive modulation is that, depending on the gain and noise levels of each subchannel, it contains a varied amount of adaptive modulation bits. It has been shown that adaptive modulation considerably enhances the performance of multicarrier systems. The subchannel signal-to-noise ratio may be regulated and changed by changing a number of parameters in adaptive modulation. Data rate, transmit power, instantaneous BER, constellation size, and channel coding or scheme are some of these[1].

By allocating zero power and dividing the data across the usable subcarriers, subcarriers that are prohibited from the useable bandwidth owing to regulations or interference with other wireless applications may be rendered useless. A dependable feedback channel that sends accurate channel status information from the reception end to the transmitter end may be used to assure a noticeable improvement while utilizing adaptive modulation. This may be done by allocating certain subcarriers for channel estimate or inserting known pilot symbols at the appropriate times.Numerous bit/power loading algorithms that aim to maximize system capacity can be found in the literature. The algorithms may be divided into two groups based on their goal functions:Margin-adaptive algorithms that aim to lower the transmit power level overall. Data rate and BER limitations are frequent requirements placed on MA algorithms.rate-adaptive algorithms that work to maximize the total data rate within the limits of transmit power and BER.There are also other loading techniques in the literature that try to reduce the BER of a system when dependability is a top concern. The approach suggested by Goldfeld et al., which ensures low aggregate BER and assumes that the constellation size is consistent across all subcarriers, is an illustration of this.

The majority of loading algorithms may be classified into three groups based on how they function fundamentally: Until the maximum capacity is reached without violating the power and/or BER constraints, incremental algorithms that incrementally allocate an integer number of bits to the subcarrier that has the lowest penalty in terms of the constraints. This kind of algorithm is sometimes referred to as a greedy algorithm since it selects the optimal position for the current step without considering the overall impact of its decision. The approach put out by Hough-Hartog, which begins with zero bits for all the subcarriers, is an early example of incremental loading. Then, until the BER or power constraints are broken, bits are incrementally loaded to the subcarriers requiring the least amount of incremental energy. The technique that begins with all subcarriers assigned the largest constellation size is another example of gradual loading. Once the constraints are reached, bits are gradually removed from the subcarriers with the worst BER performance.

Algorithms based on channel capacity, where a non-integer bit placement for the subcarriers is approximated using a closed form expression of the channel capacity. Bits that are not integers must be rounded to the closest integer, which deviates somewhat from the ideal outcome. BER expression-based techniques that also employ closed-form expressions to obtain the bit allocation and then round any non-integer values may be used if the transmitter side subchannel SNR is known.

System security for PLCs

All communication systems, especially those that rely on a shared medium, like wireless and power line systems, have a serious security problem. However, PLC systems are inherently safer than wireless communication systems. This is because the PLC's physical media is difficult to access. Wi-Fi systems, on the other hand, make use of a common media that anybody inside the network coverage area may access. With the right tools, network traffic may be intercepted, and the interceptor can even reconfigure the network device. The possible risk associated with the existence of the AC electrical signal is another security benefit of PLC networks. Furthermore, it is more challenging to extract the information from intercepted signals due to variations in SNR and channel frequency response between different nodes in the network. Different subcarriers may be modulated or even channel-coded differently when utilizing OFDM with adaptive modulation. As a result, in order to extract the information, one must be well familiar with the signal's modulation characteristics.

Power line networks are more resistant to assaults by nature, but they are not completely secured, and software security is necessary to offer adequate security levels. Eavesdropping, attacks aimed at disrupting network communications and inhibiting their functioning, and assaults aimed at gaining access to network devices and changing them at whim are the major sorts of threats that PLC networks are subject to. The following techniques may be used to combat such security risks:Intruders cannot access the information transferred in a network because of cryptography. Before being sent across the medium, the information is encrypted using a key. As a result, the signals are unclear to the invader. The information included in the signal is retrieved at the receiver side using a decoding key.Another security mechanism used in PLC and other wired and wireless networks is authentication. Access to the network is only granted through authentication once the user has been verified. Authorization to use the network won't be given until then.Integrity control is used to determine if data sent across a network has been altered while in transit.

Asymmetric key cryptography, sometimes known as public key cryptography, and symmetric key cryptography are the two basic types of cryptography. A single key is used to both encrypt and decode the data in the symmetric-key approach. The challenge of securely transmitting the key to the receiver arises because this key must be accessible to both the transmitter and receiver. The public-key strategy, which makes use of two separate encryption keys, is used to overcome this difficulty. The first is the private key, which is used to decode data and has to remain secret. The second is a public key that is used to encrypt data and is supplied to users in plain text. It is highly challenging to determine the value of one key using the other since the two keys are connected together using a mathematical formula.Electronic signatures may be used for sender identification and verification as well as integrity management. Electronic signatures are also used to determine if the data received has been altered or changed during network transmission[2]–[4].

DISCUSSION

Standardization of the PLC Technology

The PLC technology has what it takes to expand widely and successfully compete with the current wired and wireless technologies, as was shown in the earlier portions of this dissertation. PLC is now an established technology, and there are now products on the market that can provide physical layer rates of up to 200 Mbps. This technology offers excellent coverage for indoor networking and removed the need for additional cable installations. What is preventing PLC from making a significant dent in the market for telecommunications systems is the topic at hand.

The absence of an international standard that is endorsed by all stakeholders in the PLC sector is sometimes blamed for the limited uptake and partial implementation of PLC technology worldwide. By allocating particular resources in the electromagnetic spectrum, the standard must take into consideration the coexistence with the various wired and wireless communication systems. Interoperability between PLC devices that are based on diverse industrial standards is another crucial job. PLC standards have previously been created by individual firms and groupings of companies in an effort to further the general use of the PLC technology that those companies make and support. HomePlug, IEEE, and the OPERA consortium are the three primary organizations active in the pre-standardization and standardization of PLC. We go through some of the previous, present, and upcoming standards in the high-speed PLC industry in this part. It should be mentioned that there are several PLC standards for slow data rates that have been around for a while and have been widely accepted. The X-10 standard, which has been used to command and control applications, is a notable example of such standards. Utilizing Binary Phase Shift Keying, X-10 technology uses the electrical power signal to add one or two bits at each zero crossing. As a result, power lines that use 50 Hz line cycles may reach an extremely low data rate of just 100 bps[5], [6].

Specifications for HomePlugs

Around the year 2000, a number of businesses made the decision to establish the HomePlug Power Line Alliance with the aim of defining the technical requirements for in-home power line networking technology and promoting its accessibility and adoption globally. The HomePlug Alliance was established in March 2000 and now has over 65 member businesses. Representatives from Cisco, Comcast, GE Energy, Gigle, Intel, Intellon, Motorola, NEC, Sharp, and Texas Instruments are on the Alliance's Board of Directors.

The HomePlug Alliance's initial standard, Home-Plug 1.0, was created with the goal of enabling broadband communications between devices connected to the home network. The HomePlug 1.0 industry standard, which was launched in June 2001, employed a Media Access Control based on Carrier Sense Multiple Access with Collision Avoidance and offered a PHY speed of up to 14 Mbps. The HomePlug 1.0.1 standard was subsequently created by making a few minor updates and modifications to the Home- Plug 1.0 specification.

In order to deliver high-quality, multi-stream networking utilizing the existing power line in-home networks, the HomePlug AV industry standard was introduced in 2005. HPAV offers PHY data speeds of roughly 200 Mbps for data, audio, and video, allowing entertainment-oriented networking with tools like High-Definition TV and Voice over IP. HomePlug BPL and HomePlug Command and Control are two non-LAN standards that are currently being developed by the HomePlug Alliance. The HomePlug standards are reviewed in the sections that follow.

1.0 HomePlug

This standard employs 84 evenly spaced subcarriers and orthogonal frequency division multiplexing, which was discussed in section 2.7.3, to achieve a 14 Mbps PHY layer data rate. The frequency range used by HomePlug 1.0 is 4.5 MHz to 21 MHz. The standard uses a cyclic prefix that is appended to each OFDM signal in order to avoid the inter-symbol interference brought on by multipath propagations. In order to eliminate the requirement for receiver equalization, it also makes use of differential modulation methods. The adaptive tone allocation method used by HomePlug 1.0 to address channel fluctuations and selective fading allows subcarriers with extremely low SNR to be disabled. Data interleaving is used with FEC to mitigate impulsive noise occurrences. In HomePlug 1.0, a robust modulation mode is specified that employs stronger error correcting codes and temporal diversity, resulting in a slower data rate. For the transmission of crucial management signals, the ROBO mode is used.

The MAC layer in HomePlug 1.0 employs the CSMA/CA method with four degrees of priority. The nodes in this access strategy must detect the media before data transmission. If the medium is congested, transmission is postponed until the medium is free of traffic. In order to prevent collisions with packets from other waiting nodes, the node may now begin broadcasting after a randomly selected amount of time. HomePlug 1.0 also employs an adaptive window size control strategy. Data encryption based on the 56-bit data encryption standard is used in the HomePlug 1.0 specification to secure data.

HomePlug 1.0 has a total theoretical data throughput of roughly 8 Mbps at the application level, although real data rates in common house power line networks were measured to be between 4 and 7 Mbps.The HomePlug 1.0 standard was later modified to create HomePlug 1.0.1, which served as the foundation for Intellon's HomePlug Turbo, which offers rates of up to 80 Mbps. Higher order modulation methods were used to increase the data speeds in HomePlug Turbo from 14 Mbps in the original HomePlug 1.0 standard.

AV HomePlug

After the first specification's success, the HomePlug Alliance released HomePlug AV in 2005, a much more sophisticated technology specification. The HomePlug Alliance's second generation PLC technology is represented by HPAV. In order to create home networks employing AC power lines with PHY data speeds of up to 200 Mbps allowing for high-quality broadband services including high-speed data, audio, video, and other multimedia applications, it makes use of cutting-edge PHY and MAC technology. In order to support data multi-stream entertainment applications like HDTV, SDTV, and VoIP, HPAV wants to be the network technology of choice. The frequency range utilized by HPAV, which is a little bigger than the one by HomePlug 1.0, is 2 28 MHz.

The 200 Mbps total channel rate is split into 150 Mbps of information rate by the PHY layer. Windowed OFDM with 917 subcarriers and adaptive bit-loading are used to reach this rate. Depending on the subchannel fading circumstances, constellation sizes ranging from 1 bit to 10 bits may be assigned to each subcarrier separately. This, as described in section 2.8 and discussed in section 6, significantly enhances the overall BER performance by turning off the subcarriers that would otherwise dominate the BER.

Additionally, the system data rate can be significantly improved by assigning the subcarriers with high SNR values to carry up to 10 bits per QAM symbol. In order to take into consideration the changes in the channel delay spread and get rid of any ISI, the PHY layer additionally uses a flexible cyclic prefix. HPAV utilizes FEC with strong turbo convolutional coding at various code rates to reduce the impact of impulsive noise.

HPAV provides a high level of efficiency at the MAC layer because to the use of time-division multiple access and CSMA-based schemes that are timed to the AC line cycle. High dependability and assured bandwidth reservations are two examples of the quality-of-service assurances offered by TDMA. Additionally, using CSMA with four levels of priority improves efficiency.

As was covered in section 2.2.5 of this dissertation, synchronization with the AC cycle increases resilience against the often occurring periodic impulsive noise synchronized with the mains frequency. In terms of network administration, HPAV has sophisticated network management that may provide service provider setups as well as plug-and-play configurations. Using the 128-bit Advanced Encryption Standard, data transmission in PLC networks built on the HPAV standard is guaranteed to be secure. HomePlug 1.0 is compatible with HPAV, which also offers optional and required modes to provide coexistence with other network types. It is possible to receive a summary of the HPAV system's architecture.

BPL HomePlug Access

Broadband via power lines is the common name for the method of connecting a house or business to the internet using AC power lines. The HomePlug Power line Alliance established a working group to handle the access BPL side of the PLC system in addition to the in-home networking standards. The goal of the HomePlug BPL working group, which was established in 2004, is to create the market needs for the HomePlug BPL standard. In June 2005, a market need paper was completed. The HomePlug Access BPL standard's first draft was finished later in March 2007 by the Access BPL working group. Through the IEEE 1901 working group, the draft standard was incorporated into the IEEE Standard for Broadband over Power Line Networks. The key features of the IEEE Standard for Broadband over Power Line Networks will be discussed in the section that follows.

With the aim of becoming the premier standard for enabling Smart Grid applications that seek to improve energy use, the HomePlug Alliance recently produced the HomePlug Green PHY standard.

IEEE Standard 1901

Technologies for broadband PLCs have been on the market for some time. Due to the rising demand for high-speed broadband applications, the technology was generally well received by users across the globe. There hasn't been a single standard to serve as the foundation for these technologies, despite the modest success of contemporary PLC systems. To provide a uniform standard for high-speed PLC devices operating at frequencies of 100 MHz, the IEEE developed the IEEE P1901 Cor- porate Standard Working Group. The standard takes into account both the access cluster, which is concerned with providing broadband communications over the LV and MV power grids to the consumer's premises, and the in-home networking cluster employing low voltage in-home cabling.In June 2005, the IEEE P1901 Working Group was established. The IEEE Standards Association's Standards Board accepted the I EEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications on September 30, 2010, and it is scheduled to be published in February 2011.

A solution with a common MAC layer and the ability to support two PHY layers is offered by the IEEE 1901 Standard. One of the two PHY layers is based on FFT-OFDM, while the other is based on wavelet-OFDM. The compatibility with the present PLC devices, which are based on the two transmission modes, is the rationale for having two PHY layers. While devices based on HD-PLC Alliance industry specifications use wavelet-OFDM, HomePlug specifications are based on FFT-OFDM. Through an intermediary layer known as the Physical Layer Convergence Protocol, the MAC layer communicates with the two PHY layers. According to, the proposed FFT-OFDM based PHY utilizes the frequency range 1.8 48 MHz and employs a maximum number of 1893 subcarriers to achieve significant data speeds of up to 400 Mbps. Flexible frequency notching is available in this PHY layer to take regional and application needs into consideration. It uses a configurable guard interval and bit-loading technique and may utilize QAM modulation to transmit 1, 2, 3, 4, 6, 8 or 10 bits per data signal. This PHY employs the turbo convolutional code as its FEC algorithm. By synchronizing with the mains cycle, periodic impulsive noise that is synchronized with the AC cycle is explained.

Wavelet-OFDM is the foundation of the second PHY layer of the planned IEEE 1901 Standard. Wavelet-OFDM's excellent spectrum confinement and capacity to battle ISI without the inclusion of a cyclic extension, which might reduce system throughput, are its two key advantages. The 512 subcarriers used in the wavelet-OFDM suggested for IEEE 1901 are distributed evenly over the 228 MHz frequency spectrum. The possible data rate may be increased to over 500 Mbps by using an optional band that can be occupied for up to 60 Hz. Pulse amplitude modulation with real constellations M = 2, 4, 8, 16 or 32 bits per data symbol is the modulation technique utilized. Concatenated Reed-Solomon/convolutional coding schemes are used to accomplish FEC, and a low-density parity check code is optional.The proposed IEEE 1901 Standard includes a hybrid access control that uses both CSMA/CA and TDMA techniques at the MAC layer. The MAC specifies a conflict-free time and a contention phase in order to effectively regulate traffic with various transmission needs.

PLC applications

The usage of electric grids for communication in the early days of PLC technology was driven by the need for a practical communication connection to maintain the functionality of power networks. The key responsibilities of this connection were operations management, monitoring, and troubleshooting. Then, more PLC-based narrowband applications, such as those that use single- and bidirectional communications to read meters and control different home automation systems, started to appear. Due to the growing demand for high data rate broadband applications, PLC technologies now cover a wide range of applications, including voice, video, multimedia, networking, and other areas. An outline of PLC's present and future uses is given in this section.

Local Area Networks based on PLCs

The creation of a local area network in the house or workplace using the indoor electric wiring is a frequent and broad application of PLC. The primary benefit of PLC for this application is the widespread accessibility of power outlets in homes and workplaces, which makes it simple to connect numerous computers in a LAN using the pre-existing power lines. PLC-based LAN networks function similarly to other LAN technologies in that they provide the sharing of files and printers without the addition of additional cables. Sharing files and printers is especially crucial in business computer networks.

All computers connected to the same PLC network may share a single Internet connection. Regardless of the method used to connect the client premises to the Internet, a PLC device may reroute the data flow into the electrical network. In this way, the Internet is accessible from every outlet in the home or office. a local area network built on PLCs that has access to shared files, printers, and the Internet. The streaming of data from diverse sources is another use for LANs created using PLC technology. This may be shown by sending audio signals in different formats from an audio files server to every computer connected to the electrical network at home or at work. Audio equipment may be connected to speakers and to one another over the PLC network. Other pastimes like network games that may be played across different network stations can also be done using the PLC connection.

PLC may be combined in a variety of ways with other LAN technologies. The PLC may act as a backbone for the well-known WiFi networks. Although Wi-Fi networks give users in a building mobility and flexibility, complete coverage of enormous buildings might not be possible without using numerous wireless routers connected by a wired backbone. This backbone connection between Wi-Fi routers employing PLC devices may be made possible via electrical wire.

Video, audio, and other media

Applications like audio, video, and multimedia may be supported by the high data rates provided by PLC. For instance, one of the first PLC uses was telephone, which was tried for the first time in 1918. The bit rate needed for telephone voice transmission may be as low as 5.6 Kbps, which PLC can readily accommodate. However, there are other issues to consider when transmitting phone conversations over PLC in addition to data rate. The maximum amount of time between information transmission and receipt for a trustworthy application involving human contact is 300 milliseconds. This implies that the total round trip time for speech bits in a phone call via PLC cannot exceed 300 ms. For voice communications using PLC, synchronization at the receiver is an additional problem. The information being transferred must reach the recipient at precisely synchronized moments[7].

VoIP technology may be used to transport voice over PLC as IP packets. This method divides the voice into IP packets, which are subsequently sent across PLC and other networks. The CSMA/CA protocol is often used to control network access.For video applications like video streaming, video surveillance, cable TV, and videoconferencing, PLC can also accommodate larger data rates. The time delay restriction may be reduced if the application simply needs a single-direction information flow, as in the case of video streaming. The delay between when the source begins transmitting information and when the video starts playing on the other end might be several seconds. This permits the receiver to have enough packets in memory before starting to watch the video, preventing disruptions while it is playing. The use of electrical wires for video surveillance is another unidirectional use. Since a power outlet must be close by in order to power the camera, the use of PLC in this application provides a great deal of flexibility regarding the location of the camera. PLC also has the benefit of not requiring additional cables, unlike other wired systems that are often utilized in video surveillance.

MPEG standards are often used in the encoding of video. The quality of the pictures that make up the movie might vary depending on the compression method and ratio used. Generally speaking, the picture quality increases with decreasing compression. The attainable data rate that may be employed to transmit video picture frames is a significant factor that influences the quality of images. As long as the PLC network is not overused, there shouldn't be any issues with the data rate requirements for video transmission with television quality for PLC based on modern standards like HomePlug AV and IEEE 1901. These PLC standards can handle HDDTV as well. However, the number of users in a network is very constrained due to the high bit rate required for HDDTV. HDDTV cannot be supported by earlier PLC standards like HomePlug 1.0 because to their restricted data rate capabilities.

Another capability that may be used with PLC systems is videoconferencing. High data rates of many megabits per second are needed to provide a quality comparable to television. The needed data rate for videoconferencing at movie theater quality may reach 50 Mbps. Videoconferencing incorporates human interaction, which imposes the time delay limitation, much as telephone via PLC. Another issue with videoconferencing is synchronization, which has to be adequately managed. The PLC technology may also transmit multimedia files that include audio, video, and other sorts of data. High bit rates are often required for multi-media applications depending on the kind of data provided. Using PLC devices, high data rates can be offered in accordance with current standards. However, synchronizing the concurrent applications that make up a multimedia process is necessary when sending multimedia files.

Online accessibility

Customers in the last-mile region may access the Internet and other IP services using the PLC technology by using the LV power grids as an access network. This is accomplished by employing a PLC device to inject the PLC signal into the LV power grid. This situation is shown in 2.20. Another PLC device at the subscriber end receives the Internet signal and sends it into the electrical network within the building, where other communication devices may connect to the network by plugging their devices into power outlets. The master PLC device, which is next to the MV/LV transformer, controls communication. The master PLC apparatus serves as a base station for the PLC apparatus of the subscribers. Conventional communication techniques, including as optical fibers, radio connections, and so forth, as well as the usage of MV power grids, may be used to connect this base station to the wide area network[8], [9].

CONCLUSION

This included conducting communications across electrical lines. In addition to providing a short account of the historical advancements of PLC systems, the topologies of power line networks and their physical characteristics were also described. The literature's models that may be used to characterize the PL channel and the current noise were also discussed. Each model's benefits and weaknesses were also identified and described.

The offered an overview of the methods for reducing impulsive noise that were documented in the literature. The three primary types of those approaches were time-domain, frequency-domain, and FEC-based methods. To help the reader choose whether modulation strategy is more effective, several modulation strategies and their usefulness in PLC were also examined. Adaptive modulation is necessary and the superiority of OFDM has been discussed. This article provided a review of the various adaptive modulation types and techniques. Along with a survey of the past, present, and future PLC standards, a brief overview of the security of PLC technology was provided. the concludes by highlighting a few of the current.

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CHAPTER 8

NONLINEAR TECHNIQUES FOR IMPULSIVE NOISE REDUCTION AND FUZZY LOGIC

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ABSTRACT:

Fuzzy logic is a computational technique that deals with reasoning and decision-making in situations where the boundaries between categories are not well-defined or where imprecise or uncertain information is present. It is a mathematical framework that allows for the representation and manipulation of vague or fuzzy concepts, such as "large," "small," "hot," and "cold," using linguistic variables and fuzzy sets.Fuzzy logic has a wide range of applications in various fields, including engineering, control systems, pattern recognition, data analysis, and artificial intelligence. The key advantage of fuzzy logic is its ability to handle incomplete and uncertain information, which is often encountered in real-world problems.Fuzzy logic provides a flexible and intuitive way to model complex systems and make decisions based on incomplete or imprecise data.

KEYWORDS:

Adaptive Filters, Decision Feedback Equalizer (DFE), Impulse Noise, Median Filter, Nonlinear Processing, Nonlinear System, Noise Reduction.

INTRODUCTION

In communication systems, impulsive noise, which results from abrupt spikes or bursts of unwanted signals that may distort the original signal, is a typical problem. In order to improve the signal quality in communication systems, impulsive noise reduction is a key job. We will concentrate on numerous nonlinear noise reduction methods that have been put up in this review study[1]–[3].Impulsive noise reduction using nonlinear methods:An effective method for cutting down on impulsive noise is median filtering. This method's primary benefit is its capacity to eliminate impulsive noise while maintaining the signal's edges. Each pixel is changed to have the median value of its neighbors to achieve this. However, in situations where there is a lot of noise, this method might not work well.

Adaptive Median Filtering is an improvement on median filtering that adjusts to the amount of impulsive noise in the input signal. Based on the signal's local volatility, the algorithm chooses the right window size. The signal characteristics are maintained while impulsive noise is successfully removed using this method.

Wavelet Thresholding: Another well-liked method for impulsive noise reduction is wavelet thresholding. A thresholding function is used to the wavelet coefficients after the signal has been broken down into its component parts. Noise is reduced using the thresholding function, which eliminates coefficients below a predetermined threshold. The signal features are kept when impulsive noise is successfully removed using this method.

Fuzzy Logic: A well-liked method for impulsive noise reduction is fuzzy logic. To reduce the impulsive noise, fuzzy logic rules are used after translating the input signal to a fuzzy set. The capacity of this method to deal with ambiguity and imprecision in the input signal is by far its greatest benefit.Networks of neurons Impulsive noise reduction often employs neural networks. They operate by teaching a network how to translate an input signal to an output signal. The network learns to eliminate the impulsive noise from the input signal after being trained on a dataset of clean and noisy signals. The signal features are kept when impulsive noise is successfully removed using this method.

The need for high-speed communication signals sent through electric power lines utilizing PLC technology is increasing quickly. Power line networks, on the other hand, are quite different from traditional communication channels like twisted pair, coaxial, or fiber-optic cables in terms of topology, structure, and physical qualities since they were not initially intended for data transmission. Power lines are a hostile environment for higher frequency communication transmissions since they were only intended to carry electric signals at 50/60 Hz. The most important channel characteristics that affect how well high-speed communications function are noise, attenuation, and multipath propagation. Noise in power line channels cannot be characterized by an additive white Gaussian, in contrast to many other communication channels. noise that is impulsive noise-related. The random time-varying behavior of this kind of noise ranges in length from a few microseconds to milliseconds. Practical power line investigations demonstrate that, when an impulse occurs, the power spectral density of impulsive noise surpasses the PSD of background noise by at least 10-15 dB and sometimes by up to 50 dB. Thus, in order to limit its impact on data transmission, mitigation techniques must be used[4]–[6].

A straightforward method of reducing impulsive noise is to introduce a memoryless nonlinearity before the receiver. A traditional detector preceded by a memoryless nonlinearity is able to detect arbitrary signals in impulsive noise environments at local optimum levels, assuming low SNR values. Modern OFDM receivers use suboptimal clipping or blanking techniques to lessen the impact of impulsive noise. Zhidkov has addressed this approach for wireless applications using traditional OFDM receivers. It is crucial to research the effectiveness and suitability of such strategies for PLC systems.In this, we look at the effectiveness of three nonlinear approaches in reducing the impact of impulsive noise in PLC systems based on OFDM. To address the threshold selection conundrum in these nonlinearities, an adaptive threshold that reduces BER is provided based on the analysis and outcomes of the three strategies. The papers and, respectively, are the results of a research on the adaptive threshold for both clipping and blanking nonlinearities as a method to lessen the impact of impulsive noise in PLC systems.

Then, an integrated technique for suppressing impulsive noise in the time and frequency domains is suggested. A well-liked and operationally tested PLC multipath channel model is used in computer simulations to provide the desired results. The terms "Heavily disturbed," "medium disturbed," and "weakly disturbed" are used to describe three distinct impulsive noise situations. The findings were released in the 2008 Australian Telecom- munication Networks and Applications Conference proceedings.

DISCUSSION

OFDM System

OFDM is the transmission system used to evaluate the effectiveness of nonlinear methods for reducing the impact of impulsive noise. In section 2.7.3, the OFDM transmission scheme was covered in great depth. OFDM performs better than single carrier modulation systems in the presence of impulsive noise,. This is because, during the discrete Fourier transformation process at the receiver, OFDM distributes the impact of impulsive noise across a number of symbols. Along with its resistance to impulsive noise, OFDM has a high spectral efficiency and the ability to deal with multipath and narrowband interference[7]–[9].

Network Model

In terms of topology, structure, and physical characteristics, power line networks are quite different from traditional communication channels like twisted pair, coaxial, or fiber-optic cables. Power lines provide a challenging environment for higher frequency communication signals since they were not intended for data transfer. Signal distortion caused by frequency-dependent cable losses, multi-path propagation, and noise are the characteristics of this hostile medium that have the most effects on the efficiency of high speed communications. A useful multipath channel model was developed by Zimmermann and Dostert and is ideal for characterizing the transmission characteristics of power line channels.

Sound Model

Data transfer may run into many noise kinds in PLC settings. There are five different types of noise in electricity lines. Which are:

1. Colorful ambiance noise
2. Confined-band noise
3. Cyclical, impulsive noise that is not of phase with the mains frequency
4. Cyclical, impulsive noise that matches the frequency of the mains
5. impulsive asynchronous noise

Included information on the several forms of noise that may be heard in power line channels, as well as its characteristics and sources. The first three categories of noise mentioned above may be categorized as background noise since they often stay motionless for extended periods of time. The latter two forms, which may be categorized as impulsive noise, are time-varying in character. Power supply or network switching transients are the major causes of impulsive noise. The Poisson-Gaussian model is used to simulate impulsive noise.This model, which has been used in several investigations, provides a straightforward and effective description of impulsive noise in power line channels. On the other hand, impulsive noise's amplitude follows a Gaussian distribution with a mean of zero and a variance of two. Since impulses can actually last for arbitrary lengths of time, it is assumed that the impulse width follows a Gaussian distribution with a mean equal to the typical impulse width.

To examine how various nonlinearities behave under various noise situations, three impulsive noise scenarios are taken into consideration. All three scenarios' attributes are derived from actual measurements. The average impulse rate the quantity of impulse occurrences per second and the average disturbance ratio DR in the channel define them. The "heavily disturbed" situation was recorded in the evening at a transformer substation in an industrial neighborhood. The "medium disturbed" scenario, in which measurements were taken at a transformer substation in a neighborhood with detached and terraced homes, is the least disturbed scenario. The third instance is referred to be "weakly disturbed" and was captured at night in an apartment housed in a large structure. According to the specifications in 3.3, 3.3 is the total noise for all three noise circumstances, which includes both background and impulsive sounds. The Poisson-Gaussian model is used to create impulsive noise. The noise in a highly disturbed environment is shown in Figure 3.3. on order to identify the impulsive noise from the background noise, which is provided as AWGN, a smaller scale on the x-axis is utilized due to the very high number of impulses that occur per second in this circumstance. The reciprocal of the impulse rate's value for the average inter-arrival time between impulses in this noise situation is 8.2 seconds.

Using time-domain nonlinearities to reduce impulsive noise

Since the energy of the impulse noise is dispersed over the simultaneously transmitted OFDM subcarriers, the long symbol duration in OFDM systems increases the signal's robustness to impulsive noise. However, impulsive noise can significantly affect the performance of OFDM systems if mitigation strategies are not used, particularly in a channel like power lines where the presence of impulsive noise is a common occurrence. In reality, if the impulse energy rises over a particular threshold, it will actually be detrimental to distribute it among OFDM subcarriers. In this situation, impulsive noise might have a negative impact on all subcarriers.

The literature has considered a variety of impulsive noise attenuation strategies. A summary of a few of these methods was provided. Because they are so straightforward, memoryless nonlinearity techniques are frequently used in real-world settings to lessen the negative effects of impulsive noise in data communications. They are used at the front-end of an OFDM receiver before fast Fourier transforms (FFT) are used to demodulate the signal. An OFDM block diagram shows a memoryless nonlinearity block for impulsive noise reduction before the FFT is used to demodulate the signal. These methods merely alter the signal's amplitude in accordance with a predetermined threshold, not its phase. The previous article's section 2.6 covered the three time-domain nonlinearities. Here is a quick summary of these methods for the reader's convenience.

Threshold Choice

Any nonlinearity's ability to function depends heavily on the choice of a particular threshold value above which a signal sample will change. If a signal sample's amplitude exceeds this limit, it will either be clipped or blanked. This threshold must be carefully chosen to ensure that the nonlinearity unit only changes the samples impacted by impulsive noise and avoids moderating the original non-affected signal samples in order to reduce the BER at the receiver. The majority of the received samples of the OFDM signal are clipped or replaced with zeroes when Tc or Tb is extremely tiny. This increases the number of mistakes in the output signal and raises the BER. The nonlinear preprocessor is more likely to exclude the received samples, even those impacted by impulsive noise, for extremely high values of Tc or Tb. Therefore, impulsive noise may have a significant impact on the system's performance, and nonlinearity may not provide any benefits. A correctly chosen threshold lowers the likelihood of impulsive noise being mistakenly detected and enhances the performance of the nonlinear clipping or blanking nonlinearities.

Performance findings for nonlinearities with a set threshold

Through computer simulations, the three different impulsive noise scenarios were used to examine the performances of the three time-domain nonlinearities in OFDM-based PLC receivers. According to the explanation in the preceding section, the threshold values used in the nonlinearities were optimized via simulations of various threshold values at a specified SNR of 30 dB, and the chosen values were fixed for all other SNR values. The author has released this piece of art. A randomly generated binary stream is converted into QPSK symbols and modulated using 128 subcarriers of OFDM on the transmitter side. Then, this signal is passed through a PLC multipath channel with 15 paths and parameters from equation 3.2. While the background noise is assumed to be AWGN, the arrival of impulsive noise is assumed to follow a Poisson distribution as given by. The OFDM signal is supplemented by the overall noise coming from impulsive and background disturbances. The memoryless nonlinearity is initially applied to the received signal rk at the receiver side before it is demodulated by a DFT unit. After demapping the signal, the BER performance is calculated. A random bit stream with a length of 1600000 bits is created and broadcast via the channel based on the stated system 100 times throughout the simulation in order to get accurate results. a comparison of the three straightforward nonlinearity methods used in OFDM-based PLC systems for the reduction of impulsive noise. Results for "heavily disturbed," "medium disturbed," and "weakly disturbed" impulsive noise environments, respectively, are obtained in these s. As shown in Figure 3.7, clipping outperforms blanking nonlinearity for SNR values between 25 and 35 dB, whereas the latter approach works better for high SNR values for fixed threshold values, outperforming the former by around 2 dB. Simulations for the identical impulsive noise characteristics demonstrate that the combined clipping/blanking method is the optimum nonlinearity solution to impulsive noise in this instance. This method may sometimes provide performance gains of more than 5 dB above clipping and blanking. For this setting, it should be noted that all three approaches provide very little benefit for high SNR values[7]–[9].

The performance of blanking nonlinearity, using the same threshold values as the other two approaches, is the best in the "medium disturbed" environment, as in. All three methods significantly lessen the impact of impulsive noise in this environment. The BER of an OFDM-based PLC receiver may be reduced from 7 103 to 105 when the SNR is equivalent to 45 dB in a moderately disturbed environment. As can be shown, at fixed threshold levels, the effects of clipping and blanking approaches on "weakly disturbed" power lines are similar. The least effective technique in this impulsive noise environment was clipping/blanking.The BER performance of the OFDM system has an error floor because of the multipath effect in power line channels. This error floor is impacted by impulsive noise that occurs and is brought on by inter-symbol and inter-carrier interference. The BER is not improved by increasing the signal strength since doing so amplifies the ISI and ICI effects. The number of OFDM subcarriers, the symbol length, and the channel impulse response are some of the variables that affect the level of the error floor.

Threshold-adaptive Nonlinearities

Communication signals in PLC networks do not always travel in a straight line from the transmitter to the receiver. Power line branching results in several network reflections, which cause multiple delayed copies of the original signal to be received. Power line channels' multipath and frequency selectivity characteristics might vary from network to network. In addition, the received signal is attenuated differentially depending on the length of the propagation route. Choosing the best threshold value under these circumstances and when time domain nonlinearities are used at the front-end of the receiver becomes a highly crucial challenge. Depending on the SNR of the received signal under the same channel circumstances, the optimal threshold may change somewhat. The following describes how, using a minimal BER technique, the threshold value may adjust to the channel state and the quality of the received signal. The adaptive-threshold approach is then tested in a power line channel that has impulsive noise interference. Results are acquired at various threshold levels and noise levels to demonstrate the improvements made possible by the adaptive approach.

Synopsis of the System

An adaptive threshold selection is given in this part in order to maximize the effectiveness of clipping and blanking in mitigating the influence of impulsive noise at varying channel circumstances. By setting the nonlinearity threshold value to the ideal level, this technique aims to reduce the output BER. In this method, a very low value predetermined threshold is first set. After that, the threshold is raised incrementally, with each increase resulting in a new measurement of the BER. The adaptive threshold clipping or blanking block receives the updated BER values through a feedback channel from the BER estimate. The use of training sequences and pilot subcarriers may be used to estimate BER. However, it is assumed in this section that the receiver is equipped with knowledge of the BER. The BER begins to rise after a certain number of rounds, suggesting that the optimal threshold has been reached. The resulting value is then used to determine whether to clip or blank.

Nonlinearity in blanking

The BER performance of the proposed adaptive-threshold blanking method for suppressing impulsive noise. In these research, the same three levels of noise disturbance "heavily disturbed," "medium disturbed," and "weakly disturbed" are shown to produce the same results. Similar to clipping nonlinearity, three threshold values are used to represent low, medium, and high threshold levels, respectively. It should be noted that the appropriately selected blanking threshold is higher than the clipping threshold for the same signal and identical channel conditions. The results presented in the literature have been verified by our investigation. It should be noted that the recommended thresholding method outperforms blanking nonlinearity with fixed threshold for all fixed threshold values in all three noise scenarios. For instance, in a mildly disturbed environment with SNR equal to 40 dB, the recommended adaptive-threshold blanking decreases the BER from 7 105 to less than 6 107. The BER can only be reduced to a minimum of around 1.8 106 under the same conditions and SNR when a well selected threshold Tb of around 0.36 is used. As can be shown, the adaptive-threshold strategy nearly completely eliminates the effect of impulsive noise and results in performance that is quite similar to the case when the PLC channel is only affected by AWGN. Similar to clipping nonlinearity, the adaptive technique provides the best performance of the blanking circuit and is a major improvement over blanking with a fixed threshold.A technique for reducing impulsive noise in OFDM receivers was introduced. The technique is based on a frequency-domain approach in which, following OFDM demodulation, FFT is employed to adjust for impulsive noise. In this section, we provide a succinct description of this approach. Regarding the method, there are more details in.

Noise Suppression for Joint TD/FD Impulsives

Previous portions of the thesis have explored and provided examples of the detrimental effects of impulsive noise in communication systems in general and in power line communications in particular. Due to the high power and unpredictable nature of impulsive noise, mitigation of its effect during high data rate communications over PLC mediums is not possible. We provide a hybrid time-domain/frequency-domain technique in this section for decreasing impulsive noise in PLC systems that use OFDM.

Synopsis of the System

In this part, we discuss a combined time-domain/frequency-domain method for OFDM-based PLC systems to reduce impulsive noiseillustrates the implementation of this strategy in OFDM systems, which combines the frequency-domain suppression technique presented with the time-domain nonlinearities that were explored in earlier sections of this. Using the combined clipping/blanking nonlinear preprocessors described, the impulsive noise in the received OFDM symbols is first reduced. Particularly, clipping/blanking nonlinearity is known to perform better than the clipping and blanking nonlinearities separately. This conclusion was tested using simulations in PLC channel settings. After channel equalization and DFT demodulation, the frequency-domain suppression approach described is next applied to the OFDM signal in order to further enhance the impulsive noise mitigation. The method is put to the test using impulsive noise on a power line. The results of a simulation are shown in the section that follows, and they demonstrate a considerable decrease in bit error rate when compared to both traditional OFDM systems and OFDM systems with nonlinearity-based impulsive noise reduction.The effectiveness of the suggested combined time-domain/frequency-domain impulsive noise abatement approach was investigated using MATLAB software. A random bit stream is converted into QPSK symbols, modulated using 128 subcarriers of OFDM, and sent across a 15-path PLC multipath channel. The OFDM signal is then accompanied by noise, both background and impulsive. While the impulsive noise is modeled using the Poisson-Gaussian noise model, the background noise is modeled as an AWGN noise. Gaussian impulses are used in this model, and

One can see that the suggested hybrid TD/FD impulsive noise suppression method outperforms the frequency-domain method and the three time-domain nonlinear methods. In addition to the frequency-domain suppression mentioned in section, the curves in this part show the BER performance of the proposed combined TD/FD approach and the three time-domain nonlinearities discussed as a result of simulation in a multipath power line channel with 15 propagation routes. Impulsive noise is severely disturbing the channel. Only at high SNR levels can the frequency-domain suppression strategy outperform time-domain nonlinearities in this noise situation. However, at all SNR values, the proposed TD/FD technique outperforms all other techniques, including the FD technique. For instance, the combination TD/FD offers an improvement of more than 5 dB over all the other approaches at BER of 104. The suggested approach provides BER performance comparable to that of the signal with just AWGN in a noisy environment and with SNR values of 35 dB, meaning that the impact of impulsive noise is virtually completely avoided.

the BER performance of every strategy for noise reduction that has been researched on a power line channel that is only mildly influenced by impulsive noise. The FD noise reduction approach does not provide any benefit over TD procedures with suitably chosen thresholds in this noisy environment. It should be noted that although the disturbance ratio and impulse rate are set for each noise scenario, the impulsive-to-background power ratio, as stated in, is kept at a value of 3 for all three noise scenarios. Regarding and for fixed, the power of impulsive noise in the medium- disturbed scenario will be significantly higher than in the heavily disturbed scenario, and it is even higher in the weakly disturbed scenario. This is because the disturbance ratio is lower in the moderately and weakly disturbed settings than it is in the strongly disturbed environment. According to, when impulsive noise is encountered, the FD approach does not perform as well since the prior assessment of the transmitted signal becomes incorrect. As a result, the impulsive noise vector Ik is incorrectly estimated, which lowers the effectiveness of the FD suppression strategy. The curve for the combination TD/FD approach demonstrates that this strategy works better than the other investigated techniques and considerably lessens the impact of impulsive noise. Performance of the combined TD/FD approach in a weakly impulsively noisy power line channel. As previously mentioned, the high peaks of the impulsive noise cause the FD approach to perform worse than the straightforward TD nonlinearities. However, of all the methods examined, the joint TD/FD performs the best at reducing the impact of impulsive noise[10]–[13].

CONCLUSION

In this, the effectiveness of nonlinear methods for reducing impulsive noise in OFDM under real-world PLC channel conditions was taken into consideration. Through the use of computer simulations, three distinct nonlinearities clipping, blanking, and clipping/blanking were compared. The impulsive noise in PLC channels was simulated using three noise scenarios based on actual observations. This introduced an adaptive-threshold method based on minimal BER for nonlinear impulsive noise reduction. When compared to nonlinearities with fixed thresholds, the BER performance of OFDM with adaptive threshold nonlinearities performed better. The obtained findings demonstrate that, in comparison to clipping with a fixed threshold value, the adaptive-threshold approach enhances the performance of OFDM-based PLC receivers. Additionally, introduced was the joint Time-domain/Frequency-domain im- pulsive noise suppression method. Through the use of computer simulations, the performance of this technique is examined against well-known time-domain nonlinearities. The obtained findings demonstrate that the combined TD/FD approach outperforms realistically used nonlinearities and may greatly lessen the negative effects of impulsive noise. In a channel that is heavily disturbed by impulsive noise, the effect of impulsive noise can be roughly eliminated using the TD/FD technique and at SNR values.

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CHAPTER 9

PERFORMANCE OF BIT-INTERLEAVED CODED OFDM IN PLC SYSTEMS

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ABSTRACT:

Bit-Interleaved Coded Modulation (BICM) is a widely used technique in modern communication systems to improve the performance of digital communication over wireless channels. BICM can achieve high data rates and reliable communication by combining coding and modulation in a single system. This technique interleaves the data bits and maps them onto a constellation, which enables the receiver to decode the data more accurately.This paper presents an analysis of the performance of Bit-Interleaved Coded Modulation using different coding schemes and modulation techniques. We investigate the effect of various parameters such as channel conditions, signal-to-noise ratio (SNR), and the number of iterations on the performance of the system. We also compare the performance of BICM with other coding techniques such as Turbo coding and Low-Density Parity-Check (LDPC) coding.

KEYWORDS:

Bit Error Rate (BER), Bit-Interleaved Coded Modulation (BICM), Channel, Coding, Forward Error Correction (FEC).

INTRODUCTION

Impulsive noise and other narrow-band interferences have a negative impact on power line channels. Particularly impulsive noise may drastically lower the performance of PLC systems based on OFDM. Therefore, channel coding is crucial to enhancing the dependability of communication over PLC channels. Convolutional codes, BCH, Reed-Solomon, and low-density parity check are a few examples of such channel coding systems.

In order to take into consideration, the bursty nature of impulsive noise in PLC channels, interleaving in addition to coding is required. Investigated in was the performance of coded OFDM in PLC channels. However, no interleaving was applied, and no information is provided regarding the quantity of impulsive noise used in the simulations.

The channel memory is decreased and the channel faults are distributed by interleaving. As a result, a coding scheme that is intended to control independent faults may be used more effectively.

The bit error rate performance of bit-interleaved convolutionally coded OFDM in the presence of impulsive noise is simulated in this section using the same PLC multipath channel model as was presented in earlier sections of this thesis. In 3.3 in 3, three distinct impulsive noise situations are taken into account[1].

Synopsis of the System

The transmission method for sending coded data bits across the PLC channel is thought to be OFDM. PLC channels' multipath and frequency selectivity are well-handled by OFDM. By dividing the data into several orthogonal subcarriers and using the inverse discrete Fourier transform, it also achieves a high level of efficiency. Furthermore, because OFDM uses the discrete Fourier transform in the receiver to spread the effect of impulsive noise across multiple subcarriers, it performs better than single-carrier modulations in the presence of impulsive noise. To address the bursty, impulsive noise, convolutional coding is used with interleaving for forward error correction. The part that follows gives a quick overview of this coding system. The PLC multipath channel model that was given must provide dependable results. It has been shown in practice that this model accurately simulates the behavior of transmission channels in the frequency range between a few hundred kHz and 20 MHz. Colored background noise, narrow-band noise, periodic impulsive noise asynchronous to the mains frequency, impulsive noise synchronous to the mains frequency, and asynchronous impulsive noise are all various forms of noise found in power lines. The two main categories of these five different kinds of noise are background noise and impulsive noise. Modeling of background noise uses an AWGN with a mean of zero and a variance of two. On the other hand, impulsive noise is thought to adhere to a Poisson-Gaussian model in which impulses with Gaussian amplitudes come in accordance with the Poisson process.[2]

Coding using Convolutions

Convolutional coding uses a linear finite-state register with K stages to convert information bits into a coded bit sequence. A convolutional encoder produces n bits at the output when given a binary sequence of k bits as input. The coding rate, r = k/n, is determined by the ratio between k and n. The constraint length of convolutional codes, which is determined by the number of steps in the shift register K, is another crucial element. Viterbi decoding is often used in practice to decode a convolutionally coded data stream. Convolutional coding is used to encode the information data to produce the simulation results shown in this, using constraint length K = 8 and code rates r = 1/2 and r = 1/3. The encoder uses the most widely used convolutional encoders, generating polynomials of and for coding rates 1/2 and 1/3, respectively.

In the literature, it is often presupposed that impulsive noise in power line networks arrives as independent, symmetrical complex random variables. Impulsive noise, in fact, often manifests as bursts of high-peak impulses that, on occasion, last long enough to obscure fully formed communication symbols. Given that coding schemes created for individual errors do not effectively correct burst errors, this fact should be taken into account when designing PLC systems. The issue of impulsive noise burstiness may be resolved by using an interlocutor. The data bits are rearranged by the inter-leaver to decrease channel memory and disperse mistakes across the sent data. As a result, the decoder views the faults brought on by short bursts of impulsive noise as separate problems that are simple to fix[3].

DISCUSSION

Simulation Set-up

the coded OFDM simulation system. An initial random bit sequence is generated at the transmitter side, and it is then encoded using convolutional coding with code rates of 1/2 and 1/3.

The encoded bits are interleaved using a random interleaver to prevent bursty impulses and enable the capabilities of convolutional codes to be fully used. The Inverse Discrete Fourier Transform is used to convert the interleaved coded bit sequences into QPSK symbols before modulation. The inverse is carried out at the receiver side, where the signal is first demodulated using a Discrete Fourier Transform, followed by demapping, deinterleaving, and lastly Viterbi decoding. Three impulsive noise scenarios, described in 3, based on actual measurements of impulsive noise in actual power line networks, are taken into consideration to examine the BER performance of coded OFDM in PLC channels. These are classified as "heavily disturbed," "medium disturbed," and "weakly disturbed" in 3.3. The energy per bit (Eb) and the total noise PSD (Nm) are the parameters used to evaluate the performance of the coded system[4].

$$DR.Ni + No = Nm$$

where DR is the average disturbance ratio brought on by impulsive noise during the measurement period and No and Ni are the PSDs of background noise and impulsive noise, respectively. For all the outcomes shown in the section that follows,

Adaptive Power Loading for PLC Systems Based on OFDM

A crucial component of both current and future PLC systems is OFDM. It is renowned for being resistant to multipath, selective fading, and other interferences. When paired with adaptive modulation, the performance of OFDM and other multicarrier systems may be considerably improved. Data rate, transmit power, instantaneous BER, constellation size, and channel code or scheme are some of the factors that may be changed in adaptive modulation to account for channel fading. A feedback channel must provide transmitter-level channel status information in order to improve one or more of these parameters. The literature has many bit/power loading algorithms. Based on their objective functions, the majority of these algorithms can be divided into two groups: rate-adaptive algorithms, which aim to maximize the data rate while being constrained by power and BER, and margin-adaptive algorithms, which try to minimize transmitted power while being constrained by data rate and BER. The well-known water-filling strategy may provide the ideal bit/power loading, but at the expense of unnecessary complexity.

The MA loading approach is examined in this. It offers a solution to the nonuniform BER distribution and uniform bit allocation power reduction issue for OFDM. With a set data rate and a target BER, the power allocation is optimized. In the presence of impulsive noise, this results in the formulation of closed form formulas for BER and power distribution. Based on these formulations, a straightforward adaptive power loading strategy is described and put to the test using computer simulations in a well-known model of impulsive noise-damaged power lines. To examine how well the proposed algorithm performs under various noise settings, the impulsive noise power is changed. This research has been documented in the IEEE International Symposium on Power Line Communications and its Applications proceedings [5].

Intelligent Power Loading

Problem Definition

Finding a margin-adaptive method in the face of impulsive noise is the issue that we are attempting to resolve here. In this technique, we want to reduce the transmit power pTot while maintaining a set bit rate Rb per OFDM symbol and a maximum goal bit-error rate PT. Lui et al. provided a strategy that is comparable to the one used in this. The research in this article, however, concentrates on PLC systems and investigates the impact of impulsive noise with varying impulsiveness levels using a widely used power line channel model. Equal amounts of bits are distributed across subcarriers.

Algorithm for Loading Power

This part introduces a power loading strategy suitable for OFDM-based PLC systems with impulsive noise impairment based on the results stated in the preceding section. The algorithm follows these steps:

For all N data subchannels, determine gwn = |Hn|2/2.

Compare gwn to the criteria, identify the subchannels that do not comply, and disable their transmit power. Update the number of utilised subchannels N = N k after counting their number k.Set = 0 if there is no impulsive noise in the channel. Otherwise, if there is impulsive noise, calculate in accordance with the impulses that were detected. An easy threshold detection circuit can identify impulsive noise in the frequency or time domain.Determine the QAM symbol's bit density using the formula b = Rb/N.Give the remaining subcarriers power in accordance with.

It should be noted that this procedure may be utilized even when an impulsive noise detection circuit is not used or when the influence of impulsive noise is reduced by the use of a method or robust channel coding. The setting = 0 does this.

Results of Simulation

Computer simulations are used to assess the performance of the suggested technique in OFDM-based PLC systems under various impulsive noise conditions. The standard OFDM system, in which all subcarriers are given equal transmit powers, is contrasted with this method. There are 512 subcarriers in use. The simulations employed a 15-path PLC multipath channel model with the values from 3.2. To determine the subcarrier BER and power, we utilize the equations and. For varied target bit-error rates and impulsive noise conditions, the performance is shown in terms of Eb/No.

In this, the impact of impulsive noise on OFDM-based PLC systems' adaptive power loading was investigated. The power line channel was represented using the multipath model that was described in earlier sections of the dissertation. The simulations were made more accurate by assuming 15 major echo routes. In the presence of impulsive noise, closed form equations for BER and power allocation were proposed. To reduce transmitted power under constant data rate and target BER limitations, we introduced a straightforward power loading approach. A well-known power line channel model with impulsive noise impairment was used to evaluate the suggested technique using computer simulations. The suggested technique may significantly outperform traditional OFDM with uniform power allocation, according to the results.[6]

Adaptive Bit Loading for PLC Systems Based on OFDM

All subcarriers in a traditional OFDM system use a set constellation size. Therefore, the subcarriers with the lowest signal-to-noise ratios dominate the overall error probability. Using adaptive modulation may considerably improve the performance of OFDM when channel state information is available. According to the subchannel fading circumstances, several parameters, such as data rate, transmit power, instantaneous bit-error-rate, constellation size, and channel code or scheme, may be changed.

In the literature, many loading algorithms have been reported. The majority of those loading algorithms fall into one of two categories, depending on the objective function they try to maximize: margin-adaptive algorithms, like the power loading algorithm shown in Figure 5, which aim to minimize transmitted power subject to data rate and BER constraints, or rate-adaptive algorithms, which aim to maximize data rate subject to power and BER constraints. Additionally, the literature contains a few algorithms with various objectives. For instance, the approach put out by Goldfeld et al. aims to reduce the likelihood of mistake. Such algorithms are beneficial for systems with set power levels, fixed data rates, and maximum reliability requirements. There is often a trade-off between computational complexity and algorithm performance in all of these methods.

The well-known water-filling method may be used to load bits and power optimally. Utilizing incremental allocation, some loading algorithms can also reach close to ideal solutions. However, both approaches come at an excessive cost in terms of computational complexity. Approximations of channel capacity or closed-form BER formulas may be used to simplify bit allocation. However, this approach necessitates rounding the constellation size to integer numbers, which deviates from optimal allocation. Wyglinski et al. suggested a simplified optimal bit-loading. Because the method uses a separate iterative algorithm to find the initial peak BER in addition to the main algorithm, it is still quite computationally complex, especially when the number of subcarriers is high.

In this, we try to solve the goal overall BER constraint rate maximization issue with uniform power distribution. A straightforward, low-complexity bit-loading technique that approaches the highest throughput is provided. The effectiveness of the method is confirmed using a well-liked power line channel model.

Modular Bit Loading

The optimization issue is initially introduced and stated in this section. A simple loading procedure suitable for PLC systems is developed using the findings of the search for a solution to the issue.

Problem Definition

Given a target mean BER PT, a fixed energy distribution over the network, and the following rate-adaptive issue, the suggested loading method seeks to solve it with the least amount of complexity. respectively, BER. Similar to prior research, this one makes the assumption that both the transmitter and the receiver have complete knowledge of the channel gains. Various loading algorithms that have been developed to address this issue have been covered in the previous section. However, these algorithms either don't achieve the highest throughput or are overly complicated. In order to increase throughput while maintaining low computational complexity, an algorithm is required. A constructed and discussed algorithm with such qualities is provided below.

Network Model

The PLC multipath channel model that was previously discussed in this dissertation is utilized here to evaluate the discrete bit loading algorithm's performance in a PLC setting. The model is the most widely used model for power line channels because it is based on accurate measurements of real power line networks. The multipath model is chosen over transmission line models for a number of reasons, as was previously discussed in this dissertation. Since TL models necessitate a thorough understanding of the topology and physical characteristics of the PLC network, they are hardly ever useful in actual applications. The time-domain multipath model used here, in contrast, does not need for extensive knowledge of the channel's structure. Based on the acquired average number of bits per subchannel, computer simulations are used to compare the performance of the proposed bit-loading process to two other loading methods. The equal-BER loading algorithm and the incremental algorithm are the two algorithms.

All subcarriers are originally situated in the maximum signal constellation in the incremental loading technique that was applied here. Once the overall BER satisfies PT, bits are incrementally removed from the subcarrier with the worst BER based on the channel feedback. The best bit allocation may be accomplished in this method. However, the number of OFDM subcarriers and the channel gain conditions have a significant impact on how this algorithm is computed. The computational cost of incremental loading may be considerable for low SNR levels and if many subcarriers are used. A constant BER threshold is established for all subcarriers in an equal-BER allocation, however, and each subcarrier is given the maximum number of bits for which its Pn is PT. The bits in each subchannel may be calculated using this approach, rounding to the closest lower integer. This rounding process reduces the bit rate as a whole and often produces considerable deviations from the feasible bit rate. The following simulation results use approximation and all techniques with OFDM and 1024 subcarriers in the frequency range of 1.8 30 MHz. A maximum of 10 bits may be given to each subchannel.

This demonstrated a straightforward, non-iterative discrete bit-loading technique that aimed to optimize data rate while adhering to goal BER and uni-form power distribution constraints. A computer simulation model of a power line communication channel was used to evaluate the technique. Results demonstrate that the suggested approach increases data rates obtained by equal-BER loading with a minimal complexity penalty. The suggested approach achieves comparable speeds to incremental loading, but with substantially less computing complexity.

Recommendations and Next Steps

In this dissertation, the use of orthogonal frequency division multiplexing in power line communication systems as well as the impact of impulsive noise have been discussed. Although PLC technology has the potential to be a successful and widely used technology that enables high-speed broadband Internet and network applications, it faces significant difficulties and channel impairments. This dissertation looked at the issue of impulsive noise and proposed appropriate mitigation strategies. Later parts introduced and looked at techniques for using adaptive modulation to speed up and improve the performance of OFDM-based PLC systems. In addition to submitting a journal article, the author's PhD research led to the publication of eight papers at conferences with worldwide peer review. First, a review of the theoretical features of PLC technology may be found in 2. Power line grid topologies, architectures, and physical characteristics were described. On the one hand, it was shown that this technology has a lot of potential to compete with well-known broadband Internet access methods like ADSL as well as methods for implementing local area networks like Ethernet and Wi-Fi.

The widespread use of the transmission medium over the world is a special benefit of PLC. However, power lines have significant drawbacks such as high attenuation and susceptibility to impulsive noise with high amplitude. Particularly, the issue of impulsive noise has been thoroughly discussed, and the methods already in use to lessen its impact on communication systems have also been researched.The available power line channel models have also been addressed in the literature. The power line channel may be modified using either a time-domain or a frequency-domain method. The multipath model with a time-domain foundation was discovered to be the best model for understanding the transmission behavior and attenuation characteristics of PLC systems. The multipath model may properly describe the channel via a transfer function without the requirement for in-depth knowledge of the network architecture, unlike frequency-domain-based transmission line models.

In addition, the spread-spectrum, single carrier, and OFDM modulation approaches for PLC were discussed and compared in 2. OFDM was chosen as the modulation technology for the work reported in this dissertation because to its exceptional benefits. In addition to frequency selectivity and resilience against multipath, impulsive noise's impact is lessened by OFDM by dispersing it across a number of symbols. The effectiveness and efficiency of systems based on OFDM may be greatly increased when paired with adaptive modulation methods. Additionally, the issue of threshold selection was looked into, and time-domain nonlinearities such as clipping, blanking, and combined clipping/blanking were used in the OFDM receiver to combat impulsive noise. It has been discovered that nonlinear approaches may significantly lessen the impact of impulsive noise in OFDM-based PLC systems with suitable threshold selection. A BER-based adaptive threshold selection approach has been offered as a solution to the threshold selection conundrum, and simulations have shown its effectiveness.

It has been suggested to use a method that blends time domain nonlinearities with a frequency-domain approach to further enhance the receiver's capacity to lessen the impact of impulsive noise. Impulsive noise's impact may be decreased with this method to an acceptable degree. Four refereed conference papers were published as a result of the work discussed in this. In a PLC environment, a convolutional encoder and random interleaver were used in an OFDM system. In the presence of the system, its performance was examined.of impulsive noise under various circumstances. The aforementioned performance increases were seen using two coding rates. The multipath channel model discussed in section 3.2.2 served as a representation of the PLC channel. The simulations employed both the 15-path detailed model and the four-path reduced model. The data received is decoded using a Viterbi decoder. The acquired findings demonstrated that a fairly considerable gain may be made, particularly in circumstances where impulsive noise is a major factor. The proceedings of the 209 International Conference on Advanced Technologies for Communications included these findings.

The effectiveness and performance of PLC systems were improved by investigating adaptive modulation methods in Sections 5 and 6. A power loading technique has been created and published in the proceedings of the 2010 IEEE International Symposium on Power Line Communications and its Applications. This approach reduces the power cost to achieve certain data rates and a target BER. Power loading and BER allocation have closed-form formulas that have been developed. The suggested algorithm's performance was contrasted with that of traditional OFDM. Results shown that the suggested algorithm may result in large power reductions with very little complexity.

In Chapter 6 of this dissertation, a brand-new bit-loading method has been designed and described. The algorithm optimizes data rate and obtains rates comparable to those of very computationally complicated incremental loading, which is supported by simulation results. However, by using closed-form expressions and limiting the number of algorithm iterations to one, the complexity of the algorithm is kept at a very low level. The 2011 IEEE International Symposium on Power Line Communications and its Applications has approved this innovative method for oral presentation and publishing in the symposium's proceedings.

Upcoming Directions

This dissertation has a number of topics that may be expanded upon by more study, including the following:

The findings of this study are based on computer simulations that represented the power line channel and the existing noise using well-known models. The next stage is to do real-world measurements in power line networks. This will provide an extra tool to assess the viability of both new and old PLC methodologies. Since different topologies, structures, and wire types can have an impact on the transmission behavior, measurements of channel and noise should be made in Australian power line grids[7]. The dissertation proposed a threshold selection approach that is based on the obtained BER at various threshold settings. If the approach is to be used in real applications, the computing complexity should be lowered even if the results may be better, particularly in a time-varying channel affected by frequent impulsive noise like the power line channel. Further study on this subject is possible.

In Chapter 4 of this dissertation, the research examined the use of convolutional coding in power line communications when impulsive noise was present. Other coding systems including turbo codes, low-density parity checks, and Reed-Solomon codes may be included in the work. In PLC settings impacted by impulsive noise, the usage of mixed codes in the form of outer and inner codes may also be investigated.Other adaptive modulation criteria can be researched in addition to the bit/power loading strategies created in this work. This could include subcarriers' code rates or schemes being adaptively adjusted such that the subcarriers with weak channel conditions can employ more resilient coding techniques.

This dissertation's investigation and development of bit- and power-loading algorithms made the assumption that both the transmitter and the receiver had complete access to channel information. This suggests that the receiver achieves flawless channel estimation. Furthermore, a very trustworthy feedback link that transmits error-free channel state data from the receiver to the transmitter is required. Since AWG noise and impulsive noise may also affect channel information, this may not always be the case in actual PLC systems. By assuming that channel state information is inadequate, the investigations done in sections 5 and 6 may be expanded. This increases the CSI's error term, which is frequently represented using AWGN[8].

CONCLUSION

In conclusion, Bit-Interleaved Coded Modulation is a promising technique for improving the performance of digital communication over wireless channels. The results of this study can be used to optimize the design and implementation of BICM systems for different applications.The results of the simulation show that BICM can achieve a higher coding gain and better performance compared to other coding techniques. The performance of BICM also improves as the SNR increases, and the number of iterations increases. Our analysis also indicates that BICM performs better when used with higher-order modulation schemes.

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CHAPTER 10

A BRIEF DISCUSSION ON NARROWBAND AND BROADBAND POWER LINE COMMUNICATIONS

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ABSTRACT:

Broadband Powerline Communications (BPLC) is a technology that uses the existing power grid infrastructure to provide high-speed data communication services. It is a promising solution for delivering broadband access to homes and businesses, especially in areas where traditional wired or wireless access technologies are unavailable or impractical.An overview of the BPLC technology and its various applications. We discuss the advantages and challenges of BPLC, including its ability to leverage existing infrastructure, its potential for high-speed communication, and its susceptibility to interference and noise. We also examine the regulatory and standardization efforts related to BPLC, as well as the recent technological advancements and deployment experiences.

KEYWORDS:

Broadband Over Powerline (BPL), Carrier Current, Channel Capacity, Channel Modeling, Electromagnetic Interference (EMI), Frequency Allocation.

INTRODUCTION

PLC systems and power line channels are introduced here. First, the topologies of the power line networks are examined with a focus on the low-voltage level. The introduction of data transmission across power lines is then made, and two methods for characterizing the channels are then presented. Cyclostationarity is described as a unique property of power line channels and as the one that poses the most challenges for PLC. Finally, a summary of the PLC technologies and standards currently in use across various frequency bands is provided[1]–[3].

Low-Voltage Power Line Network Topologies

The structure of power line networks is initially examined to start the research of power line channels. According to the illustration in, power supply networks are often separated into three levels: high voltage, medium voltage, and low voltage. In theory, communications are possible on all three levels. The LV level has generated the greatest attention in the PLC sector because of its broad distribution, ease of access, and inexpensive signal coupling. This level will be our main concern in this endeavor.

Despite the fact that HV and MV supply topologies are quite similar everywhere, LV distribution grids may vary greatly from region to region. For instance, the 50 Hz three-phase system is used in Europe, Africa, and the majority of Asian nations, including China and India, with either 230 V or 220 V as the home voltage. The 60 Hz split-phase system is used in the majority of

American nations, including the USA, Canada, and Brazil, as well as several Asian nations, including Japan. Residential voltages range from 100 V to 127 V.

A LV network may be further geographically separated into the access domain and the indoor network, according to PLC. The LV network between LV transformer stations and building connections is often considered to be the access domain. As suggested by its name, the indoor network consists of all connections found inside of structures. Different LV distribution grid structures are compared in both domains in the section that follows.

Obtain Domain

Similar to in, each LV transformer station in a three-phase system feeds a "supply cell," which may include up to 350 homes in up to 10 branches. In rural networks, its size is often decreased. When the loads, for instance, are primarily one-family houses, a branch may extend up to 1 km. Shorter cables are usually used to link subgroups of numerous homes. Four-wire supply cables, which include three live wires for each of the three phases and one neutral wire, are often used for the connection. Five-wire cables are also utilized in certain places, like China, and provide one additional wire for the protecting earth. Instead of being locally grounded in this scenario, residential outlets are linked to the PE wire. Each cable entering a home in split-phase systems, like the one in 2.3, has three wires: two hot wires and a neutral. It is important to note that the phase difference between the two hot wires is 180 degrees, not 90 as in early 20th-century two-phase systems used in the USA. The split-phase systems in the USA and Japan often feature smaller supply cells with fewer residences per transformer and shorter connections, up to roughly 100 m, than the three-phase systems in Europe.

Indoor Space

In most nations, star and tree topologies are the norm; the UK, however, has a ring topology. Typically, a cable entering a building first passes the main breaker and the meter to reach the user panel, then connects to the wall outlets to distribute the energy, as in 2.4. The wires stretch into several branches in a star or tree form to reach outlets in every wall. With the ring configuration, a single cable circles a portion of a house, occasionally even the entire structure, especially in older structures. There are two types of wall outlets: grounded and ungrounded. To achieve 120 V or 240 V voltage in split-phase systems, an outlet may be placed between one hot wire and the neutral wire or between two hot wires. Each outlet in a three-phase system is wired between a live wire and a neutral wire. Additionally, 5-wire outlets with all three live wires can be found in old buildings. The connections between rooms in the same home are possible.

Power supply networks have long been utilized for data transfer; despite being initially exclusively intended for energy delivery. The need for a quick bidirectional message flow to sustain the functionality of extended HV networks led to the first effort to send voice communications via HV networks in the 1920s. At that time, no telephone network could completely cover all of the operational regions, therefore power supply networks emerged as a desirable option for communication. Despite the widespread use of wired and wireless telephone networks today, power line networks continue to have a distinct advantage over other data mediums because to its omnipresent infrastructure, particularly at the LV level. The physical concept of data transmission via LV power lines and the topology of common PLC devices are briefly covered in this part. The bottom-up and top-down techniques to characterizing power line channels are then introduced. Any structural model created using a bottom-up methodology can eventually be transformed into a top-down behavioral model[4]–[6].

DISCUSSION

Transmission in Common Mode and Differential Mode

Every hot/live wire in LV power line networks travels parallel with a neutral wire, as described in Section, creating a transmission line made of parallel wires. In addition, the PE and each hot/neutral wire combine to create another TL. Due to the neutral wire's connection to ground at the LV transformer, such a TL with a hot wire often has drastically different characteristics from the TL with the matching neutral wire. Therefore, the common mode and the differential mode, as shown in 2.6, are the two different transmission modes for signals over power lines. Studies show that CM signals are substantially less attenuated than DM signals. However, some noise types are noticeably stronger when received in CM. Aiming to exclusively employ the differential mode, the majority of single-input single-output LV PLC devices typically send and receive signals between a live wire and the matching neutral wire. Contrarily, the common mode has drawn attention primarily because of its use in MIMO PLC systems, which are not covered in this thesis. However, when the load is uneven or there is asymmetry between the two lines, the CM and DM components can be partially converted into one another. The mode coupling or mode conversion are terms used to describe this occurrence[7], [8].

There are three main types of communication linkages in an LV network, depending on the network topologies discussed in Section: links within the same branch/ring, links within separate branches on the same phase, and links on different phases. In the final scenario, communication signals are linked at the LV transformer from one phase to another. Tens of decibels of attenuation may result from this cross-phase transmission. The wave may always be repeated in loops and/or reflected at the tips of branches. In 2.7, two basic examples are given. In the tree-shaped network in 2.7, the wave may be echoed through the nodes before eventually reaching the receiver R if the impedance at nodes A and B is not matched. Even if the impedance is matched at every node, the wave in the ring-shaped network in 2.7 may recurrence around the loop through the nodes A-B-C-D or A-D-C-B an infinite number of times before it is eventually picked up by the receiver R. Multiple propagation paths are present in both situations depending on the echoes' recurrence times. As a result, the channel consistently displays multi-path characteristics including notches and phase shifting.According to, connecting the building's neutral wire to ground will make the notches considerably more important. This phenomenon confirms that multi-path fading is less robust in CM than in DM.

Common PLC Devices

Numerous PLC devices have been developed to communicate over power lines. Their structures are comparable despite the variations in how they are implemented. As stated in the previous section, a typical PLC modem, which contains a power supply, coupling circuit, line driver, analog front-end, physical layer controller, media access control unit, and application controller. A grid interface is shared by the coupling circuit and the power supply. The power supply module acquires the mains voltage via this grid interface in order to provide DC supplies for the modem's internal circuitry. The power source has to be free of interferences. In order to prevent signal attenuation, it must also exhibit high gridside impedance. On the other hand, the coupling circuit uses the same interface to send communication signals between the modem and the power line network. To allow the communication signal to flow through while safeguarding the modem circuits from mains voltage harm, this coupling circuit must have a band-pass property.

A digital transceiver is made up of the PHY controller, AFE, and line driver. The AFE serves as a link between the analog and digital worlds between the PHY controller and the coupling circuit. It performs operations including low-pass filtering, automated gain control, and analog-to-digital and digital-to-analog conversions. The PHY controller handles digital processing on the physical layer, including channel coding, error detection and correction, modulation and demodulation, and synchronization. In order to enhance the output power and get around the significant channel attenuation, the line driver is inserted between the coupling circuit and the transmitting side of the AFE. The MAC unit handles addressing and channel protocols to allow several nodes to communicate with each other peacefully while sharing the power network. All operations above the physical layer and MAC sublayer are carried out by the application controller. Through a digital interface, it communicates with a computer or other controlling devices.

Power line channel characterization: bottom-up and top-down approaches

The initial problem is to describe and model power line channels in order to design dependable PLC systems. In recent years, this duty has taken on more significance as contemporary PLC systems prepare for increased data rates. Since the last decade, a lot of work has gone into developing deterministic and statistical models of power line channels. These efforts may be broadly classified into two categories: bottom-up and top-down, depending on the channel characterisation technique.

Building structural models of power line channels is done from the bottom up. Power consumers and outlets are connected via cables that are designed as two-port networks. Each power user is described as a noise source with a complex-valued inner impedance that is linked in parallel. The structural model in 2.9 is a typical example of this kind. A scattering matrix, which may be acquired in one of two methods, describes each 2PN. First, the S-parameters of a 2PN can be measured directly if it can be isolated from the rest of the grid. Alternatively, but more often, one may calculate a 2PN's electro-magnetic characteristics to determine its S-parameters if they are fully known from a physical standpoint. The channel transfer function and the total noise at the receiver may both be calculated using the TL theory when all the S-matrices are available and all loads are known. Statistical models may be produced by randomly but fairly modifying the loads, S-matrices, and network architecture. On the other hand, the top-down strategy adopts a wholly behavioral perspective on power line pathways. It describes each power line channel as a black-box system with a specific access impedance and an additive noise generator at the output, as shown in 0. This ignores wiring and load specifics. The channel's output impedance

The transmitted and received signals, sT and r, are shown in the structural model of a power line channel, respectively. The impedances of the transmitter and receiver, respectively, are ZT and ZR. Since most receivers are built with very high input impedance, every noise source ni with the corresponding impedance Zi models a load at a power outlet is ignored here as usual. Real-world measurements must be taken to determine not just the route loss but also the access impedance and the additive noise. In order to simplify the categorization, parametric models like those presented in are often summarized and based on measurements. One may acquire the statistics of the model parameters and subsequently a statistical channel model using a large measurement record.

The top-down approach is often used for power line networks that are already in place. Because it would be impractical to obtain complete knowledge of the wiring and loads in such a network, the structural model cannot be constructed. On the other hand, the analysis of fictitious networks, which is often done to show off research findings, benefits from a bottom-up strategy. because it does not need the costly network construction or extensive field measurements as the top-down technique does.

Behavioral Modeling from Structural Models

There is no one-to-one mapping between the structural and behavioral models since the bottom-up method is synthetic and the top-down approach is analytical. Numerous different structural models can be found to match any given behavioral model. But every structural model can be analytically transformed into a distinct behavioral model. Behavioral models do, in fact, have a similar structure to structural ones, although they are merely predigested into a single 2PN.

Consider the simple network in Figure 1, where the transmitter and receiver are linked by only two cable segments and one power consumer. The first step is to transform both S-matrices into the matching ABCD matrices. The received voltage signal r equals the total of the received voltages in Figs. 1 and 1 by the superposition theorem. Next, with attention on 1, the load impedance Z1 alone likewise creates a straightforward 2PN, as in 1. It is simple to combine the three cascaded ABCD matrices into one, as shown in 1, from which the network's access impedance ZA and CTF H may be calculated.

Within Power Line Channels, Cyclisation Phenomena

The power line channels are not only frequency selective, but also noticeably time changing, in contrast to the ideal systems in classical system theory, which are linearly time-invariant, and the conventional radio propagation channels, which are often described as Rayleigh or Rice fading. They are often referred to as "cyclic short-term and abruptly long-term time varying", which is more correct. Long-term sudden fluctuation is mostly brought on by arbitrary network topology changes, such as turning on or off power consumers or a home's main breaker. Periodic channel estimation and adaptive filtering are efficient ways to reduce its influence on communication. Contrarily, the cyclic change often occurs even more quickly than the time required for system adaptation, which may significantly lower communication quality. This has emerged as the main barrier to a trustworthy, high-speed PLC. This section will present the cyclic time-varying phenomena in power line channels, including CTFs and interferences.

Cyclo-stationary Processes Explained

Power line channels' cyclic time-varying phenomena are often represented as cyclostationary systems. The definition of stationarity is first examined as background information before being generalized into wide-sense local stationarity. Finally, the definition of cyclostationarity and the derivation of its relationships to wide-sense local stationarity and wide-sense stationarity are presented. The Relationship Between Cyclostationary Phenomena and Channel Transfer Functions. As stated in the introduction, the channel transfer function always displays a short-term fluctuation, generally with half of the mains period, even when there is no sudden change in the architecture of a power line network or the associated load. This is explained by the fact that the instantaneous amplitude of the mains voltage affects the electromagnetic properties of various electrical equipment.

The coupling loss in PLC is given great significance for two good reasons, including the fact that it is studied independently from the CTF. First off, most typical transceivers have severe impedance mismatching due to the fact that the access impedance (ZA) in actual power grids is always relatively low, particularly at low frequencies. Second, ZA changes with time and may possibly show a strong periodicity.

A lot of effort has gone into trying to reduce coupling loss in PLC. Impedance-adapting couplers were presented in as a system- atic method to cope with the low ZA under various loading circumstances. Adaptive algorithms and unique coupling circuitries were developed, based on micro-controllers, to account for the periodic temporal fluctuation in ZA. For communication systems with these characteristics, the impact of HA may be almost completely disregarded, and the total CTF H primarily relies on HP, which exhibits strong periodicity at higher frequencies up to 20 MHz but only little periodic variation in the frequency region up to 500 kHz. Otherwise, HA can show a strong periodicity and take control of H's behavior, especially when other appliances connected to the network close to the transmitter. H should typically be represented as cyclostationary.

Cyclostationary Phenomena with Respect to Interference

The cyclostationary phenomena inside interferences in PLC are far more important and have received more attention than the periodic fluctuation of CTFs. According to common consensus, there are four types of interferences in PLC: p narrowband noise, p periodic impulsive noise, p aperiodic impulsive noise, and p colored background noise. Long-term and in confined frequency bands, NBN manifests as intense interference. The NBN has two different origins. First, 500 kHz NBNs may be produced by electrical devices such switched-mode power sources, fluorescent lights, and monitors. Second, power cables that are long enough to serve as antennas may couple radio waves from the atmosphere into the grid. Many contributions have reported on the cyclical behavior of NBN. The coupling and propagation of NBNs via power lines might change periodically under the influence of the mains voltage, the first sort of sources, and other factors. In order to be synchronized to the mains, NBNs are often amplitude modulated by periodic envelopes. Additionally, it was reported that swept frequency noise, a unique subclass of NBN that has periodic central frequencies and bandwidths, is produced by power factor correction circuits.

Among all noise types, PIN exhibits the most significant cyclic characteristics. It is made up of brief periodic pulses with high amplitude that come from non-linear circuits linked to the network, whose electrical characteristics fluctuate with time. PIN is often further classified into two classes: synchronous to the mains voltage and asynchronous to the mains voltage, depending on the cyclic period.In a prior research, the cyclostationary properties of NBN and PIN in LV power line networks were examined. It was found that they are, respectively, cyclostationary in accordance with classes A and B. APIN, often referred to as asynchronous impulsive noise, reacts to irregular pulses that don't happen on a regular basis. Transients that occur when electrical equipment are connected to and disconnected from each other are the main cause of APIN. It happens less often than PIN, has longer pulse lengths, and a greater immediate power. Most notably, APIN comes at random times and has no regularity. It is the only one of the four forms of noise that is not cyclostationary. The term CBGN, which derives from several unidentified noise sources, includes the remaining components of PLC interferences. When compared to other noise types, its power is relatively low and tends to decrease with frequency. A periodic temporal variation in the power density function of the CBGN has been noted in several contributions, while being sometimes ignored in the literature.

Broadband and Narrowband PLC

Some mature technologies and standards have been established for various frequency bands over the course of the past decades of ongoing research and development in the PLC field. This section introduces the frequency ranges that PLC applications now occupy before reviewing the PLC technologies and standards that are already in use. An introduction to a recent effort to develop a unique PLC technology that operates adaptably in narrowband or broadband applications follows. Its advantages and difficulties are examined in some detail.

Frequency Bands in Use for PLC

Existing PLC technologies, according to, have utilized frequency bands up to 250 MHz, covering the super, ultra, low, medium, high, and ultra high frequency bands specified by the International Telecommunications Union. Three categories of PLC technologies exist: ultra-narrow band, narrowband, and broadband. UNB- PLC can only operate unidirectionally and at very low data rates because to the severely constrained bandwidth. Although it is still used in some applications with low speed requirements, like AMR, it has lost its appeal in more recent research. Currently, NB and BB are the main topics of interest in PLC.

Nearly every aspect of PLC on the physical layer and the data link layer is fixed by standards, in addition to the frequency bands. The organizations mentioned in have supported various international standards in the past, including those listed in 2.2. On these standards, the majority of contemporary PLC technologies rely. The NB-PLC technologies are often further divided into two generations: low data rate and high data rate. The first refers to technologies with data speeds of a few kbit/s that are based on single-carrier or spread-spectrum modulation. The latter describes systems that provide data speeds of up to 500 kbit/s and are based on orthogonal frequency division multiplexing.

The maximum attainable data rate differs significantly between the NB-PLC and BB-PLC standards, which are stated in 2.3. The well-known Shannon-Hartley theorem, which states that $C = B \log2$ where C is the channel capacity, B is the available bandwidth, S is the average received signal power over the bandwidth, and N is the average noise or interference power over the bandwidth, indicates that this is due to the physical constraint. We can observe that the channel capacity is proportional to the bandwidth at a given SNR. Therefore, BB-PLC can support faster data transmission due to the higher bandwidth.

However, BB-PLC also has a built-in flaw. Power line channels are often low-pass connections because of the loss brought on by the wires. In narrow bands, certain high-pass features may be seen locally, but in broadband applications, the channels are typically low-pass connections. As a result, at higher frequencies, with the same transmitting power, the received signal strength S is more attenuated, resulting in a lower C in any given bandwidth B. The loss is greater for BB-PLC than NB-PLC because of the larger operating frequency range. Additionally, as the cable length increases, multi-path fading also gets exponentially worse. Losses may increase in severity as a transmission line lengthens, eventually outweighing the advantages of larger bandwidth. In BB-PLC systems communicating over long distances, repeaters and relays must be deployed to overcome the strong attenuation and maintain the SNR on a reasonable level. However, the cost can be significantly increased by these hardware components.

As observed so far, the choice of an acceptable PLC frequency band is greatly influenced by the needs of the application. High-speed communications over short distances are often chosen by BB-PLC, whereas low-speed communications over long distances are better suited to NB-PLC. Further complicating band selection are situations where the requirements for data rate and attenuation level can both be time-varying. This difficulty led to an effort at adaptive band selection between 0.15 and 10 MHz. Instead of following any predetermined specifications, this innovative PLC system is designed to choose its operating frequency range based on the actual channel circumstances. This system can operate over a large frequency range if broadband communication is permitted by the channel; otherwise, it identifies and utilizes the optimal sub-band. The power line channel may be used with great efficiency and flexibility thanks to this cognitive technology. Additionally, it is possible to lower the cost of developing and maintaining the system.

There are two key obstacles to the installation and optimization of such a system. First, a model of power line channels that bridges the traditional narrowband and broadband approaches needs to be clearly defined for the new band of interest. Although previous channel modeling work already fully covers NB and BB, the results cannot simply be applied to cover the new band due to the different measurement and characterization methodologies. Before advancing to higher layers, the new system must first be tested and appraised on the physical layer. System testing in actual power line networks, however, is too rigid, and simulating power line channels with standard laboratory equipment is insufficiently precise. Since the last decade, flexible laboratory PLC testbeds have been using power line channel emulators based on FPGAs, but they have not yet been specified for this new band[9]–[11].

CONCLUSION

Overall, BPLC has the potential to provide a cost-effective and reliable solution for delivering broadband services, particularly in areas with limited infrastructure or difficult terrain. While there are some technical and regulatory challenges, the recent advancements and deployment experiences suggest that BPLC can be a viable option for many applications. Provides valuable insights into the state of the art and the future prospects of BPLC technology.The paper also presents an analysis of the performance of BPLC systems in different scenarios, including home networking, smart grid communication, and Internet of Things (IoT) applications. We discuss the factors that affect the performance of BPLC, such as the frequency band, channel characteristics, and interference. We also compare the performance of BPLC with other communication technologies, such as wireless and fiber-optic communications.

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CHAPTER 11

MEASURING AND MODELING LV POWER LINE CHANNELS

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ABSTRACT:

Modeling Low Voltage (LV) Power Line Channels is a critical task in designing reliable and efficient communication systems over power lines. LV power lines are used for delivering electricity to homes and businesses and are subject to various impairments such as noise, attenuation, and interference, which affect the quality of the communication signal.

Therefore, accurate modeling of the channel is essential for predicting the performance of power line communication systems and optimizing their design.an overview of the various models and techniques used for modeling LV power line channels. We discuss the characteristics of the power line channel, such as its frequency response, impulse response, and noise level, and how these affect the performance of communication systems. We also describe the various modeling approaches, including deterministic and stochastic models, and their advantages and limitations.

KEYWORDS:

Measurement Techniques, Noise Reduction, Power Line Communication, Signal Attenuation, Signal-To-Noise Ratio (SNR), Transmission Line Models.

INTRODUCTION

Power line channels must be well defined in this frequency range to assist the development of new PLC systems operating between 0.15 and 10 MHz. The transfer function and noise scenario may be used to describe a power line channel in the behavioral perspective, which was first discussed in Section 2.2.3.Since the beginning of the twenty-first century, researchers have been measuring the channel transfer functions of power lines. The broadband and narrowband techniques have both been the subject of reported field measurements. Most of them just pay attention to CTFs' frequency selectivity or only take long-term temporal fluctuation into account. The CTF of a power line channel, however, may also display periodic temporal variation over a brief period, as discussed in Sec. 2.3.2. The current technologies must be improved in order to measure and simulate the CTFs more precisely.[1]

In recent decades, much research has also been done on the noise situation. Many measurements have been made across a variety of locations, and developed models have been created for the noises that have been observed. However, the techniques used to extract various classes of noise from the measurements are still crude and inaccurate. A better noise modeling requires more sophisticated methods.

Channel Transfer Functions Measuring and Modeling

System for Distributed CTF Measuring

The coupling loss HC and the path loss HP may be separated from the channel transfer function H of a power line network, as was mentioned in Section 2.3.2. It is more feasible to measure the path loss rather than the total CTF when the coupling loss depends on the device. If not specifically stated, the phrase CTF in this always refers to the route loss HP.

A vector network analyzer is often used to assess system transfer functions because to its broad working frequency range, high accuracy, and capacity to measure phase features. Unfortunately, there are three main reasons why VNAs are rarely effective for measuring power line channels. First, directional couplers at the input/output ports of the VNA must be protected from the high mains voltage, so LV couplers must be used to connect the VNA and the power line network. An accurate VNA calibration is exceedingly challenging since these couplers often display time-varying EM characteristics and are affected by the mains voltage. Second, lengthy cables are required to link the VNA and the LV couplers because the input and output ports of power line channels are often placed at dissimilar locations that are far apart. The cable length might vary by hundreds of meters depending on the size of a supply cell. These lengthy cables increase calibration challenges and decrease measurement accuracy. Finally, VNAs typically only measure S-parameters and have I/O ports that are fixedly matched to 50 Ohms. However, power line channels are never matched, resulting in measurement results that always include additional coupling losses and necessitate extensive additional computation to determine the path loss.

For power line channel measurements, distributed CTF measuring systems are often utilized instead, as shown in 3.1. A channel sounder, a transmitter that produces a precisely created signal sT and feeds it into the channel with the proper strength, is located on the input side. A measurement receiver is located on the output side, from which a voltage signal called rMea is received. A second receiver is connected to the input in parallel with the channel sounder to capture the voltage signal rRef at the channel input as well as to eliminate the effects of coupling loss and transmitter behavior.

Pseudo Noise Sequence and Dual Sweeping Tones are two sounding signals.

For time-invariant channel measurement, the pseudo noise sequence and dual sweep-ing tones are two forms of sounding signals that are often utilized. A PN sequence has an impulse-like ACF and is a binary sequence, thus its power is dispersed over the spectrum. It is feasible to measure the channel's impulse response and, thus, estimate the CTF once completely by passing a PN sequence across it. In contrast, the dual sweeping tones approach uses two single-frequency sounds that gradually shift in frequency. The CTF at the tonal frequencies may be measured by transmitting a pair of tones via the channel. The CTF may be sampled across the target band as the tones sweep over a wide frequency range. Both techniques will be expanded in this subsection to measure time-varying channels. The approaches in this study are only validated using numerical simulations because of the time constraints, which prevent hardware implementation or actual measurement from being achieved.[2]

CTF Calculation PN Sequence-based

A pseudo noise sequence, which is often implemented as a maximum length binary sequence, is a semi-random sequence in that the whole sequence repeats endlessly yet seems random during the duration of the sequence. The most popular way to create M-sequences is utilizing linear feedback shift registers. An M-bit-deep LFSR may produce an M-sequence that is 2M 1 bits long.

DISCUSSION

Performance Comparison

Under the proper configurations, both PN sequences and dual sweeping tones have been validated for time-invariant power line channel measurements, but no performance comparison between the two has yet been documented. Configurations of the sounding signal, such as PN sequence length and tones aperture, are more severely regulated when taking the temporal variation into account. It is worthwhile to compare the two approaches under the same circumstances, such as frequency resolution, transmit power, and time measurement. Additionally, both approaches are built on the premise of uncorrelated white noise. This assumption is false in actual power line channels, and as a result, the measurement performance declines. The two sounding approaches are briefly studied using simulations and contrasted in the section that follows with regard to how well they function in less-than-ideal channel circumstances. Because it is more important than the phase response for communication systems, the magnitude response is the one that is concentrated on. Also discussed is the effect of non-linear hardware behavior.[3][4]

Adaptability to Background Noise

We take into account a cyclic channel with an invariant scale (TI) of 100 s, a cyclic period (TC) of 20 ms, and a random scale (TR) of less than 5 s. The channel switches between up to 200 distinct states throughout each cyclic cycle. Both methods were used in simulations to calculate the CTF. Only one state was estimated and analyzed in order to streamline the computation, and the CTF was created using a sample network. To simplify, zero-mean additive white Gaussian noise was produced as channel noise.

The PN sequence and sweeping tones techniques' parameters were set in accordance with s. 3.1–3.2 such that both methods used the same transmitting power and total measurement time. The acquired after testing both approaches with various noise power levels. Both techniques exhibit good AWGN performance, even in the presence of loud noise and high attenuation. Although a PN sequence's power is evenly distributed across its entire frequency range, resulting in a lower SNR in each measurement than the sweeping tones method, the sequence's brief duration permits a high number of repetitions. The AWGN's power is decreased by averaging, improving the SNR.

Resistance to Narrowband Noise

In actual power line channel interference conditions, broadband background noise is often not as significant as narrowband disturbances. They frequently have amplitudes that are noticeably higher than the ambient noise, and their presence can last for hours. The aforementioned simulations were rerun with a weak AWGN and two strong NBNs at the measuring receiver to examine the resilience of both approaches against NBN. The parameters were used to create the NBNs as amplitude modulated signals. A median filter of order 7 effectively reduced the mistakes brought on by the NBNs for both the dual sweeping tones technique and the PN sequence method, which were both marginally worsened by the NBNs.

Strength Against Non-Linear Hardware

A high transmission power is required to guarantee measurement accuracy. But frequently, this causes the transmitter hardware to become overloaded and results in non-linear behavior. Therefore, harmonics have the potential to distort the sounding signal. Simulations were run where the sounding signals were altered by second order harmonics of varying degrees to examine the effects of undesired harmonics on the measurements. The resilience of both approaches to the harmonics is pleasing.

Synchronization

Two different types of synchronizations are necessary in a distributed power line CTF measurement system. To perform the correlated measurements, particularly when the phase response is of interest, the reference receiver and the measuring receiver must first be precisely synced. A global positioning system receiver on either side, which offers time information precise to 0.1 s, may be used to do this. Second, the measurement must be synchronized with the mains period as well, provided that the CTF's cyclic behavior is. A zero-crossing detector may be used to get the phase information of the mains voltage at the receiver in accordance with its zero-crossing time, as shown in 3.10, to resolve this issue. It is important to note that, depending on the network architecture and distance, the mains phase varies between the sending side and the receiving side. However, for a specific channel, this phase difference stays constant within the random scale, necessitating only one side to be measured for the mains phase.

Calibration and setup

As previously mentioned, a channel sounder, two receivers synced with GPS, and a ZCD should be part of a comprehensive setup for a distributed CTF measurement system. In-depth, similar to every PLC device that has been developed, the receiver must incorporate an AFE and a coupling circuit, neither of which have optimal all-pass properties. As a consequence, the measurement's uncalibrated result is A calibrating measurement should be performed with the channel sounder and both receivers directly linked in order to reduce this system inaccuracy.

Time-Invariant Linear Models

The short-term fluctuation of the CTF over time effects communication relatively significantly when the data transmission rate is low, hence it had been typical to neglect the temporal variation and characterize the CTF of power line networks using LTI models. A long-term averaged channel information was thus enough. Recall that when examined on the invariable scale, power line channels may also be thought of as LTI systems. The two main categories of existing LTI models for power line channels are multi-path models and resonant circuit models.

Interference Phenomena at Power Lines Measuring and Modeling

Power Line Noise Mains Capture Filter

The measurement of noise in power lines has two distinct difficulties that are not present in other channels, such as wireless channels. Power lines have two transmission options: CM or DM. Because most PLC devices operate in DM, the DM noise is typically of greater interest. However, it has been noted that when the measuring system is connected directly to the same PE as the point being measured, the CM noise can be significantly increased in the measurement. Second, when linked to the local power line network, the measurement system's power source produces its own noise and couples it into the channel through the cable, changing the noise situation. As a result, in the relevant frequency range, the measuring device must be electromagnetically separated from the point under measurement.

In most cases, the first issue may be resolved by using a sufficient capacitance to ground the measurement system to the PE rather than a direct connection. There are two options available to solve the second problem. First off, all measuring instruments can be powered by batteries instead of by a PE connection. The equipment may also be linked to the mains via a mains filter, which is made up of an isolation transformer and a line impedance stabilization network, at a power outlet located distant from the place of measurement, such as on another phase or in a neighboring building. An LISN is a well-designed low-pass filter that attenuates all high-frequency signals and background noise in the frequency range of interest while passing the mains voltage at 50 or 60 Hz. Liu described a better design for the off-the-shelf mains filter that uses air core coils instead of magnetic core coils in the LISN and an uninterruptible power supply in lieu of the isolation transformer that is linked to the mains.

An LISN for the frequency range up to 10 MHz was developed as described in 3.19 using the parameters specified in. 3.5, in accordance with the theories put out in for developing LISNs with air coils. A VNA was used to test its S21 parameter, much as in 3.19. Up to 10 MHz, significant attenuation is obtained. When the LISN was connected to an electrical outlet, the voltages on both sides were calculated as in 3.19. It is clear that the LISN does not distort or weaken the 50 Hz mains voltage [5][6][7].

Coupler Design for LV

A band-pass coupling stage is always required in a PLC noise measurement system, much like in PLC communication systems. This stage simultaneously blocks the high-amplitude mains voltage while transferring the high-frequency noise without attenuation. Additionally, grids may experience high-voltage wide-band spikes at any time, which could harm the analog-to-digital converters in the measuring devices. So, the couplers must include protection circuits against such transients. In general, hybrid, inductive, and capacitive structures can couple AC signals. A transformer serves as the simplest inductive coupler, while a pair of capacitors linking the source and the load serves as the simplest capacitive coupler. One may create a hybrid coupler by cascading the two of them. Inductive couplers cannot be used for LV PLC applications because they have negligible impedances at the mains frequency and shorten the LV grid as a result. Pure capacitive couplers are also not favored owing to their undesirable low frequency performance. As a result, the hybrid construction is often selected, particularly in the briefly described transformer-capacitor architecture. This design displays improvements in mains isolation and spike limitation when compared to straightforward LC bandpass filters.

LV PLC couplers are designed using transformer-capacitors.

L and L2 are the leakage inductances on the main and secondary sides of the transformer, respectively, while RP is the capacitor's parasitic resistance. The PLC device's corresponding impedance is ZD. When choosing the coil core for PLC modems, the saturation threshold must be taken into account because the transmitting power must be high enough to overcome the PLC channels' significant attenuation. In this instance, the saturation threshold is less important for noise measurement, but a high impedance is needed to prevent coupling loss. Magnetic zinc is thus chosen as the material for the coil core of the transformer in order to execute the transformer with a significant inductance and a manageable size. Both the transformer and the capacitor are meticulously adjusted via simulation to get the best coupling performance between 0.15 and 10 MHz; the results. Although common transient voltage suppressor diodes are frequently used in transient protection circuits, their high capacity can negatively affect the frequency response of PLC couplers operating above 1 MHz. As a result, devices with capacities less than one picofarad, such as positive inherent negative diodes, Schottky diodes, and extremely low capacitance TVS arrays, are chosen.

Taking Note of the General Channel Noise

The total channel noise r on the receiving side is of importance in the behavioral power line channel model. The measurement equipment was set up as shown in 3.21 in order to record r. The receiver was a universal software radio peripheral with two separate receiving channels equipped with AFEs and ADCs. To sample the channel noise, one channel was coupled to the test power outlet using an LV PLC coupler and a 0/20 dB switchable attenuator. The attenuator should be adjusted to 20 dB for further attenuation when strong peaks occur and have a clipping effect; otherwise, it may be set to 0 dB. The raw measurement data must be post-processed to account for this attenuation, and it should be noted that the additional 20 dB attenuation, when active, increases the quantization error because of the fixed quantizing level. The output of a ZCD that was also plugged into the same power outlet was sent to the other channel in order to access the mains phase. The USRP was linked to a personal computer for data storage and control. To prevent affecting the channel noise, a UPS provided the aforementioned LISN to both the USRP and the PC. some essential USRP requirements Two example measurements, both in the form of spectrograms and temporal wave- patterns. The tests reveal a variety of sounds, and background noise is where the larger quantization error in the office noise B value is most noticeable.

Detecting the Noise, a Power Consumer Produces

Although the behavioral model is primarily concerned with the overall channel noise, there should also be a discussion of how to capture noise produced by a power consumer. Instead of using a standard power outlet, the consumer under test is powered by a UPS with LISN, ensuring that only the noise produced by the consumer is recorded. two representative measures. It is clear that the noise pattern varies greatly depending on the kind of consumer: the monitor, for example, produces some narrowband noise in addition to the periodical impulses that the dimmer bulb produces virtually exclusively.

Additive Power Line Channel Noise Model

The total power line channel noise is always a mashup of several interferences, each of which behaves differently in the time-frequency domains, as stated in the introduction and with measurements. These interferences are often thought to be produced by many sources, independent of one another, and as such received collectively at the output side of power line channels. According to this theory, Hooijen originally categorized power line noise for narrowband applications before Zimmermann et al. expanded it for broadband applications. Since then, it has been customary to use the additive model to simulate power line noise problems.

$$n = nNBN + nPINS + nPINAS + nAPIN + nCBGN,$$

where n is the overall channel noise at the receiver, as in 0. nNBN,nPINS,nPINAS, nAPIN and nCBGN are the components of narrowband noise, periodic impulsive noise synchronous to the mains voltage, pe- riodic impulsive noise asynchronous to the mains voltage, aperiodic impulsive noise and colored background noise, respectively. As afore- mentioned in Sec. 2.3.3, it is also usual to call PINS and PINAS collec- tively as periodic impulsive noise, so that the model can be written as

$$n = nNBN + nPIN + nAPIN + nCBGN,$$

where nPIN = nPINS + nPINAS is the component of periodic impulsive noise. For a deeper noise analysis, each of these noises must be individu- ally modeled.

Narrowband Noise Model

Electrical devices and radio transmissions are the principal contributors to the narrowband noise described. Numerous narrowband interferers with various central frequencies, bandwidths, and powers are typically present at once in an interference scenario. Consequently, a linear model with the form Estimating Narrowband Noise can describe the NBN component. As was said above, each individual narrowband interferer should be defined with its central frequency, bandwidth, and deterministic enve- lope in order to characterize the NBN component in a power line noise measurement. In case the NBN is interfering with the analysis of noise of other sorts, it is also crucial to cancel the NBN from the noise. In, Liu proposed an NBN extraction algorithm that estimates a narrowband interferer's deterministic envelope and cancels a narrowband interferer with a known central frequency and bandwidth. As a result, NBN characterisation may be reduced to a narrowband interferer detection and bandwidth estimate job. This goal requires doing a spectral estimate together with the noise measurement.

The periodogram S = S = TS | xwej2nk f |2, where x = x is the sampled measurement, w is window function, T0 is the sampling interval, N is the number of FFT points, and f is the frequency resolution, is a straightforward non-parametric estimator. However, the presence of large impulses, which increase the overall noise power in a wide frequency range for power line noises, can significantly lower the periodogram's accuracy. As an example, several noises were generated. The NBN was produced following the model with just one interferer, by which fC = 100 kHz, B = 3 kHz, and the envelope was a 50 Hz triangular wave; the PIN is 100 Hz cyclic. The CBGN was produced by filtering an AWGN with an LTI low-pass filter. The CBGN and NBN were first used to create the noise. The PIN was then inserted after that. Both times, a Hamming window was used to calculate the periodograms, same as in 3.26. It is evident that the PIN increased the number of new peaks in the periodogram and decreased the importance of the NBN peak.

Simulated noise components at a 1 MHz synthesizing rate The Welch's approach, in which the measurement is split into numerous equal-length segments, the periodogram of each segment is calculated, and the averaged periodogram is used as the estimate of the spectrum, is often used to lessen this impact. This approach is representable

Model for Aperiodic Impulsive Noise

The actions of connecting and disconnecting electrical devices in the network may produce the aperiodic impulsive noise. The APIN is often wideband, lacks a predictable occurrence pattern or waveform, and can thus only be understood by stochastic models. Two main categories may be used to categorize existing APIN models. The Middleton's Class-A model impulsive index, which is lower when the noise is more impulsive and approaches + when the noise is Gaussian, is an example of how the first class models the APIN together with the background noise and concentrates on the probability distribution of the noise amplitude. The probability distribution and the occurrence are two distinct components of the second class's model of the APIN. The partitioned Markov chain model and the Bernoulli-Gaussian model are two popular models in this category.

In general, both of them may be expressed as nAPIN = nG, where nG stands for Gaussian noise and 0, 1 represents a random process that indicates the occurrence of APIN. It becomes 1 when APIN is present, but it is 0 when APIN is not there. The comparatively straightforward Bernoulli process is used in the Bernoulli-Gaussian model. The partitioned Markov chain model uses the Markov to explain the process.

Decomposition in the empirical mode

The EMD, sometimes referred to as a component of the Hilbert-Huang transform, was put out by Huang et al. in and has since established itself as a potent time domain technique for the examination of non-stationary signals. In contrast to other non-stationary signal analysis techniques like the short-time Fourier transform and the locally stationary wavelet analysis, the EMD operates without regard to the window or wavelet basis that is chosen. It breaks down a given time signal into a collection of intrinsic mode functions, which are characterized as meeting the two requirements below:

1. At every location, the mean value of the envelope formed by the local maxima and the envelope defined by the local minima is zero.
2. In the whole data set, the number of extrema and the number of zero-crossings must either be identical or vary by one. This concept, which was developed, necessitates an IMF to be wide-sense stationary or at least locally stationary.

APIN Detection and Extraction Using EMD

Various EMD-based artifact-removing algorithms have been developed in recent years to combat interference in non-stationary signals. The impulsive artifacts in intracranial pressure signals studied in and show a strong resemblance with the APIN at power lines by being p random, p aperiodic, p impulsive, p and mostly generated by transients in circuits.

Feng made the observation that big amplitude oscillations in the first IMF component may exactly correspond with all the artifact episodes in the original measurement in an effort to address these artifacts. Power line noise exhibits the exact same phenomena. Additionally, it can be seen that the first IMF is insensitive to PIN when comparing the 1st IMFs of two segments in the same noise measurement, one with PIN and APIN components and the other without.

Model for Periodic Impulsive Noise

As stated before, non-linear circuits with regularly time-varying electrical characteristics, such rectifier diodes or switching regulators, are the source of the periodic impulsive noise. A PIN may be either synchronous or asynchronous to the mains voltage, and is categorized as either PINS or PINAS depending on the duration of operation of its source device. PINS and PINAS exhibit the same behavioral pattern, occurring regularly with high amplitude and short duration, although having distinct cyclic periods. As a result, in the section that follows, we model PIN in general without making a distinction between PINS and PINAS.The PIN in a noisy setting should be seen as the sum of several independent components, much like the NBN model. [8]–[10]

CONCLUSION

Overall, accurate modeling of LV power line channels is essential for designing and optimizing reliable and efficient communication systems over power lines. This paper provides valuable insights into the various modeling approaches and their impact on the performance of power line communication systems.

The results of this study can be used to improve the design and implementation of power line communication systems for various applications, such as smart grid communication, home networking, and Internet of Things (IoT) applications.

Presents an analysis of the performance of power line communication systems based on different channel models. We discuss the factors that affect the performance of the system, such as the modulation scheme, coding scheme, and equalization method. We also compare the performance of different power line communication systems, such as HomePlug, G.hn, and IEEE 1901, and their corresponding channel models.

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CHAPTER 12

STRUCTURE OF A TYPICAL EMULATOR-BASED PLC TESTBED

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ABSTRACT:

Emulator-based Power Line Communication (PLC) testbeds are widely used for evaluating and testing the performance of PLC systems. These testbeds simulate the real-world conditions of power line channels and enable researchers to conduct repeatable and controlled experiments under different scenarios. The structure of a typical emulator-based PLC testbed consists of several components, including the power line emulator, the PLC modem, and the test control software.The structure and components of a typical emulator-based PLC testbed. We discuss the function and characteristics of each component, including the power line emulator, which generates the power line signal, and the PLC modem, which modulates and demodulates the signal. We also describe the test control software, which controls the testbed and collects the data for analysis.

KEYWORDS:

Channel Modeling, Emulation, Error Performance, Fading Channels, Interference.

INTRODUCTION

The server sends out configuration directives, which are then received, decrypted, and executed. The basic signal conditioning tasks carried out by the AFEs include buffering, low-pass filtering, and amplification. In particular, the AFE on the output side additionally mixes the filtered signal and the simulated interferences with a customizable SNR[1], [2].

Challenges and Solutions for EMC

In the emulator-based PLC testbed, there are typically three major EMC issues that might reduce accuracy and reliability:

1. **Crosstalk via undesirable routes:** The signal delivered by the DUT to the emulator input may also go across the air or through wire connections to the receiver at the output in addition to the channel that the emulator has added. External parallel transmission lines become chaotic as a result of this crosstalk. Particularly when a high attenuation is intended and imitated, this influence is substantial.
2. **Inconvenient internal sounds:** The power amplifier in the AFE and the switching regulators in the DC power supply, for example, are two examples of analog components with high operating power and the ability to produce loud sounds. The FPGA module must also provide rectangular clocking signals for timing, which often have a frequency more than 100 MHz. These clocks are extensively dispersed across the whole digital circuitry and

are often rather powerful. Through air and wires, all of these sounds and clocks can easily escape and reach the DUT.

3. **Distracting outside sounds:** The DUT may also pick up environmental sounds like diffuse radio waves and power line noises coming from adjacent power lines.

The circuit boards must be carefully built, according to tight EMC guidelines, to minimize effects from these phenomena. For example, the digital and analog components should be distributed independently and should not share the same ground. Additionally, LISNs should be implemented, and a suitable shell should incorporate the emulator. An LISN may significantly reduce high-frequency signals while still passing the mains voltage, as was mentioned. The two LISNs are positioned between the DUTs in 4.1 to prevent direct signal transmission over the power wire, which might otherwise result in significant crosstalk. Additionally, the LISNs attenuate the noise produced by the UPS, reducing the amount of outside noise at the testbed's output.

Shell emulator

The shell must be purposefully built in terms of size, material, and wiring in order to increase the emulator's EMC as well as provide mechanical protection for it.Despite being slightly too short to function as ideal antennas for frequencies up to 10 MHz, the wires connecting the DUTs and the testbed can still transmit and receive some power into and out of the air. A high coupling between the wires may occur if the testbed's input and output ports are located near to one another, leading to substantial crosstalk. The coupling is suppressed as the distance increases. Since the testbed's dimension is much smaller than the wave length, there is no far field approximation, only complicated near field radiation, making quantitative analysis difficult. However, a shell of a size that is generally considered to be large is needed, and the two AFEs should be placed at opposite ends of the shell.

The conductivity of the shell's material is its most significant characteristic. Unwanted internal sounds may be mitigated by using a closed shell consisting of a conductive substance, such metal, which can effectively screen the DUTs from emulation noises. However, because the electric field potential is constant throughout the surface of such a shell, the effective distance between the DUTs is decreased, which increases crosstalk. Due to the high transmitting power of the majority of PLC devices, crosstalk typically has a greater impact than internal noise. Dielectric materials, like plastic, are thus recommended for the shell. Although grounding the emulator can be risky, it is necessary for safety reasons at electronic devices with high voltage levels. When linked to an extended ground plane, analog ground, which is widely dispersed throughout the emulator, may provide a strong common mode connection between the input and the output as well as severe crosstalk. Consequently, there should be no protective earth connection throughout the entire emulator.

DISCUSSION

Synthesizing the Mains Phase for Channel Emulation

It is inevitable to synthesize the mains phase as a time reference for channel emulation since power line channels are very synchronized to the mains voltage. A sinusoidal wave with a fixed period that can easily be produced with a digital timer is the perfect mains voltage path. The mains frequency in actual power systems constantly swings somewhat, albeit stochastically, around its optimum value owing to an imbalance between power output and consumption, which adds to the difficulty of mains phase synthesis[3].

One approach is to add a random interval to the timer, which an FPGA can easily provide. Götz proposes two M-sequence-based digital implementations of uniformly distributed random numbers. Four distinct methods of generating Gaussian random numbers using UDRN were built by Liu et al. and their performance and hardware costs were compared. These techniques may be used to digitally manufacture a random mains frequency with a specified mean value and variance. This approach is adaptable and requires just the FPGA as additional hardware, but it is unreliable due to the fact that PLC devices' immediate performance and the power line channel are often synchronized with the mains voltage. Therefore, if the time reference of the channel emulation is not dependent on the actual mains voltage supplied by the UPS, it may cause a deviation in the system evaluation.

Using Direct Convolution and Fast Convolution to Implement Digital Filters

As mentioned in Section 3.1.5.3, the transfer function of an LV power line channel may be approximated as an LSTV filter, which is built using many LTI filters, and an LPTV filter, which can be modelled as an LPTV filter. The LTI filters must first be implemented in order to create such an LSTV filter in an FPGA. For LTI filters, there are typically two types of digital implementations: direct convolution and fast convolution. A common technique that implements the desired filter's temporal behavior is direct convolution. FIR filters calculate the output signal as the correlation of the input and filter coefficients; IIR filters need loop-back structures. The input signal is processed block by block using the fast convolution, sometimes referred to as block convolution or FFT-based convolution. Each block's DFT is generated, and it is then multiplied by the target filter's frequency response to perform the filtering in the frequency domain.

Both implementations have been used in power line channel emulators that are already in existence. For instance, Caete chose the fast convolution whereas Götz, Bauer, Liu, and Weling preferred the direct convolution. Liu presented a performance comparison of the two techniques in and noted that, if the order of the filter reaches 40, fast convolution may be quicker and more effective than FIR-based direct convolution. The fast convolution is more effective because, according to the system requirements in 4.1, a typical power line CTF with an impulse response of 15 s needs a filter order of 750 when utilizing a sampling rate of 50 MSPS. The fundamental drawback of the rapid convolution approach is, however, also mentioned in the same paper as an inherent latency in the signal processing chain. For some low-speed PLC systems that use the zero-crossings of the mains voltage as a synchronizing reference, this latency can cause a synchronization error. However, this risk is minimal given that this is aimed at new, high-speed PLC technologies. As a result, quick convolution is favored.

Implementing Fast Convolution: In order to cope with the time of segmentation, the fast convolution implementation needs overlap-add and overlap-save buffers as well as zero-padding. If the input signal is divided into blocks that are each L samples long and the filter's impulse response is P samples long, the associated output of each input block is L + P 1 samples long, and as a result, so is the block's DFT. The input block and the channel impulse response must both be zero-padded to L + P 1 samples before their DFTs can be calculated in order to produce such an output DFT block. In addition, L sampling intervals separate each pair of adjacent output blocks, ensuring that P 1 samples are always overlapped. There are two distinct rapid convolution implementations, referred to as overlap-add and overlap-save, depending on how the output buffer handles the overlapping section.

LPTV Channel Transfer Functions Simulator

The rapid convolution is expanded with multiple recorded frequency responses to provide an LSTV filter, which may be used to simulate LPTV CTFs. A random-access memory bank may hold up to 10 separate complex-valued frequency responses, each of which represents a single LTI filter. A cyclostationary CTF may be simulated by periodically switching between the saved frequency responses. A is kept in RAM and records the filter switching time points with reference to the mains period in order to properly synchronize the switching operation. A timing logic shifts the filter at appropriate time instants in accordance with this and a synthetic mains phase. A time resolution of 1% of the mains period is attained, as specified by the standards and backed by the mains synthesizing accuracy.

CTF Emulation calibration

Other parts of the signal processing chain, including the AD/DA converters and the AFE, have an influence on the simulated transfer function in addition to the rapid convolution performed in the FPGA. To measure HExtra between the testbed's input and output, the fast convolution module may be configured as a time-invariant zero-phase all-pass filter. The fast convolution should then be employed to construct the calibrated CTF given a target CTF HTarget.

FPGA generation of APIN

A Markov chain that has been partitioned may produce it. This model was put out by Götz in and is taken here using an FPGA. A n cumulative probability distribution matrix with the form is created from a transition probability matrix P defining an APIN scenario with n states.

Burst Noise Emulation

In the simulation of power line sounds, the burst noise is often considered independently as a particular instance of APIN. A collection of aperiodic impulses that come all at once is known as a burst event. A two-level Markov chain is often used to describe this kind of noise, and each level may be built in the same manner as an ordinary APIN generator. The strategy and execution

Periodic Impulsive Noise Emulation

PIN should be formed as the sum of numerous independent components, as the name indicates. Each component should be produced using an LPTV filter, which is often implemented in an LSTV architecture, as shown in 3.14, in accordance with the spectrotemporal model. This LSTV filter may be reduced to an on-off-keying structure, as in 4.9, thanks to the approximation in. An impulse generator is in charge of producing a binary periodic impulse series with which a synthesized WGN is on-off-keying modulated to synthesize the PIN component, cPIN,i, in accordance with the IAT TPIN,i and the impulse width PIN,i. A reset signal is attached to the impulse generator, especially if TPIN,i corresponds to one or one half of the mains period, i.e., cPIN,i is synchronous to the mains. In order for the created impulse series to display the necessary time offset to the zero-crossings, this reset signal is regularly given in accordance with the synthesized mains phase and the Generating a PIN component inside the FPGA impulse arrival time tPIN,i.

The implementation of four of these units in the emulator allows for the generation of up to four distinct PIN components, and the outputs from these units are combined to simulate PIN in its entirety.

Colored Background Noise Simulation

The spectrotemporal cyclostationary model and its LSTV approximation state that a WGN generator and an LSTV filter may simulate the CBGN. In order to generate a cyclostationary CBGN at its output, the FPGA implementation of the LSTV filter explained in Sec. 4.3.3 is replicated and given a synthetic WGN as input. Up to 10 distinct states in a mains period may be established for the CBGN using the same configuration as for the CTF emulation, and moving between states can provide a temporal resolution of 1% of the mains period[4]–[6].

Calibration and Mixing of Different Types of Interferences

The ultimate simulation of an interference situation is built by assembling the simulated sounds of various types. The act of accumulating is split into three steps in order to increase computing efficiency. This allows the FPGA's advantage of parallel processing to be used, which speeds up the accumulation. It should be noted that the burst noise event is created independently in this simulation since it is distinct from conventional APIN.The simulated interference scenario is impacted by hardware outside the FPGA, which may be expressed as NEmu = NFPGA HExtraN, much as the situation.

In contrast to CTF emulation, noise emulation's signal processing chain excludes both the AFE at the emulator's input and the ADC. HExtraN /= HExtra, where HExtra is the transfer function of hardware outside the FPGA from, shows how the hardware has various effects on the CTF and noise emulation. The noise emulation thus requires a custom calibration.When all noise types other than CBGN are set to zero and the LSTV filter is configured as a time-invariant all-pass filter for CBGN, a normalized

The emulator's analog front end

As two analog front-ends are positioned between the emulator's AD/DA conversion stages and the transmitting and receiving DUTs, respectively. The two AFEs are not symmetrically constructed due to the functional variations. Two buffer amplifiers A1 and A2 are utilized, both of which are configured to have high input impedance and low output impedance, to prevent magnitude coupling losses and to make up for the 6 dB attenuation generated by the LPF in its passband. Their gains are set to

$$|G1| = |G2| = 3 \text{ dB}$$

AFE at the Output of the Emulator

The AFE at is more functionally and structurally sophisticated than the AFE at the emulator's input. It contains two channels in the beginning, one for the communication signal that is filtered by the simulated power line channel and the other for the simulated noise. A reconstruction filter is required for each channel.

Second, to acquire the full power line channel output, both channel outputs must be blended in a programmable ratio. Before being delivered to the receiving DUT through an LV PLC coupler, the mixed signal must also be amplified in power.

Broadband width Access Options

Every time firms in New Jersey attempt to alter the prices they charge customers for natural gas, electric, water, wastewater, or telephone service, the Ratepayer Advocate advocates and defends the interests of all utility users residential, small business, commercial, and industrial. In establishing energy and telecommunications policies that will influence the delivery of services in the future, the Ratepayer Advocate also represents customers. The goal of the Ratepayer Advocate is to guarantee that all utility users, regardless of their class, get safe, appropriate, and proper service at fair, nondiscriminatory, and reasonable prices. The Ratepayer Advocate also strives to ensure that all customers are aware of their options in the nascent era of utility competition. In keeping with its role, the Division of Ratepayer Advocate provides an overview and evaluation of the technological viability of Broadband over Power Lines (BPL), as well as an assessment of the likelihood that BPL will become a substantial competitor in the market and the accompanying regulatory control problems.

Despite the recent expansion of broadband technology, a sizable portion of the globe still lacks access to high-speed Internet. The additional costs of laying cable and constructing the required infrastructure to supply DSL or cable in many places, particularly rural ones, are too high when compared to the relatively small number of clients Internet service providers would acquire. However, there would be no need for new infrastructure if broadband could be provided through power lines. Broadband service may be available everywhere there is power.

The availability of high-speed data transport technology via the current electric power distribution network is becoming closer. By employing medium- and low-voltage lines to connect to clients' homes and places of business, Broadband Over Powerline is poised to provide an alternate method of delivering high-speed internet access, Voice over Internet Protocol (VoIP), and other broadband services. Developers have developed a method to transmit data across power lines and into houses at rates ranging from 500 kilobits to 3 megabits per second (similar to DSL and cable), integrating the technical concepts of radio, wireless networking, and modems. The BPL developers might collaborate with power companies and Internet service providers to offer broadband to everyone with access to electricity by changing the present power grids with specialized equipment.

In light of the development of new networks and the emergence of competing technologies, the technological advancement over the next years will be crucial for BPL's ability to remain competitive. For a comparison of access technologies. The new alternative broadband access solutions most likely to appear in the next years are fiber and enhanced wireless broadband.These might also be incorporated into a BPL system as a whole. The potential for BPL implementation is also being strengthened by federal policy assistance. In a market dominated by digital subscriber line (DSL) and cable modem service, the FCC and others have lauded BPL as a possible "third wire" that may assist enhance the availability and cost of broadband services. The government Communications Commission (FCC) modified Part 15 regulations to include steps to reduce radio interference brought on by broadband over powerline as part of the government effort to eliminate obstacles to BPL adoption. BPL's ability to interfere with radio and telecommunications signals would virtually be mitigated by the FCC's decision on October 14, 2004.

Many jurisdictional and classificational questions are still unresolved, though. For instance, are the broadband services provided by BPL considered telecommunications or information services? This has consequences since the Telecommunications Act of 1996 imposes rules on telecommunications services, most notably common carrier obligations. As of October 2004, the FCC is involved in two actions that deal with the categorization of wireline broadband Internet access services for regulatory purposes: one focuses on cable modem services, and the other covers all wireline broadband Internet access services in general. BPL service would be exempt from most, if not all, common carrier rules, with the exception of paying into the universal service fund (USF), if it were designated as an information service.

The primary issues for state commissions are the safety and dependability of the electricity supply system and the provision of high-quality services. Cross subsidization difficulties and affiliate transaction restrictions are also significant concerns. State Commissions are required to stop an asset created with ratepayer money from being used unfairly for the advantage of shareholders. Additionally, they must make sure that electric utilities do not have an unfair advantage over rivals. Thus, a number of options, including the establishment of unregulated BPL subsidiaries or the adoption of accounting regulations that prevent cross-subsidization, may be taken into account.

Rights of way and difficulties with access to poles will also need to be addressed by the state regulators. As an instance, some communities could try to impose taxes for BPL rights of way. Due to possible interference issues, pole attachment regulations may also need to be revised.Electric utilities are becoming more interested in the deployment of BPL due to the technological viability, FCC legislation that mitigates interference, and news of the commercial-scale testing of BPL. The business case attractiveness of BPL in comparison to well-established DSL and cable services will be shown via market testing and commercial deployments. However, there is also interest in BPL's capacity to act as a networking tool for the power delivery system's network management. The electric utilities will assess if the system's advantages for enabling customer telecom services, other consumer services, and core utility network communications contribute to BPL's interest in the business model.

Utilities may take into account using the following three simple business case models:

1. The landlord model involves renting the conduit and the assets to a third party, most likely with a maintenance contract.
2. The utility constructs and controls the infrastructure under the "Developer Model," which is a partnership or contract with an Internet service provider (ISP); the ISP manages all aspects of customer marketing, sales, and service.
3. The system is managed by the Service Provider Model-utility, which also acts as the Internet service provider.

Each utility will evaluate BPL in accordance with its own business goals, risk appetite, and processes. Cost, market size, pricing, distinguishing BPL characteristics, bundled services, average revenue per user, and utility applications are the variables to be considered. While the primary application driving the deployment of BPL networks may be broadband Internet access, there are a huge number of other potential uses for such a communications network that must be taken into account as the business model is created.

A range of technologies, network designs, and transmission techniques are used to give broadband access and services. The most important broadband technologies are as follows:

1. DSL, or digital subscriber line
2. Technology Fiber
3. Wireless Coaxial Cable BPL (Broadband Over Power Lines)
4. The access technologies mentioned above are each briefly described here.
5. Digital Subscriber Line (DSL): Faster copper with broadband

The same lines as a typical telephone line are used by DSL, a highly fast Internet connection. Two copper wires make up a typical telephone installation in the United States. This pair of copper wires has enough capacity to support both voice and data traffic. Only a small portion of the wires' capacity is used by voice signals. DSL takes use of this residual capacity to transmit data across the connection without interfering with voice communication.

The frequencies that switch, telephones, and other equipment may convey are restricted by standard phone service. The frequency range for human voices speaking in natural conversational tones is 400 to 3,400 Hertz (cycles per second). The majority of the time, the cables themselves are capable of handling frequencies up to several million Hertz. The capacity of the telephone line may be securely used considerably more by modern technology that transmits digital (rather than analog) data, and DSL provides precisely that[7]–[10].

Benefits of DSL

a. Use of a phone line for both voice calls and an Internet connection simultaneously is possible.
b. a speed that is far faster than a standard modem (1.5 Mbps vs. 56 Kbps).
c. uses the existing phone line rather than installing new wiring.
d. In most cases, providers supply a modem with the installation.
e. DSL's limitations
f. The closer you are to the provider's headquarters, the higher the connection quality.
g. Over the internet, receiving data is quicker than sending it.
h. DSL service is not universal.

CONCLUSION

Overall, emulator-based PLC testbeds are an essential tool for evaluating and testing the performance of PLC systems. This paper provides valuable insights into the structure and components of a typical emulator-based PLC testbed, as well as its performance in different scenarios. The results of this study can be used to improve the design and implementation of emulator-based PLC testbeds for various applications, such as smart grid communication, home networking, and Internet of Things (IoT) applications.The performance of a typical emulator-based PLC testbed in different scenarios, such as channel characterization, interference analysis, and system optimization. We discuss the factors that affect the performance of the testbed, such as the accuracy and fidelity of the emulator, the quality of the PLC modem, and the performance of the test control software.

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CHAPTER 13

A BRIEF DISCUSSION ON DIGITAL SUBSCRIBER LINE VARIATIONS

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ABSTRACT:

Digital Subscriber Line (DSL) technology is widely used for delivering high-speed broadband access over existing copper telephone lines. DSL technology has evolved over the years, and various variations have been developed to meet the increasing demand for high-speed broadband services. This paper provides an overview of the various DSL variations, including Asymmetric DSL (ADSL), Very High Bitrate DSL (VDSL), and G.fast, and their characteristics and applications.ADSL is the most widely deployed DSL technology and is optimized for delivering high-speed downstream data rates up to 24 Mbps, and slower upstream data rates up to 3.5 Mbps. ADSL is designed for residential and small business users who primarily consume content from the Internet, such as web pages, video, and audio.

KEYWORDS:

Bit rate, broadband access. Carrier less amplitude,digital,discrete multitone, high-bit-rate,Internet Access.

INTRODUCTION

The DSL technology comes in a number of different forms. When referring to DSL in general, the term xDSL is often used, where x is a variable.

1. **Asymmetric DSL (ADSL):** This kind of DSL is referred to as "asymmetric" since the upload speed is slower than the download speed. Due to the fact that the majority of Internet users view or download significantly more data than they send or upload, ADSL operates in this way.
2. **High bit-rate DSL (HDSL):** HDSL can transport data at speeds similar to a T1 line (about 1.5 Mbps), but it needs two lines that aren't connected to your regular phone line.
3. **ISDN DSL (ISDL):** Designed especially for current ISDN customers, ISDL operates at a fixed rate of 144 Kbps in both directions, making it slower than most other types of DSL. Customers of ISDL benefit from using their current equipment, however the actual speed increase is often just 16 Kbps (ISDN operates at 128 Kbps).
4. **Multi-Rate Symmetric DSL (MSDSL):** This kind of symmetric DSL may support multiple transmission rates. The service provider determines the transfer rate, often depending on the service (pricing) level.
5. **Rate Adaptive DSL (RADSL):** This well-liked ADSL variant enables the modem to modify the connection speed in accordance with the length and caliber of the line.

6. **Symmetric DSL (SDSL):** Similar to HDSL, this version offers the same speed for data transmission and reception. While SDSL also needs a separate line from your phone, it only uses one line as opposed to HDSL's two lines.
7. **Very high bit-rate DSL (VDSL):** This incredibly fast connection uses asymmetric copper phone lines and can only operate over a limited distance.

VoDSL, or voice-over DSL VoDSL, a kind of IP Telephony, enables the consolidation of many phone lines into a single phone line with data-transmission capabilities. Most households and small businesses have an asymmetric DSL (ADSL) connection linked to them. The way that ADSL splits up a line's available frequencies is based on the idea that most Internet users view or download a lot more data than they transmit or post. According to this presumption, the user will typically gain the most if the connection speed from the Internet to them is three to four times quicker than the connection from them back to the Internet.

How much of a benefit a user will experience will depend on how far away they are from the provider of the ADSL service. A distance-sensitive technology is ADSL: Signal quality deteriorates and connection speed declines as the length of the connection grows. Although many ADSL providers set a lower limit due to speed and service quality, the maximum distance for ADSL service is 18,000 feet (5,460 meters). While customers closer to the central office have faster connections and may eventually experience extremely high speeds, customers farther from the central office may experience speeds far below the promised maximums. At a distance of around 6,000 feet (1,820 meters), ADSL technology may provide maximum downstream (Internet to customer) speeds of up to 8 megabits per second (Mbps) and upstream rates of up to 640 kilobits per second (Kbps). In reality, the fastest rates currently being commonly provided are 1.5 Mbps downstream and 64–640 Kbps upstream[1]–[3].

DSL is restricted by distance, while voice calls are not. This is because tiny amplifiers known as loading coils are used to increase (amplify) the speech signals. A voice coil in the loop between a phone and the phone company's central office will prevent a user from using ADSL since these loading coils conflict with ADSL signals. Additional elements that could prevent a user from receiving ADSL include:Bridge taps are connections that provide service to additional consumers between the user and the central office. In a typical phone system, consumers would not be aware of these bridge taps, but they may cause the circuit's overall length to exceed the service provider's permitted distance.

Fiber-Optic Cables: If a component of a telephone circuit uses fiber-optic cables, ADSL signals cannot pass through the conversion from analog to digital and back to analog that takes place.

Distance: Even if you know the location of your central office, which is unlikely given that phone companies don't promote them, a map will not tell you how far a signal needs travel to reach the office from your home.

Two sets of equipment are used by ADSL, one at the provider's end and one at the consumer end:

There is a DSL transceiver at the customer's location, which could also provide additional services. DSL transceivers are often referred to as DSL modems by residential consumers. It is known as an ATU-R, or ADSL Transceiver Unit - Remote, by the engineers at the phone company or Internet service provider. Whatever name it has, the transceiver is the device that connects the user's computer or network to the DSL line. A customer's equipment may be connected to the transceiver in a number of ways, although most home installations employ USB or 10BaseT Ethernet connections. However, the devices used by businesses may combine network routers, network switches, or other networking equipment in a single box, unlike the majority of ADSL transceivers sold by ISPs and telephone companies, which are merely transceivers.

To accept client connections, the DSL service provider has a DSL Access Multiplexer (DSLAM). The device that makes DSL possible at the access provider is the DSLAM. A DSLAM combines connections from several users into a single, high-capacity Internet connection. DSLAMs are often adaptable and capable of supporting several DSL types as well as offering extra services like routing and dynamic IP address assignment for users. Many consider VDSL (described above) to be the next step in offering a whole home communications/entertainment bundle. Currently, a few businesses, including U.S. West (now a subsidiary of Qwest), provide VDSL service in a few locations.Although there are a few differences, VDSL and ADSL both use copper wires to transmit data. VDSL is capable of astounding speeds of up to 16 Mbps in the upstream and 52 Mbps in the downstream. That is significantly faster than ADSL, which offers speeds of up to 800 Kbps (kilobits per second) upstream and 8 Mbps downstream. VDSL, however, is distance-sensitive. It can only function over the copper wire for a few hundred meters, or roughly 4,000 feet.

It is obvious that the transition from the existing broadband technology to VDSL might be as important as the transition from a 56K modem to broadband, given that ADSL or cable modems have a maximum speed of 8 to 10 Mbps. The fact that many of the telephone companies' primary feeds are being replaced with fiber-optic cable is the key to VDSL, however. In reality, many phone companies want to replace all current copper lines up to the point where a phone line branches off to a residence (FTTC), which stands for fiber to the curb. Most businesses plan to at least adopt Fiber to the Neighborhood (FTTN). With FTTN, fiber is connected to the neighborhood's main junction box rather than being installed down each street.

The distance restriction is removed by installing a VDSL transceiver in a residence and a VDSL gateway in the junction box. The ADSL over fiber-optic connections issue with analog-digital-analog conversion is fixed by the gateway. It transforms the information obtained from the transceiver into light pulses that may be sent across the fiber-optic network to the central office, where the information is then sent to the proper network to reach its target. The VDSL gateway transforms the signal from the fiber-optic connection and transmits it to the transceiver when data has to be transferred back to the computer.

Two rival consortiums are working to standardize VDSL. They employ carrier technologies in their proposed standards that are incompatible with one another. The carrier system used by the VDSL Alliance, a collaboration between Texas Instruments, Alcatel, and other companies, to enable VDSL is known as Discrete MultiTone (DMT).

The majority of the ADSL equipment deployed today, according to equipment makers, utilizes DMT.The VDSL Coalition is the name of the other VDSL organization. The Coalition, lead by Lucent and Broadcom, suggests a carrier system that makes use of two technologies dubbed Carrierless Amplitude Phase (CAP) and Quadrature Amplitude Modulation (QAM).Even though VDSL outperforms all other versions in terms of performance, it must first be standardized before it can be widely used.

DISCUSSION

Fiber Technologies

Recently, carriers have started building completely fiber optic cable transmission facilities that connect the loop demarcation point at an end-user customer premise to a distribution frame or its equivalent at the central office of an incumbent local exchange carrier (ILEC). Fiber-to-the-home (FTTH) loops are the name given to these loops. More capacity is available with FTTH technology than with any copper-based technology. For instance, Wav7 Optics offers a FTTH solution today that achieves transmission rates up to 500 Mbps shared across a maximum of 16 users using commercially available equipment. If needed, this system can symmetrically provide up to 500 Mbps to a single customer. The amount of people online and the time of day also affect how fast a user will actually experience things. A typical FTTH system may provide multiple telephone lines, current and next-generation data services at rates above 100 Mbps, up to 870 MHz of cable television video services (for HD definition television), or IP video services[4]–[6].

To deliver FTTH, three different styles of architecture are often employed. Technology called Passive Optical Network (PON) is the most widely utilized architecture. Multiple homes can share a passive fiber network thanks to this technology. This form of network uses only passive components in the field; no electronics are required between the client location and the head-end at the central office. The other designs in use are hybrid PONs, which combine home run and PON architecture. In home run fiber or point-to-point fiber, subscribers have a dedicated fiber strand, and active or powered nodes are employed to handle signal dispersion.

FTTH technology is still in its infancy, yet FTTH implementation is rapidly expanding. Additionally, FTTH equipment costs have dropped significantly. Carriers have introduced FTTH technology to 128 localities in 32 states as of May 2004. Future FTTH deployment will increase, according to businesses. Additionally, FTTH infrastructure is being built by rival carriers.In addition to FTTH technology, some carriers are building fiber-to-the-curb (FTTC) infrastructure, which only extend 500 feet from the subscriber's premises to a pedestal rather than all the way to the subscriber's house. The pedestal is then connected to the network interface device at the customer's location via copper cables. FTTC technologies enable carriers to provide high-speed data in addition to high-definition video services due to the restricted usage of copper.

Coiled Cable

Television provides news, entertainment, and instructional programming into the homes of millions of people. Because cable TV offers better reception and more channels, many people choose it to receive their TV signal.Many consumers who subscribe to cable TV may now obtain a fast Internet connection via their cable provider. Subscribers may access high-speed data services through cable networks that are typically built using a hybrid fiber-coaxial (HFC) architecture thanks to cable modems. Although primarily used for homes, cable modem service may also offer some small business services.

Technologies like Asymmetrical Digital Subscriber Lines (ADSL) compete with cable modems. Here's a look at how a cable modem works and how 100 websites and cable television channels may all be accessed with a single coaxial connection.Signals from the different channels in a cable TV system are each assigned a 6-MHz slice of the cable's available bandwidth before being transmitted all the way to your home. Cable television uses coaxial cable, which has the capacity to transport hundreds of megahertz of signals and consequently many channels. Coaxial cable is the sole medium utilized for signal distribution in certain systems. In other systems, fiber-optic cable travels from the cable provider to various communities or regions. The fiber is then cut, and the signals are transferred to coaxial cable for delivery to specific homes.

Because the cable modem system sends downstream data data sent from the Internet to a specific computer into a 6-MHz channel, when a cable company provides Internet access over the cable, Internet information can use the same cables. The data appears just like a TV channel on the cable. Thus, the amount of cable space required by Internet downstream data is equal to that required by a single channel of programming. Since it is assumed that most people download far more data than they upload, upstream data information sent from an individual back to the Internet only uses 2 MHz of the cable's bandwidth. A cable modem on the end of the consumer and a cable modem termination system (CMTS) on the end of the cable provider are needed in order to transmit both upstream and downstream data through the cable television network. All computer networking, security, and administration for Internet access through cable television are implemented between these two pieces of technology.

Benefits and Drawbacks of Coaxial Cable

You can get access to almost the whole channel's bandwidth if you are one of the first people to connect to the Internet using a certain cable channel. The drawback of coaxial cable, however, is that you will have to share that bandwidth when additional users, particularly those with heavy access, are connected to the channel, and your performance may suffer as a consequence. It's likely that performance will be significantly below the theoretical maximums during periods of high use with lots of people connecting. The cable provider may fix this specific performance problem by dividing the customer base and creating a new channel.

The performance of the cable modem for Internet connection does not rely on the distance from the central cable office, in contrast to ADSL, which is another advantage. A digital CATV system is designed to provide digital signals to client homes at a certain quality. The burst modulator in cable modems, which is located upstream, is configured with the head-end's location and gives the right signal strength for precise transmission. At least 90% of residences served by cable networks now have access to broadband services thanks to the cable business. The cable industry anticipates that industry-wide facility modifications necessary to provide residential consumers broadband Internet access will be finished soon.

Wireless

Unauthorized Wireless

There has been a fast proliferation of goods and markets in bands designated for unlicensed use ever since the Commission initially assigned spectrum in the 902-928 MHz range for use on an unlicensed basis under Part 15 of the regulations. The widespread adoption of equipment including cordless phones, security alarms, wireless bar code scanners, and data collecting systems initially occurred in the Industrial, Scientific, and Medical (ISM) band. Many original equipment manufacturers still offer point-to-point and point-to-multipoint system hardware for uses like data acquisition and supervisory control. Additionally, there are numerous suppliers of wireless LAN hardware in this band.

Wi-Fi

The abbreviation Wi-Fi, which stands for Wireless Fidelity, is a catch-all word for any product or service that adheres to the 802.11 family of standards created by the Institute of Electrical and Electronics Engineers (IEEE) for wireless local area network connections. Wi-Fi networks deliver numerous data speeds up to a maximum of 54 Mbps and operate on an unlicensed basis in the 2.4 and 5 GHz radio bands. The users split the available bandwidth. Personal digital assistants (PDAs) and other wireless devices with Wi-Fi capabilities may transmit and receive data from any place that is within signal range of a base station or access point (AP) with Wi-Fi capabilities.Mobile devices must typically be 300 feet or less away from a base station.

The "wireless cloud" that is created by Wi-Fi technology encompasses the hotspot area. Depending on the climate and power requirements for the equipment being used, the coverage area's precise dimensions change. The typical coverage radius is between 300 and 500 feet. Reaching potential clients may be hampered by environmental factors like the weather and line of sight.Hotspots have multiplied quickly as Wi-Fi access to the Internet has increased. Hotspot networks with several access points have been built to span bigger spaces, including airports.

WiMax

Because Wi-Fi or IEEE 802.11-based wireless local area networks (LANs) have been so successful, the emphasis in wireless is shifting to the wide area. The vast area market is still very much open even though Wi-Fi predominates in the local neighborhood.With their 2.5G/3G data services, cellular carriers entered this market first, but they were set up to provide basically add-on telephony services. WiMax, a new data-oriented technology, may be the actual threat to cellular data services.Worldwide Interoperability for Microwave Access, or WiMax, is the abbreviation for any broadband wireless access network built on the IEEE 802.16 specifications. Internationally, WiMax/802.16 addresses the same topic as the HIPERMAN effort from the European Telecommunications Standards Institute (ETSI), which uses part of the same technologies.

Fixed systems using a point-to-multipoint architecture and operating between 2 GHz and 66 GHz are included in WiMax. Broadband wireless access (BWA), which is based on WiMax and is often referred to as wireless DSL, would provide data speeds of 512 Kbps to 1 Mbps. Delivering low-cost, user-installable, indoor premises equipment that does not need to be in line with the base station—i.e., having the antenna in the premises equipment integrated with the radio modem—will be crucial.Broadband wireless access (BWA) for urban areas is what WiMax is intended to provide. BWA aims to compete with cable modems and DSL by offering a fixed location wireless Internet access service. WiMax systems are designed to serve as the foundation of a carrier service and could support users at distances of up to 30 miles.

To meet the needs of carriers worldwide, the WiMax specifications allow a significantly larger spectrum of possible implementation. When the 802.16 standard was first published, it targeted devices using the 10 GHz to 66 GHz frequency range. Line-of-sight (LOS) to the base station is necessary for such high frequency systems, which raises costs and restricts the client base. Additionally, in LOS systems, when a new cell is added to the network, customer antennas need to be realigned. The 2003 802.16a standard has altered the playing field since its first introduction. Systems that operate between 2 GHz and 11 GHz are covered by the 802.16a standard. The non-line-of-sight (NLOS) capabilities of these lower frequency bands make it unnecessary to align the client unit with the base station. gives a brief overview of WiMax (802.16) radio connections.

Wi-Fi implementations employ unlicensed frequency ranges, as was already noted. On the other hand, WiMax can function in both licensed and unlicensed spectrum. There are four bands in the 802.16a frequency range (2-11 GHz) that are very desirable:

a. 200 MHz of licensed radio spectrum between 2.5 and 2.7 GHz have been set aside by the FCC for the Multichannel Multipoint Distribution Service (MMDS), which operates at 2.5 GHz.
b. Licensed 3.5 GHz Band: In the majority of the globe, a licensed spectrum band that is roughly equivalent to MMDS has been assigned in the 3.4 to 3.7 GHz range.
c. Unlicensed 3.5 GHz Band: For fixed site wireless services, the FCC has made an additional 50 MHz of unlicensed spectrum in the 3.65 to 3.7 GHz band available.
d. Unlicensed 5 GHz U-NII Band: In the United States, the 5.15 to 5.35 GHz and 5.47 to 5.825 GHz bands have each been given 555 MHz of unlicensed spectrum. The frequency utilized for 802.11a wireless LANs is known as the Unlicensed National Information Infrastructure (U-NII) band. By FCC rule in November 2003, the allotment was expanded from 300 MHz to 555 MHz [7]–[9].

WiMax vs. Wi-Fi

Wireless applications are represented by Wi-Fi and WiMax from two very distinct angles.

A local network technology called Wi-Fi was created to provide private wired LANs more mobility. Contrarily, WiMax is intended to provide a broadband wireless access (BWA) service for urban areas. BWA aims to compete with cable modems and DSL by offering a fixed location wireless Internet access service. WiMax systems might support users at ranges up to 30 miles, but Wi-Fi only supports transmission ranges of a few hundred feet. WiMax is meant to be the foundation of a carrier service, while Wi-Fi is aimed at the end-user. Apart from the difference in broadcast range, WiMax and Wi-Fi vary due to a number of advancements in radio connection technology:

Wireless Fixed Technologies

In the backhaul networks of phone companies, cable TV providers, utilities, and government organizations, point-to-point microwave links have a long history. Higher frequencies and smaller antennas are now possible because to recent technological advancements. As a consequence, carriers are now able to sell lower cost solutions for the final mile of communications.

Service for multi-channel multipoint distribution (MMDS)

Initially, cable television service was distributed using this 2.5GHz band. For household Internet service, MMDS is currently being developed.With throughputs ranging from 64 kbps to 10Mbps, "two-way" service may be provided using MMDS wireless technology. However, line of sight between the transmitter and receiver is necessary for MMDS systems. Due to the slower attenuation of the lower MMDS frequencies (2 GHz), services can be offered up to 30 miles from the hub, providing coverage for about 2,800 square miles. One of the widest coverage areas of any point-to-multipoint communication technology now on the market is offered by this one.

Service for local multipoint distribution (LMDS)

Similar to the 39GHz band, this spectrum (27.5GHz to 28.35GHz, 29.1GHz to 29.25GHz, and 31.3GHz to 31.3GHz) is utilized for point-to-multipoint applications including Internet access and phone calls. While TDMA (Time-Division Multiple Access) allows multiple users to share a single radio channel, LMDS only has a 3-mile coverage area.To supply fixed services, namely phone, video, and Internet access, the system employs a cellular-like network architecture of microwave radios located at the client's location and at the business' base station. Time-division multiple access (TDMA) and frequency-division multiple access (FDMA) technologies let several users use a single radio channel across a range of three to five miles. Customers may get data at speeds ranging from 64kbps to 155Mbps.

In an LMDS system, there are four components:

Large portions of the customer network are managed by the network management system (NMS), which is housed in the network operations center (NOC).Diverse NOCs are connected by a fiber-based infrastructure.The base station is where the transition from fibered infrastructure to wireless infrastructure takes place. It is often found on a cell tower.The customer premises equipment (CPE) generally consists of both inside and outside microwave equipment that performs modulation, demodulation, control, and interface functions for a consumer's home or place of business.

Low entry and deployment costs allow the operator to pace capital expenditures in accordance with the addition of new customers since the majority of the cost of a wireless network is not spent until the CPE is deployed.Rapid deployment - A fiberless network simply needs a radio at the customer's location and another one on a tower in a strategic place. It doesn't need trenches, backhoes, or building. This makes it possible for deployment to happen faster than with typical broadband providers. Demand-based buildout: To guarantee that service may be increased as customer demand rises, LMDS utilizes a scalable design in conjunction with industry standards.

Variable Component Cost: The infrastructure component of wireline networks often requires a significant capital expenditure. Because LMDS systems shift the cost to the CPE, the operator only incurs costs when a customer signs up for a revenue-paying service.

LMDS's drawbacks include:

a. Line-of-site (LOS) between the CPE and base station hub is necessary for the system. To forward signals across obstructions, repeaters can be needed.
b. Moisture has an impact on LMDS signals, which may cause "rain fade," or signal degradation as a consequence of heavy rain. The majority of the time, rain fade issues may be resolved by increasing the signal power [10]–[13].

CONCLUSION

Overall, DSL technology has evolved over the years to meet the increasing demand for high-speed broadband services. This paper provides valuable insights into the various DSL variations, their characteristics, and applications. The results of this study can be used to improve the design and implementation of DSL systems for various applications, such as home networking, small business connectivity, and broadband access in multi-dwelling units.An analysis of the performance of various DSL variations in different scenarios, including channel characteristics, distance, and interference. We discuss the factors that affect the performance of DSL, such as the frequency band, channel coding, and signal processing techniques.

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CHAPTER 14

A BRIEF DISCUSSION ON SATELLITE INTERNET CONNECTIVITY

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ABSTRACT:

Satellite Internet connectivity is a critical technology for providing high-speed broadband access to remote and underserved areas where terrestrial infrastructure is not available or feasible. Satellite Internet connectivity provides a reliable and cost-effective solution for delivering broadband services to residential, commercial, and government users. This paper provides an overview of satellite Internet connectivity, its characteristics, and applications.The technical aspects of satellite Internet connectivity, including the satellite network architecture, frequency bands, modulation and coding schemes, and signal processing techniques. We also describe the various satellite constellations used for providing global coverage and their advantages and limitations.

KEYWORDS:

Bandwidth, Broadband Internet, Geostationary satellite, Latency, Low Earth Orbit, Modems.

INTRODUCTION

For rural Internet customers who seek broadband access, satellite Internet connectivity is suitable. Satellite Internet employs a satellite dish for two-way (upload and download) data connections rather than phone lines or cable networks. The 500-kbps download speed is about one-tenth of the upload speed. Although satellite systems are roughly 10 times faster than a standard modem, cable and DSL have faster download speeds[1]. A roughly two-foot by three-foot dish, two modems (uplink and downlink), and coaxial cables connecting the dish and modem are required for two-way satellite Internet. Since the orbiting satellites are over the equator, a clear view to the south is a crucial installation planning requirement. Additionally, just like with satellite TV, trees and heavy rains can interfere with receiving Internet signals.

A single satellite may support up to 5,000 channels of communication at once thanks to the Internet Protocol (IP) multicasting technology used for two-way satellite Internet. IP multicasting delivers data in a compressed manner from one point to many points (all at once). The size of the data and the bandwidth are both reduced through compression. The bandwidth constraints of conventional dial-up land-based terrestrial networks hinder large-scale multicasting.The satellite data downlink is identical to the typical terrestrial connection, with the exception that the satellite uses the same dish to deliver the data to your computer that is used to receive Pay-Per-View television content.

Comparative Evaluation of Access Options

Over the past few years, there has been a sharp increase in the use of fast Internet connections. The need for broadband connections grows gradually as more individuals purchase home computers and set up home networks. The industry is now dominated by Coaxial Cable (Cable Modems) and Asymmetric Digital Subscriber Line (ADSL). Despite the fact that both of these technologies provide Internet connections that are far quicker than a 56K modem, they are still too slow to facilitate the integration of home services like digital television and Video-On-Demand. Voice and Internet data may be transferred across utility power lines thanks to a technology called broadband over power line (BPL). Power-line communications or PLC are other names for BPL. PLC and BPL are often used interchangeably. For consumer uses, the FCC opted to adopt the phrase "broadband over power line".

Subscribers do not need a phone, cable, or satellite connection to utilize BPL. Instead, a customer installs a modem that plugs into a standard wall socket and pays a monthly cost comparable to what is charged for other forms of Internet access.The FCC approved a Notice of Inquiry (Inquiry)1 on April 23, 2003, expressing excitement about the BPL technology's potential to allow electric power lines to serve as a third wire into the house and establish competition with the copper telephone line and cable television coaxial cable line. On the basis of the feedback it had received in response to the Inquiry, the Commission subsequently published a Notice of Proposed Rulemaking (NPRM)2 in February 2004. The Inquiry and NPRM both address two categories of BPL: Access BPL and internal BPL are the first two.

A system known as connectivity BPL3 offers broadband connectivity across medium voltage power lines. In regions without subterranean electric service, the electric wires you see on top of utility poles along the side of the road are known as medium voltage power lines. Three electrical lines, often referred to as phases A, B, and C, each carrying several thousand volts, are used. While two or even three phases can be connected together to power the large electric motors in an industrial or commercial area, one phase is typically sufficient to power the homes on a residential street.

The Commission published a Notice of Inquiry (Inquiry) on BPL systems and technologies in April 2003. The Commission is updating its Part 15 guidelines to make it easier to implement Access BPL while maintaining the protection of licensed services, hence the Inquiry was launched to get feedback. The Commission supported the Inquiry's recommendation that Access BPL systems that adhere to the law continue to be deployed. See Notice of Inquiry, ET Docket No. 03-104, 18 FCC Rcd 8498 (2003), Inquiry Regarding Carrier Current Systems, Including Broadband over Power Line Systems[2]–[4].

Notice of Proposed Rulemaking (NPRM), ET Docket Nos. 03-104 and 04-37, 19 FCC Rcd 3335 (2004) in the matter of Carrier Current Systems, including Broadband over Power Line Systems, and Amendment of Part 15 with regard to new specifications and measurement guidelines for Access Broadband over Power Line Systems.Access BPL is described as a carrier current system installed and operated on an electric utility service as an unintentional radiator that transmits radio frequency energy on frequencies between 1.705 MHz and 80 MHz over medium voltage lines or low voltage lines to provide broadband communications and is located on the supply side of the utility service's points of interconnection with customer premises in the Report and Order on BPL by the FCC.

Report and Order, ET Docket Nos. 03-104 and 04-37, para. 29 (rel. October 28, 2004) in The Matter of Amendment of Part 15 about New Requirements and Measurement Guidelines for Access Broadband over Power Line Systems; Carrier Current Systems, including Broadband over Power Line Systems. (See: "BPL Report and Order").Home networking technique called In-house BPL4 makes use of HomePlug Alliance5 transmission standards. Because the products connect directly to the low voltage electric lines inside your home or office, in-house BPL products can fairly easily comply with the radiated emissions limits in Part 156 of the FCC's Rules.

Although intriguing and cutting-edge, in-home networking is not a top FCC policy concern. How to provide broadband Internet access across "the last mile" to the house is the actual challenge facing the FCC.The Last Mile refers to the area of the network that links end customers, such as residences and businesses, to high-speed services and the Internet. The drop wire connecting the interface on a home to the cable company's network and the wire from the interface connecting to the wall plates in the home, for example, would all be a component of the last mile for residential broadband service customers who get cable modem service.

Similar to how cable and DSL modems use silicon chips intended to convey signals over cable and telephone lines, BPL modems utilize silicon chips designed to deliver signals over electric power lines. New BPL modem chips may now carry communications signals across the power lines despite their limitations due to improvements in processing power.BPL modems are connected to the medium voltage power lines via inductive couplers. Without physically attaching to the wire, an inductive coupler wraps around it to transmit the communications signal onto the power line. How to transfer the signal from the high-voltage line to the low-voltage line that enters your home presents a significant difficulty since the transformer that reduces the electric current from thousands of volts to 220/110 might act as a barrier to the broadband signal.

A router is a device that manages networks and serves as an interface between two networks.In a network, a repeater is a physical-layer hardware device that is used to increase the physical medium's length, topology, or interconnectivity beyond the limits set by a single segment.The MV (medium voltage) grid receives end-user CPE data via a concentrator or injector. Injectors link with the MV power lines supplying the BPL service area and are connected to the Internet backbone through fiber or T1 lines. A carrier current system that acts as an unintentional radiator and transmits radio frequency energy to provide broadband communications on frequencies between 1.705 MHz and 80 MHz over low-voltage electric power lines owned, operated, or controlled by an electric service provider is referred to as a "in-house BPL" in the FCC's Report and Order on BPL. Aerial (overhead), buried, or hidden inside the walls, floors, or ceilings of the user premises are all possible locations for the electric power lines.

Industry-leading businesses that make up the house Plug Alliance are collaborating to define how the things in your house connect to the Internet and each other. The objective of the Alliance is to facilitate and encourage the quick development, uptake, and use of in-home powerline networks and devices that are affordable, interoperable, and based on standards. Check out www.homeplug.org. Interference problems between unlicensed equipment, such as BPL modems, and other electronic devices are governed by Part 15 of the FCC's Rules. Radio frequency (RF) emissions standards set by the FCC must be met by all electronic devices marketed in the US.The MV power lines carrying BPL signals and the homes in the service area are connected by extractors. Typically, BPL extractors are situated at each LV distribution transformer supplying a community of residences.

DISCUSSION

Carrier-Current System

Different BPL system types employ various methodologies and architectural designs. All of them are "Carrier-Current" systems, which is a name for systems that deliberately conduct signals via electrical wire or power lines.Interference problems between unlicensed equipment, such as BPL modems, and other electronic devices are governed by Part 15 of the FCC's Rules. Radio frequency (RF) emissions standards set by the FCC must be met by all electronic devices marketed in the US. The communications signal is insulated by the conduit and the earth when BPL modems are put on underground power lines, making it unlikely to interfere with other communications services. The FCC is especially worried about the possibility of interference from BPL signals sent over exposed, overhead medium voltage power lines[5]–[7].

Municipally owned utilities, or munis, utilize the money they make from selling power to run their infrastructure and provide better services to the local population. They are accountable to the public and are exempt from dividend obligations to shareholders.The board of directors of Investor Owned Utilities (IOUs) is chosen by the investors. IOUs are designed to benefit their owners while benefiting the general public.Co-Ops, also known as electric membership companies or cooperatives, are a third kind of utility that serve largely rural regions and are owned by their users. Co-ops are governed by an elected board of directors.

An Overview of BPL's Operation

A Powerline Telecom network, is made up of three essential segments: the backbone, the middle mile, and the final mile. The "last mile" market sector all the way to "the home" is where the BPL suppliers are largely focused. BPL technology transmits high-speed data into the customer's house across medium- or low-voltage power lines, from the viewpoint of the end user. The signal travels via the network's medium and low voltage lines using either transformers or couplers or bridges to bypass the transformer. The system delivers data, audio, and video to the end user's connection at broadband rates. A simple electrical wire from the "BPL modem" must be plugged into any available outlet, and the user must then connect a USB or Ethernet cable to the Ethernet card or USB interface on their PC. High speed Internet access may be offered by any Internet Service Provider (ISP) by allowing them to connect to the BPL network. The data signal may also link to other wireless, fiber, or other media for last-mile completion and backhaul. Although the actual hardware used for the deployment varies depending on the manufacturer, it usually has some common features.

In order to transport data through power lines and into homes at speeds comparable to those of DSL and cable, engineers have combined the technology concepts of radio, wireless networking, and modems. The BPL developers might collaborate with power companies and Internet service providers (ISPs) to offer broadband to everyone with access to electricity by upgrading the present power grids with specialized equipment. The Internet is a vast global network of networks linked by cables, computers, and other wired and wireless devices. For the purpose of moving data over the Internet and ultimately to another medium a phone, DSL, or cable line and into homes, big ISPs often lease fiber-optic connections from the phone company. Because fiber-optic lines are a reliable method of transmitting data without interfering with other types of transmissions, trillions of bytes of data are transferred every day over them.

Data transmission utilizing AC (alternating current) electricity is not a brand-new concept. Data may be sent without a separate data line by combining radio frequency (RF) energy and an electric current on the same line. Electric current and RF do not interact with one another since they vibrate at distinct frequencies. This technique has been used by electric corporations to track the efficiency of power networks for many years. Even networking solutions that use the electrical wiring in a house or company are now accessible. However, the data is not complicated, and the transmission speed is not fast.

The challenges posed by transferring data across electrical lines may be overcome in a variety of ways. The grids used by electric firms include many different parts, including the power wires. Power grids employ generators, substations, transformers, and other distributors in addition to wires to transport energy from the power plant to a plug in the wall. Power is distributed to high-voltage transmission lines after it leaves the power plant and passes through a transmission substation. These high-voltage wires are the first obstacle in transmitting broadband.

High-voltage lines transmit electricity at a voltage ranging from 155,000 to 765,000 volts. Data transmission is not suited for that level of power. It's much too "noisy." At certain frequencies, both electricity and the RF utilized for data transmission vibrate. Data must have a defined radio spectrum frequency at which to vibrate without external interference in order to transmit smoothly from point to point. Electricity at hundreds of thousands of volts does not vibrate with a constant frequency. The spectrum is completely covered by that level of power. It generates many forms of interference as it spikes and hums along. If it spikes at the same frequency as the RF being used to transfer data, it will cancel out that signal, resulting in the loss or destruction of the data transmission.By eliminating all high-voltage power cables, BPL gets around this issue. The data is transferred from conventional fiber-optic cables downstream to 7,200 volts of medium-voltage power lines, which are significantly easier to handle.

The data can only be dumped into the medium-voltage cables for a short distance before it starts to deteriorate. To combat this, special repeater devices are inserted on the lines. The data is ingested by the repeaters, who then amplify it for the next leg of the trip and repeat it in a new broadcast.Two more gadgets ride on electricity poles in one version of BPL to distribute Internet traffic. Couplers and the Bridge, a device that makes it easier to transport the signal into residences, enable the data on the line to bypass transformers. It is the transformer's responsibility to lower the 7,200 volts to 240 volts, which is the standard for typical domestic electrical service. A coupler is required to provide a data channel around the transformer since low-power data signals cannot travel through a transformer. Data may transfer smoothly and without any degradation from the 7,200-volt line to the 240-volt line and into the home using the coupler.

The last mile is the distance between the Internet provider to the subscriber's home or place of business.In the various last-mile approaches for BPL, some businesses send the signal into homes along with the electricity on the power line, while others install wireless links on the poles. The Bridge makes both possible.A powerline modem that connects into the wall picks up the signal. Your computer receives the signal from the modem.Silicon chipsets that are specifically designed to manage the workload of extracting data from an electric current are used in BPL modems. BPL modems are equipped with adaptive algorithms and specifically designed modulation methods to handle powerline noise over a broad spectrum.A plug-and-play BPL modem is about the size of a typical power adapter. It connects into a standard wall outlet, and the connection is completed by an Ethernet wire that runs to your computer. There are additional wireless variations available.

Modem BPL

It's possible that electric utilities won't want to get into the communications industry. In actuality, they could want to hand over that portion of BPL to a collaborator, such as an ISP, a Competitive Local Exchange Carrier (CLEC), or a long distance provider searching for a different last mile route to their clients. Most electric utilities are now concentrating on developing an intelligent electric distribution grid utilizing BPL. To monitor and manage the equipment in the power grid, power companies often utilize low-speed power line communication for internal purposes. This might lead to a more reliable, secure, and cost-effective electric power system, as well as reduced pollution and more dependability. The following delivery segments (5.1.1) or responsibilities may be filled by the broadband services enabling partners:

This part of the network links end customers, such as residences and businesses, to high-speed services and the Internet. The drop wire connecting the interface on a home to the cable company's network and the wire from the interface connecting to the wall plates in the home, for example, would all be a component of the last mile for residential broadband service customers who get cable modem service.The middle mile: This area of the network is made up of "middle-mile pipes" and high-speed fiber backbones that transport data between ISPs, content providers, online service providers, and other users as well as between networks that make up the Internet.

Internet service providers (ISPs) are businesses that take in, translate, and assist users in locating online content on the Internet.Content providers are the businesses that make information, products, and services accessible to customers over the Internet.Based on network functioning and the fact that each of these groups has unique economic features and regulatory concerns, these characteristics and distinctions are made. Since there is currently little competition in the middle-mile service market, existing providers are free to treat their customers unfairly. The capacity or desire of content producers to enter into exclusive contracts for the carrying of their material raises competitive difficulties, and they can pose problems for free expression and consumer protection.Since the wires component of the electricity network is the industry's simplest entry into the broadband industry, the last mile and the middle mile are the most pertinent.

Industry Organization - Key Facilitating Partners

Because each party can concentrate on what it does best, a partnership between a utility and an external third-party service provider has strategic value. While adept at creating infrastructure, utilities lack experience operating in a market that is competitive. ISPs work in a very competitive atmosphere, on the other hand. Effective customer marketing, low-cost client acquisition, and top-notch customer service are essential success components. With cable modem and DSL providers actively promoting their services and other alternative providers considering joining the market, the current broadband landscape is projected to become increasingly competitive. Most customers seem to see customer service as a major distinction. A collaboration with an ISP (or a nearby CLEC) might benefit from these significant advantages: The utility might concentrate on network administration while the ISP could concentrate on sales. The possibility of collaboration can also include joint investment.

The majority of industry participants believe that BPL might provide a number of important advantages when delivering broadband services to households and businesses. Many BPL proponents claim that this technology has the potential to expand broadband availability and boost the market's competitiveness. Many participants think that Access BPL could make broadband services more widely accessible, bring consumers valuable new services, boost economic activity, raise productivity at home, and expand economic opportunities for the American people. Given that BPL is so common, there should be a chance to offer fresh, cutting-edge services to almost any place with electrical outlets. BPL has a lot of potential as a fresh source of innovation and competition in the broadband sector, according to the National Telecommunications and Information Administration (NTIA). It thinks that BPL has the potential to open up new channels for Internet access, to make it possible for utility companies to provide new and extended services, and to build a new foundation for subsequent developments in communications technology. 7

Benefits of Networking and Homeland Security

Government authorities and security experts have determined that the United States needs a redundant communications network in the aftermath of the September 11 terrorist attacks. A third broadband technology would provide the country some of the necessary redundancy. Additionally, voice communications would have network redundancy as voice-over-internet protocol (VoIP) developed. The second advantage of BPL technology is its capacity to enhance the delivery of electric power service and hence promote homeland security. By enhancing the electric grid with cognitive capabilities, the BPL technology might also help the utility companies by increasing the effectiveness of processes like energy management, automated meter reading, and power outage notification. According to the United Power Line Council (UPLC), Access BPL would enable electric companies to more effectively monitor and manage the operations of the electric system, enhancing service dependability and lowering customer costs. According to the Mission Essential Voluntary Assets (MEVA) regulations, utilities are in charge of supplying state, municipal, and federal institutions with secure infrastructure electricity, including military sites. In accordance with the MEVA requirements, BPL will also improve security and allow other security applications, such as video surveillance.

Consumer Advantages

Supporters of BPL anticipate it will increase the market's level of competition for broadband services. It provides the long-needed third wire (telephone and cable being the other two) for last-mile broadband communication service delivery to homes and small enterprises. The United Power Line Council (UPLC) thinks that BPL presents an exceptional potential in the broadband industry and that utilities have a strong interest in BPL. BPL will boost competition in the regions currently covered by other broadband providers, improving performance and lowering costs for customers[8]–[10].

CONCLUSION

Overall, satellite Internet connectivity is an essential technology for providing high-speed broadband access to remote and underserved areas. This paper provides valuable insights into the technical aspects, performance, and applications of satellite Internet connectivity. The results of this study can be used to improve the design and implementation of satellite Internet connectivity systems for various applications, such as remote education, telemedicine, and e-commerce.The paper also describes the various applications of satellite Internet connectivity, including rural connectivity, disaster response, military communications, and maritime and aviation connectivity. We discuss the challenges and opportunities associated with each application and the impact of satellite Internet connectivity on economic development and social welfare.

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CHAPTER 15

GEOGRAPHICAL COVERAGE AND AVAILABILITY

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ABSTRACT:

Geographical coverage and availability are critical factors for evaluating the effectiveness and impact of communication technologies, such as wireless, wired, and satellite systems. Geographical coverage refers to the extent of the geographic area covered by the communication system, while availability refers to the percentage of time that the system is operational and accessible to users. This paper provides an overview of the importance of geographical coverage and availability and their impact on various communication technologies and applications.The concept of geographical coverage and its significance in different scenarios, including urban, suburban, and rural areas. We describe the various factors that affect the geographical coverage of communication systems, such as the transmission power, antenna height, terrain, and environmental conditions.

KEYWORDS:

Bandwidth Availability, Digital Divide, Geographical Coverage, Internet Access, Network Infrastructure.

INTRODUCTION

It is anticipated that Access BPL systems would enable the delivery of broadband services to rural and other underserved areas thanks to the electric power grid's widespread use. According to the American Public Power Association (APPA), 75% of its members, many of which lack internet connection, serve areas with less than 10,000 residents. 10 According to Current Technologies, the adoption of cable and DSL is constrained by technical and financial factors. It claims that Access BPL is unrestricted by these factors and can provide "broadband to many of those unserved by other broadband technologies" and "bring the advantages of the Internet to the people who need them most." Additionally, it is anticipated that the availability of Access BPL will enable those who do not currently have access to broadband to participate and compete more effectively in the information age. The District of Columbia's Office of the People's Counsel (OPC DC) supports efforts to promote BPL deployment because it has the potential to improve the District's telecommunications environment for users by bridging the "digital divide" that the District currently faces and by boosting the number of broadband service providers in the District. According to the Alliance for Public Technology (APT), BPL might hasten the rollout of cutting-edge services and offer new and improved apps to all Americans. APT requests that the FCC use all of its powers under Section 706 to lower obstacles and provide incentives for the industry's quick adoption of advanced services like BPL[1]–[3].

A More Connected Device

Every electric appliance in BPL is linked to the electrical distribution network, which is an intriguing feature. BPL could enable communication between chips in all electric devices. Of course, any appliance might have a Wi-Fi, Blue Tooth, or other wireless chip. BPL, however, could be a superior remedy. People who owned PCs before the Internet took off can recall the functional differences between a standalone PC and a networked PC. Every electric device could be networked over the power lines, potentially boosting convenience and productivity in both the home and workplace.

Opportunities for Business

Overview Of the Various Applications Available With BPL

High-speed, broadband communications via medium and low voltage lines are now possible because to advancements in BPL technology, creating significant commercial possibilities. With the use of BPL technology, utilities may now provide qualifying urban, suburban, and rural parts of the nation with high-speed access and new facilities-based competition for broadband services.

BPL may assist utilities by using the transmission and distribution network infrastructures to increase the value of their current assets. AMR, demand side management, outage notification, distribution transformer overload analysis, phase loss monitoring, fault characterization, and other more traditional market entry strategies are currently the focus of business development managers in utilities.

Financial Effects of Utility Application Delivery by BPL

The present operations of a utility become much more cost-effective when using BPL as a communications platform for monitoring and diagnostic equipment. By streamlining processes, it also increases profitability. The distribution network could immediately save money if BPL replaced the current copper, microwave, fixed wireless, and satellite communications technologies.

AMR, load management systems, and supervisory control and data acquisition systems ("SCADA") should be installed without the financial hurdles that have traditionally been present:

1. No rights of way or installation costs are paid to telephone utilities.
2. There is no need for dial-up lines or expensive dedicated landlines.

Installing fixed wireless networks throughout a whole network may be highly expensive. Eliminating the costs associated with utilizing cellular systems. With fewer employees, a smaller fleet of vehicles, and less overhead, data gathering and processing expenses will be decreased. Applications for power monitoring and control have the ability to be totally automated, maximizing efficiency and drastically lowering Operations and Maintenance (O&M) expenses. Data may be gathered and analyzed by the systems on their own to identify and detect issues before they arise.

a. BPL could: Transfer ownership to the utility of the communications platforms.
b. Be everywhere and make it easier to provide real-time information

c. Reduce the number of various architectures that need to be maintained and manage all systems on a single network to increase efficiency.
d. Reduce dependency on a different service or supplier:
e. The meters and the communications equipment would be owned by the utility.
f. Transmission of data is not hampered by malfunctioning cellular or telephone infrastructure.

The utility has total control over scheduling maintenance and repairs. According to UTC Research, installing a BPL system in an urban market may result in annual utility savings of over \$30 million. Enabling 100% coverage for automated meter reading (AMR), traditionally the most expensive utility application owing to the high cost of meter retrofitting, might lead to a slight reduction. The payback period for Kansas City Power and Light's substation monitoring program was under two years. Engineering and installation (E&I) expenditures as a whole were reduced by \$228,000 annually[4]–[6].

DISCUSSION

BPL Business Models

Each utility must address regulatory problems as well as choose the best BPL business model to use, which differs according on the commercial and economic goals of an electric company. Choosing a company model is still an exploratory and evolving process. Some utilities could allow a third party to install BPL equipment by opening up their lines to them. Some people could want to provide broadband directly. Depending on their desire for risk and return. The following three essential business models are among the many options accessible to electric utilities.

The Tenant Model

This business model places a strong emphasis on joining forces with an established communications firm, which would provide an electric company rapid access to operations and marketing knowledge and staff without requiring an investment in either costs or personnel. Of course, the energy company's broadband network would be the value it offered. Conscious utilities will want to join into such partnership agreements as part of a landlord strategy in order to reduce capital or operational risk. If properly positioned, the landlord business model is a highly secure structure and may be risk-free. This paradigm permits modest rewards for modest expenditures of time and effort. Regulations may be handled to let the utility to continue creating value without needing to return all profits to the ratepayer base.

The Creator Model

Building the infrastructure and providing wholesale access are part of this paradigm. This approach will be used by utilities looking to make the most of their core strengths in creating and maintaining networks.Electric firms that are hesitant to pay the marketing expenses necessary to provide retail broadband services may want to think about marketing to a more specialized market traditional broadband provider. Traditional broadband providers are those that offer communications services, including broadband, as their main or only business. Many businesses that already have personnel with experience in the promotion and sale of broadband services have struggled to succeed as a result of the high costs of constructing networks. In reality, a large number of these businesses are dependent on ILECs to provide broadband connectivity to their clients[7], [8]. BPL gives power providers the chance to offer these businesses internet services. Electric firms might provide ready-made last-mile broadband networks for competitive broadband providers who wish to stop their reliance on ILECs, which are their direct rivals for consumers, by upgrading their power networks to incorporate internet capabilities.

The Shpigler Group and UTC Research research states that "the developer will be equally involved in network construction as a service provider but will trade lower operational burdens for diminished financial returns."

The Developer Model's Motivation

Opportunities to take advantage of the utility's position in the market are not prohibited by regulations.Internal resources are available to create a BPL network that can financially compete with other participants.There are viable options on the market that could act as the BPL service provider.There is no desire or competence to manage the network and operations.There are market sectors that are appealing, allowing for specific construction chances.

The Model for Service Providers

According to this concept, the utility interacts with the client. The service provider model may be taken into consideration by aggressive utilities looking to provide retail broadband services. The service provider business model has the most risk, but it also has the greatest potential for success.Given that they already own the poles and lines that virtually every residential and commercial customer in the US uses to access electricity, electric utilities are well-positioned to offer this service.

These customers could get broadband service by simply adding equipment to their wires. BPL consumers would instantly have in-house networks without having to buy and install extra wire in their homes, which would make it more appealing than DSL or cable modem.The problem with offering retail services, however, is that there are marketing expenses that some businesses may be unable or unable to cover. It may be quite expensive to advertise in order to gain market share. When choosing to enter this retail market, an electric company would also need to hire or retrain personnel with experience in marketing broadband services. Any utility interested in adopting the service provider model must solve difficulties with the market, operations, and network construction.

a. Joint marketing is made possible by the Service Provider Model 17 Regulations, resulting in a better expected market penetration performance.
b. A BPL network may be built and maintained internally during operations.
c. The internal resources are equipped to assist network management, operations, and marketing.
d. The market is alluring and has great potential for financial gains.

Federal regulators' backing

There are still many places where it is impossible to get high-speed Internet connection. Rural regions are most affected by this. The expense of laying cable and constructing the required infrastructure to deliver DSL or cable in rural regions is too high when contrasted with the relatively small number of consumers Internet providers would acquire. However, there would be no need for new infrastructure if broadband could be provided through power lines. Broadband service may be available everywhere there is power.

The FCC thinks that BPL has the potential to bring about a number of important advantages, including 1) expanding the reach of broadband services to homes and businesses; 2) enhancing the market's competitiveness for broadband services; 3) enhancing the caliber and dependability of electric power delivery; and 4) advancing homeland security.Regulations for the supply of BPL are laid forth in the Federal Communications Commission's (FCC) regulation from October 14, 2004. With this decision, the FCC has clearly laid out the requirements and removed any room for speculation or uncertainty about the regulatory environment for BPL. This regulation demonstrates the FCC's support for BPL.

In this decision, the FCC acknowledged the legitimate worries of licensed radio services and established new technical specifications for BPL devices, including the need for BPL to stay away from certain frequency bands and frequency exclusion zones to safeguard aircraft communications.According to the FCC, the regulations would call for the equipment to reduce interference by either notching (lowering power), changing the operating frequency, or remotely shutting down. It's a feature that many BPL technologies already have. In order to safeguard certain permitted activities that are vital to life and safety, the FCC will also prevent BPL from using specific frequencies locally or nationally. The FCC will also only demand a minimal amount of disclosure of BPL activities for a publicly available database to notify licensees who suffer interference and give contact information for the BPL operator. Finally, new measurement standards that are "consistent and repeatable" will be implemented, and BPL equipment authorization will now be subject to certification rather than just manufacturer verification. The FCC claims that these regulations eliminate ambiguity and guarantee the safety of licensed services[9], [10].

The FCC is confident that the updated Part 15 regulations will safeguard already licensed operations from harmful interference while also fostering the development of BPL technology and its attendant advantages.Broadband services using fiber to the house (FTTH) have been tested in a number of utilities, many of which are municipally owned, and several have since gone into full operation. Even though BPL has advanced significantly over the past two years, some problems most notably the absence of standards for "Access BPL" remain. However, it seems that the technologies are reliable enough to offer a paid service. In many aspects, BPL's current situation is comparable to the state of cable modem service in 1997. Standards are not yet in place, there are a number of proprietary technologies that are functional, and utility staff will need to undergo a big cultural transition similar to what happened with cable.

What constituency utilities serve to some degree determines their willingness to invest in new technology and take risks. Due to the fact that they are not required to create returns for shareholders, it seems that "Munis" have historically been more willing to adopt new technologies. Technical Access Injectors (sometimes called concentrators), repeaters, and extractors make up BPL equipment. BPL injectors interact with the Medium Voltage (MV) power lines supplying the BPL service region and are connected to the Internet backbone through fiber or T1 lines. A residential area receives electricity from an electrical substation through MV lines, which generally carry 1,000 to 40,000 volts.

For residential usage, low voltage distribution transformers reduce the line voltage to 220/110 volts.Utility poles that are normally 10 meters above the ground may carry MV power lines above. An MV distribution circuit that originates from a substation typically makes up three-phase wiring, and these wires may be physically positioned on a utility pole in a variety of ways (such as horizontally, vertically, or triangularly). From one pole to the next, this physical orientation could shift. The three phase lines may split into one or more phase lines to service different clients. A grounded neutral wire often runs between distribution transformers that provide Low Voltage (LV) electric power for consumer usage, below the phase conductors. It is possible to theoretically inject BPL signals into MV power lines between two-phase conductors, between a phase conductor and the neutral conductor, or onto a single phase or neutral conductor.

The MV power lines carrying BPL signals and the homes in the service area are connected by extractors. In most cases, BPL extractors are situated at each LV distribution transformer that supplies a community of houses. Some extractors strengthen the BPL signal enough to enable transmission via LV transformers, while others use couplers on nearby MV and LV power lines to relay the BPL signal around the transformers. Other types of extractors connect the BPL network to the customers' premises using non-BPL devices (like WiFi and WiMax). In order to maintain the needed BPL signal strength and fidelity over long runs of MV power lines, BPL service providers may use repeaters. Signal attenuation or distortion across the power line may cause this. The fundamental BPL system and may be installed in a cell-like configuration across a wide region fed by existing MV power lines.

Systems and architectures from vendors

BPL industry advancements made by BPL providers have brought it very close to becoming commercially accessible. Several North American trials have either disproved or eliminated some technical approaches while proving others. Electric utilities and their partners have a variety of architectural options to choose from, giving them flexibility in BPL business model selection and deployment strategies based on market type. Three alternative network designs utilized by BPL equipment makers are briefly described in this section.

Construction #1

By employing several narrow-band sub-carriers, Architecture #1 uses Orthogonal Frequency Division Multiplexing (OFDM) to disperse the BPL signal across a broad bandwidth. Data from the Internet backbone is transformed into the OFDM signal format at the BPL injector before being coupled into one phase of the MV power line. BPL signals on the MV power lines are also converted by an injector to the format required for the Internet backbone link. Bypassing the LV distribution transformers, two-way data are sent to and from the LV lines, each of which supplies a group of houses. The extractor transforms between access and internal BPL signal formats and routes data. The subscribers utilize internal BPL devices to access this BPL signal. Repeaters may be used to cover great distances between a BPL injector and the extractors it serves.

In this architecture, the frequency band (F1) that the injectors and extractors share on the MV power lines is different from the frequency band (F2) that the subscriber's internal BPL devices use on the LV lines. Carrier Sense Multiple Access (CSMA) with Collision Avoidance (CA) extensions is used to reduce channel congestion. Since all equipment on MV lines uses the same frequency band, this type of system is made to tolerate some co-channel interference between essentially independent BPL cells without the use of isolation filters on the power lines. The BPL signal could be resistant enough to co-channel BPL interference to allow the independent installation of two or three of these systems on nearby MV power lines. One phase line is used to pair BPL signals in this design.

Construction #2

Although this architecture also uses OFDM as its modulation method, Architecture #1 differs from it in how it transmits the BPL signal to subscribers' homes. This design pulls the BPL signal from the MV power line and transforms it into an IEEE 802.11b WiFi signal for a wireless interface to subscribers' home computers as well as nearby portable computers (see 7.1.1.2) rather than utilizing a device that utilizes LV power lines. Other technologies than WiFi might alsoutilized to connect subscribers' devices to the BPL network; it's crucial to note that in this system, LV power lines are not used for BPL.

Architecture # 2

The upstream and downstream BPL signals are separated using various radio frequency bands in this design, which also reduces co-channel interference from other adjacent access BPL devices. Repeaters may be used to cover great distances between a BPL injector and the extractors it serves. BPL repeaters utilize different frequencies than injectors and other adjacent repeaters, and they broadcast and receive on distinct frequencies from the injectors as well. When equipped with a WiFi transceiver, repeaters in this design may also provide the functionality of an extractor. This architecture/system links BPL signals to a single MV power line phase.

Construction #3

Direct Sequence Spread Spectrum (DSSS) is used in Architecture #3 to transport the BPL data over the MV power lines. A BPL cell's users all use the same frequency band. Carrier Sense Multiple Access (CSMA) is used to reduce channel congestion. Since all devices use the same frequency bands, Architecture #1 and Architecture #2 are both built to tolerate some co-channel interference between cells. The BPL service provider separately constructs two phases of the same run of three phase power lines during one experimental deployment of this architecture.

Each cell in this architecture is made up of a concentrator (injector) that acts as a bridge between the user's computer and the electrical wiring carrying the BPL signal, a number of repeaters (extractors) to compensate for signal losses in the electric power line and through the distribution transformers feeding clusters of homes, and customer premises BPL equipment. The BPL terminals and repeaters of the customers may connect with the concentrator that provides the optimal communication channel at any moment since adjacent cells often overlap. A pair of couplers on a phase and neutral line are used in this design to couple the BPL signal to the power line[11], [12].

CONCLUSION

Overall, geographical coverage and availability are critical factors for evaluating the effectiveness and impact of communication technologies. This paper provides valuable insights into the importance of geographical coverage and availability and their impact on various communication technologies and applications. The results of this study can be used to improve the design and implementation of communication systems for various applications, such as smart cities, disaster response, and Internet of Things (IoT) applications.The impact of geographical coverage and availability on various communication technologies, such as wireless cellular networks, satellite systems, and fiber-optic networks. We discuss the challenges and opportunities associated with each technology and the role of geographical coverage and availability in determining their effectiveness and impact.

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CHAPTER 16

POTENTIAL ARCHITECTURES AND THEIR FINANCIAL ATTRACTIVENESS

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ABSTRACT:

Potential architectures and their financial attractiveness are critical factors for evaluating the feasibility and sustainability of communication infrastructure projects, such as fiber-optic networks, satellite systems, and wireless networks. This paper provides an overview of potential architectures and their financial attractiveness and their impact on various communication infrastructure projects.The concept of potential architectures and their significance in different scenarios, including urban, suburban, and rural areas. We describe the various potential architectures for communication infrastructure projects, such as centralized, distributed, and hybrid architectures.

KEYWORDS:

Hybrid, Fiber,Internet Service Providers,Operational Expenditures, Optical, Network, Wireless Networks.

INTRODUCTION

BPL providers anticipate a wider range of applications that may be offered to their subscribers. High quality, multi-channel video, audio, voice over Internet Protocol (VoIP), and on-line gaming applications are expected to rapidly increase the demand for additional bandwidth. To support the typical subscriber at 1 Mbps, BPL systems are expected to operate at speeds of 100 Mbps or more on the MV power lines in the near future. A number of comments filed in response to the NOI indicate that the BPL industry is already preparing for this growth[1].

A number of BPL vendors have suggested use of frequencies up to 50 MHz. At least one vendor is considering use of 4 MHz to 130 MHz, while excluding frequencies that are actively in use by certain licensed services. One solution put forward in an attempt to mitigate interference with licensed services is to attenuate or “notch” BPL signals in frequency bands where licensed services are in nearby use. Future BPL systems may be able to accomplish this automatically without system operator intervention. To implement this solution while simultaneouslymaximizing the useable bandwidth, BPL systems are expected to use new modulations that can support more sub-carriers that are more finely spaced.

As data rates and bandwidths requirements grow, the BPL systems may require operation at greater transmitted power levels but not necessarily with higher power density than is used today. BPL vendors may employ techniques to dynamically adjust the power level to maintain a minimum signal-to-noise ratio (SNR) over the entire BPL spectrum, while limiting emissions to levels compliant with Part 15. One vendor has proposed such a solution for adjusting transmitted power to maintain a constant SNR across the BPL spectrum, with a hard limit based on Part 15 rules. The challenge will be to develop the control mechanism that can maximize transmitted power while simultaneously limiting the radiated emissions, perhaps in conjunction with frequency agility.

Nortel has developed and patented a filter that blocks BPL signals while concurrently passin g medium-voltage AC power. The judicious use of such blocking filters will enable optimal segmentation of BPL networks into cells of various sizes having low conducted co-channel interference from neighboring cells. This will enable a greater level of frequency reuse than what is currently available.Another BPL technology utilizes the 2.4 GHz and 5.8 GHz unlicensed bands. An implementation using multiple IEEE 802.11b/g WiFi chips sets has been used to demonstrate the concept of carrying data over medium-voltage power lines at rates exceeding 200 Mbps.

Consistent with the three Architecture types, the following are three distinct BPL systems.Each BPL system offers a separate set of characteristics that distinguish it from the others. These three systems are further tested in different market types to assess their financial feasibility.

a. At a high-level it can be concluded that in general:
b. Hybrid wireless-BPL systems can be very attractive in dense metro environments.
c. As the market gets smaller, classic systems will often dominate.
d. Deploying a cellular system can often minimize the capital cost for entry in a rural market.

Regulatory - Issues and Challenges

The FCC has implemented new rules after obtaining comments from proponents of the new BPL service, i.e., electric utilities and BPL vendors, as well as those who might be impacted by the BPL signals. On most electric utility poles below the four electric utility lines there is a lower segment of the pole where telephone and cable television wires are attached (referred to as the communications space). One of the questions the FCC has addressed is whether radiated signals from access BPL systems on the electric power lines would interfere with signals on the cable and telephone lines, and vice versa.

Regulations in the BPL arena can broadly be grouped into three categories of issues as shown:

Even though the Telecommunications Act of 1996 mandated that broadband service be widely available in the United States, the actual market for that service today is a duopoly—with customers in most jurisdictions connecting to the internet through either their incumbent local exchange carrier (ILEC), which provides broadband service through digital subscriber lines (DSL), or their local cable operator, which provides the service through cable modem. Duopoly does not necessarily provide consumers the opportunity to get the best combination of rates and services, and many now are looking to electric companies as a third competitive provider of broadband.

BPL technology provides the opportunity to have true competition for broadband service. Given the applications and services it can offer, it is incumbent upon regulators to adopt a uniform set of rules and regulations that will facilitate the provision of BPL service in the United States while ensuring that public interest concerns are protected. In order to provide broadband access to all Americans, the FCC and the states are defining and adopting a regulatory scheme that removes unnecessary barriers to market entry and permits electric companies to be competitive in the marketplace[2], [3].

DISCUSSION

Interference and Radio Static

Powerline system is a type of carrier current system that electric utility companies have traditionally used for protective relaying and telemetry. They operate between 10 kilohertz (KHZ) and 490 KHZ, although today many utilities rely on the 1–30-megahertz (MHZ) bandwidth for BPL transmission. A carrier current system transmits radio frequency energy to a receiver by conduction over the electric power line[4], [5]. Under Part 15 of the FCC's current rules, which regulate carrier current systems and powerline carrier systems, each is subject to different emission limits. The FCC also limits the amount of conducted radio frequency (RF) energy that may be injected into a building's wiring by an RF device that receives power from the commercial power source, including carrier current systems that couple RF energy onto the AC wiring for communications purposes.

This conducted energy can cause interference to radio communications by two possible paths. First, the RF energy may be carried through electrical wiring to other devices also connected to the electrical wiring. Second, at frequencies below 30 MHZ, where wavelengths exceed 10 meters, long stretches of electrical wiring can act as an antenna, permitting the RF energy to be radiated over the airwaves. Due to low propagation loss at these frequencies, such radiated energy can cause interference to other services at considerable distances.A BPL modem is considered an unlicensed device, like a cordless phone or garage door opener. All unlicensed devices are governed by the FCC's Part 15 rules. Part 15 mandates that all electronic devices sold in the United States must meet FCC radio-frequency emissions limits. These limits are in place to secure against interference with important transmissions like CB communications, air-traffic control and government channels. ARRL and FEMA are concerned about the interference caused by BPL signals transmitted on exposed medium-voltage power lines.Cable TV operators get around the interference problem by shielding all of their cables. "Coaxial cable" used by cable TV operators has a braided metal shield that surrounds the signal wire.

Telephone cables are also shielded. Power lines, on the other hand, have no shielding. In many cases, a power line is a bare wire, or a wire coated in plastic. The lack of shielding is where the interference concern comes from.While FEMA is willing to allow the FCC to seek a compromise, the ARRL claims that compromise is not possible because the bandwidth needed for BPL will directly interfere with ham radio and short-wave radio transmissions. Developers of BPL say that these interference issues have been solved. Meanwhile, advancement of BPL moves forward slowly as it waits for standards and logistics to be decided by regulating bodies[6].

Currently, the frequency band breaks down as follows:

Frequency Spectrum Allocation

AM radio - 535 kilohertz to 1.7 megahertz

Short-wave radio - 5.9 megahertz to 26.1 megahertz - The "short waves" - the only part of the radio spectrum that supports long-distance, intercontinental radio communication. The short waves are used for international broadcasting, aeronautical, maritime, disaster relief, and other services including the military

In nutshell:

a. Limits are stricter for Class B settings (residential) than for Class A (commercial, industrial, business environment)
b. Emissions above 30 MHz are under stricter control than those below 30 MHz
c. Internal use of BPL for activities like AMR and load balancing are likely to involve the low end of the 1-30 MHz range, thus reducing stress on Federal emissions limits
d. The FCC Notice of Proposed Rulemaking seeks to promote BPL deployment while preventing harmful interference to authorized radio operators
e. FCC is taking a cautious approach that would permit deployment under existing emission limits, but which proposes additional safeguards to mitigate interference that might occur from BPL operations

Universal Service and Pole Attachments

Currently, all interstate telecommunications, wireless phone, and paging service providers must contribute 6.8 percent of their long distance and international calling revenue to a universal service fund. The fund is designed to provide rural, low income, and other consumers access to advanced and inter-exchange telecommunications services at reasonably comparable rates charged for similar services in urban areas. The obligation to contribute to the universal fund, if applied to BPL providers, would add to the costs of providing such service.BPL presents unique issues for pole attachment regulation, including access, rates, modifications, and surveys, all of which can impact BPL operational expenses.18 FCC has jurisdiction over investor-owned utilities, unless states reverse preemption Some states that are exempt include AK, CA, CT, DE, DC, ID, IL, KY, LA, ME, MA, MI, NJ, NY, OH, OR, UT, VT, WA.19

Pole attachments have been an issue since before BPL technology arrived on the scene. Pursuant to the adoption of the Telecom Act, an electric utility had to provide access to its poles if the utility used its poles for any type of communications, including its own to any company requesting access. Under the FCC's rules, where access is mandated, the rates, terms, and conditions of access must be uniformly applied to all telecommunications carriers and cable operators that have or seek access. Utilities may deny access for reasons related to insufficient capacity, safety, reliability and other engineering purposes

Many electric companies have avoided the administrative costs of implementing a system for managing the access and use of its poles by avoiding any kind of communications assets on its poles. They would not be able to avoid it any longer, however, if they wanted to provide BPL service. Hence, these administrative costs would have to be factored into the costs of providing broadband services, unless the FCC could be convinced to create a BPL exemption as an incentive for electric companies to develop and deploy BPL networks.

Issues outstanding as they relate to BPL are:

1. Does BPL equipment represent a pole attachment?
2. Open access, safety, capacity, interoperability issues
3. Occupied space and imputation issues
4. Cost sharing and notice issues

5. Cost sharing and competitive issues
6. Local zoning restrictions, franchise fees, and right of way

Private easements – state jurisdiction

Pole attachment obligations also need to be addressed in light of interference concerns. The FCC acknowledged that this is a potential problem: “The close proximity of BPL equipment on utility poles may affect (and be affected by) the operation of cable television service and high-speed digital transmission service, such as DSL.”

Open Access

Interestingly, the regulatory paradigm for ILEC and the local cable provider has differed despite the fact that the FCC has jurisdiction over both modes of providing service.Telephone companies that provide DSL service are regulated under Title II of the Communications Act of 1934, which includes common carrier provisions and obligations that are not shared by cable operators. These provisions, adopted based on the ILECs’ historical possession of monopoly power over their respective service areas, require them to provide network access to competitors on nondiscriminatory, cost-based terms (also known as open access). Federal and state regulators currently face the challenge of determining how much market share an ILEC must lose before those obligations are eliminated. Many ILECs believe the requirements are no longer necessary given the number of competitors that have taken away their potential customers.

Cable modem broadband service, in contrast, is not subject to open access obligations because the FCC deemed cable to be an information service only. This classification has been challenged incourt and, if overturned, could open cable companies to the same requirements now imposed on ILECs. Many believe that cable’s exemption from open access obligations has been unjust because of the lack of competition in the provision of cable services - after all, many U.S. cities and towns have only one cable company - and because it has given cable companies an unfair competitive edge over ILECs.

Local/State Issues

The Telecom Act directs state utility commissions to share in the responsibility of making broadband service available to all Americans. At the same time, state laws give regulators sole jurisdiction over electric companies providing service in their state. The most basic question is whether state commissions will permit their electric companies to use their current power networks to provide broadband service. State utility commissions also will be able to decide the cost structure for how electric companies will recover any investment for a BPL network upgrade and how to treat the earnings from BPL. Will state commissions require electric companies to offset their electricity earnings with their BPL earnings so as to stay within a defined rate of return? If so, is this a sufficient financial incentive for electric companies to invest in BPL network upgrades?

Yet another issue pertains to those states that have restructured their electricity markets. Under rate-of-return regulation, electricity rates for residential customers are subsidized by the rates paid by business customers. Under a restructured market, that subsidy disappears. This presents a difficult challenge for restructured states: Low and fixed-income customers struggle to pay market-based rates. Will state commissions be tempted to ask utilities to subsidize electricity rates with BPL service earnings?

Further, investor-owned utilities and municipal utilities may face unique regulatory issues before they can offer broadband services.Section 103 of the Telecommunications Act established a simple self-certification process for investor owned utilities, that are registered holding companies under the Public Utility Holding Company Act (PUHCA) to become “Exempt Telecommunications Companies” (ETC). The process involves filing an application which requires a brief description of the ETC and a sworn statement that the ETC will be engaged exclusively in the business of providing telecommunications services, information services, other services subject to FCC jurisdiction, or products or services that are related or incidental to any of these services. This is effective upon filing and deemed granted if the FCC does not act within 60 days. As far as Municipal Utilities are concerned, twelve states have restrictions on telecom offerings by municipal entities (AR, FL, MO, MN, NE, NV, SC, TN, TX, UT, VA, and WA). Furthermore, the Supreme Court held that Section 253 of the Communications Act does not protect public entities from state laws that prohibit or have the effect of prohibiting them from offering telecommunications services. This affects BPL to the extent that state laws broadly restrict the type of communications equipment and services that municipal entities may offer. Utilities that leverage BPL as a purely internal vehicle to optimize delivery of existing utility applications may have the easiest regulatory experience. Even without a “telecom business”,utilities may seek to apply BPL technology to support operations, including such activities as automatic meter reading (AMR) and energy management systems like load balancing.

Cross-subsidies

Cross-subsidization is a particularly significant concern when a company provides one service in a competitive market, but is a monopoly provider of another service, as is the case with many electric companies. As for BPL technology, the concern is whether electric companies will use earnings or resources from the provision of electric service to subsidize their BPL businesses.

Regulators will focus on this issue for two reasons first, such subsidies could provide electric companies with an unfair advantage in the broadband market and, second, needed resources that are diverted away from the provision of electric service could hurt quality of service. The latter one is acutely important in light of the recent challenges with the restoration of electric service in many states.Both federal and state regulators have struggled with this issue in various contexts. The FCC has, at times, required companies to establish separate subsidiaries. An approach to this issue is the adoption of accounting rules that would permit federal and state regulators to guard against cross- subsidization without requiring companies to incur the cost of creating separate subsidiaries. State commissions are routinely charged to mandate fair dealing regarding the operations of a regulated electric utility and its affiliates. Rules are put in place to ensure fairness to the competitive marketplace while enabling ratepayers to be compensated for use of ratepayer-based assets.

The Broadband Market

Three trends are likely to shape the future of broadband. First, broadband adoption will continue. Second, broadband connections will become “faster,” and will be able to carry greater volume of data during a given interval. Third, a wide array of technologie s will be able to deliver broadband to consumers and businesses.

The continuing deployment of broadband and the development of more market driven services that rely upon broadband will thus have a synergistic impact. The deployment will likely spur the development of more market driven services that, in turn, will spur further deployment.A report from Strategy Analytics predicts that an additional 8.5 million homes will add broadband in 2004, totaling approximately 33.5 million users by the end of 2004, compared to 25 million users in April 2004. Of course, the rate of growth of broadband will slow as it becomes more widespread. However, the growth of market driven services using broadband will continue for a much longer period of time.

Providers of broadband access consistently assert that they will continue to increase the speed of the connections they offer their customers. They expect that within the next several years, users can expect connections providing symmetrical service at 10 to 20 Mbps. Within five to ten years, these connection speeds should increase to 100 Mbps. It is possible that some premium services may provide consumers with 1 Gbps access within next ten years.One of the most encouraging aspects of the growing market for broadband appears to be the diverse range of technologies and facilities-based platforms capable of providing broadband access. This presents two critical advantages.

First, potentially competing access technologies can promote both price and quality-of-service competition among broadband-access providers. This competition may be critical to overall adoption of broadband: as consumers discover new uses for broadband access, competition can ensure that service providers have incentives to shape their offerings to reflect fast evolving consumer preferences as well as competitive pricing.Second, access technologies may also have complementary roles that, taken together, may hasten the overall speed at which broadband access becomes universally available. For example, wireless broadband networks may provide coverage for mobile and portable devices and “fill in the gaps” where wireline broadband coverage is unavailable. Additionally, wireless broadband services, along with satellite services, may bring high-speed broadband to remote areas where wireline broadband services are currently infeasible or uneconomical. Additional access technologies, such as BPL, may play important roles in the not too distant future.new technology releases have typically generated high rate of acceptance and therefore impressive growth over short time periods. Broadband is exhibiting a similar growth pattern. BPL, if introduced in reasonable time, would share in the overall rise in broadband access services.

Competitive Position of BPL

Several market factors support the potential for an additional broadband provider. A few of these factors are highlighted here.Growth Phase: Broadband penetration is in its growth phase of lifecycle. Nationwide, broadband penetration within the residential sector stood at 23% at the end of 2003, approximately one-third of what is expected in ten years’ time.Enterprise Segment: A very significant growth is expected in enterprise usage of broadbandservices. The percentage of business enterprises with active broadband accounts is expected to more than double over the next ten years

In-home Networking: While a majority of the customers may be dial-up upgrades, non- Internet users, and new move-ins to the service territory, BPL providers may be able to leverage reliable and immediate in-home networking offer to shift significant subscribers from DSL and Cable to BPL. The BPL is well positioned to enter the market with data-led product (Internet access), followed with Voice-over-IP and other “smart home” services.Just as other players in the broadband market, utilities will need to be strategy savvy. Each utility will need to design a composite competitive strategy customized to its territory and market. While pricing will be one of the key components, other components of strategy such as product packages, Quality of Service, Incentive Programs, availability (Uptime) will be as important for retaining the customers. None of the players may want to stimulate customer churn seen in telecom industry, as no provider will profit from it.

As a fiscally prudent practice, utilities may elect to build least risky markets first. These markets will be based on a mix of potential penetration, density, cost, and other key factors.Broadband providers seek opportunities to build in areas with low cost and high customer acceptance. For utilities, keeping costs low will be based on two factors

Customer Density

Location of Utility Assets

While customer density is the same for all providers, the location of usable utility assets, by the host utility, may differentiate one market from another for BPL providers.Area demographics and the level of competitive intensity will be the drivers of customer penetration. While the deployment costs can be kept lower by building in urban and suburban areas where network density is high, often, higher market penetration rates can be achieved in underserved rural areas.

Industry research suggests price to be the greatest change agent in the Broadband industry. The research indicates a greater likelihood to purchase high-speed Internet access at lower prices, supporting industry conclusions that price elasticity among prospective customers may spur industry with lower prices for service. Overall, price factors are viewed as more important than speed for Internet connectivity. Price is an even more important factor for dial-up customers, suggesting that a marketing effort might have to stress value to entice Internet users to “graduate” to broadband. Industry research suggests that low speed (dial-up) users are the most likely to switch service providers.

Cable as a Competitor

As mentioned earlier, cable is a shared medium and all subscribers from the Head-End share the available bandwidth. Additionally, old cable networks have been upgraded to HFC (Hybrid Fiber Co-axial networks) and therefore many products and services can be bundled through cable such as video, data and voice. This could result in a discount of approximately 10 % to 15%.As the dominant providers of broadband access, cable companies are seeking ways to solidify their position rather than pushing prices down. One trend is the continued emergence of tiered service levels as a way of enticing lower potential customers while retaining margins on higher value customers. Among the offerings by cable companies are VoIP and digital cable.

Cable has extended the broadband services offering to at least 90 percent of homes passed by cable systems. The cable industry expects that industry-wide facilities upgrades enabling the provision of broadband Internet access to residential customers will be completed soon.In addition to expanding the reach of upgraded broadband facilities, cable operators have increased download transmission speeds from 200 kbps to as much as 6 Mbps. Cable companies have also continued to upgrade equipment used to deliver broadband services. The CableLabs Certified Cable Modem Project, also known as Data Over Cable Service Interface Specification or DOCSIS, has continued to develop the critical interface requirements for cable modems and cable modem termination systems used for high-speed data distribution and connection to the Internet. PacketCable, another CableLabs project, develops specifications for delivering advanced, real-time multimedia services over two-way cable plant. The PacketCable specifications enable a wide range of services, including IP telephony, multimedia conferencing, interactive gaming, and general multi-media applications.The cable industry also is reported to be pursuing "next Generation Network Architecture" (NGNA), which is in part a competitive response to wireline broadband providers and in part aresponse to Direct Broadcast satellite's (DBS) Digital Video Recorder (DVR) technology. The NGNA project seeks to define the features of a next-generation all-digital cable network, which could have broad implications for functionality and cost. The effort involves rethinking cable's basic technologies, including everything from encryption strategies to set-top boxes that can be dramatically upgraded via software uploads, to create more carriage capacity by completely migrating cable service from analog-to-digital transmission so that all services could be provided utilizing IP.

A number of cost factors effectively form the pricing floor for cable companies. These factors include:

1. Programming and labor costs have been rising steadily, and in excess of inflation rates
2. Cable companies have collectively invested over $75 billion, or over $1,000 per customer in network upgrades. Of this amount, $200 per customer has been spent in 2002 alone
3. Cable companies view satellite providers and not DSL providers as key competitors for pricing.

DSL as a Competitor

DSL technology can be provisioned on most of the existing phone networks and comes in many different flavors. As mentioned earlier in the report, ADSL is the most common DSL-type currently deployed by service providers. DSL deployments have lagged behind that of cable modem. Once projected to exceed the penetration of cable modem, DSL's market penetration today is barely one-half of its broadband counterpart. Financial failure of the entire DLEC community and the lack of strong push on the part of the ILECs have resulted in lower-than-expected DSL penetration in the market. However, today we see significantly higher growth rates than in the past, as market consolidation has returned the market to the ILECs. Key Issues are:

1. DSL is primarily a low-margin product; providers view DSL as a mechanism to sell Value Added Service ("VAS").
2. ILECs effectively controlled the provisioning process and prevented data local exchange carriers (DLECs) from being able to effectively serve customers.
3. ILECs have been relatively slow to aggressively deploy DSL for fear of cannibalizing their T1 business [7], [8].

CONCLUSION

Overall, potential architectures and their financial attractiveness are critical factors for evaluating the feasibility and sustainability of communication infrastructure projects. This paper provides valuable insights into the importance of potential architectures and their financial attractiveness and their impact on various communication infrastructure projects. The results of this study can be used to improve the design and implementation of communication infrastructure projects for various applications, such as smart cities, e-commerce, and telemedicine.The impact of potential architectures on various communication infrastructure projects, such as fiber-optic networks, satellite systems, and wireless networks. We discuss the challenges and opportunities associated with each architecture and the role of financial attractiveness in determining their feasibility and sustainability.

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CHAPTER 17

A BRIEF DISCUSSION ON TECHNICAL DESCRIPTION OF BPL SYSTEMS

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ABSTRACT:

Broadband Power Line (BPL) systems are an innovative communication technology that uses existing power line infrastructure for delivering high-speed Internet access and other communication services. This paper provides a technical description of BPL systems, including the architecture, modulation and coding schemes, and signal processing techniques used for transmitting data over power lines.The architecture of BPL systems, including the components, such as the BPL modem, BPL access point, and BPL network management system. We describe the various BPL system topologies, such as point-to-point, point-to-multipoint, and mesh networks, and their advantages and limitations.

KEYWORDS:

Access Networks, Broadband Over Power Lines (Bpl), Carrier Frequencies, Coupling Transformers, Data Communication, Data Rates.

INTRODUCTION

Within the next four years, hot spot coverage is anticipated to increase to nearly 60,000 points across the United States. The sector will have potential to profit from economies of scale as a result of this sustained expansion, since already low equipment prices will continue to decline. While the Wi-Fi application is developing, a number of issues are also being addressed: Comparing simplicity and convenience vs. network safety Radio waves often cross the predetermined physical bounds of signal propagation. Users' failure to adopt the Wireless Encryption Protocol (WEP) has often resulted in network security breaches. The adoption of 128-bit encryption in the 802.11i standard, which may be used in addition to 802.11b or 802.11g, may offer greater security[1].Short range limits market reach, which is a concern for developers who want to expand their businesses beyond a single hot spot. New technologies, however, are anticipated to expand reach and provide more opportunities to create a broadcast access market play.

An effective long-term expansion plan requires the establishment of a format to create IP roaming, which has not yet been done. Roaming agreements are not always required for a pure hot spot market approach, but they are necessary for a growth plan.Issues with interference - The Industrial, Scientific, and Medical ("ISM") spectrum band may experience interference from high deployment levels. Numerous industry experts anticipate that WiMax (802.16) will have a significant market. Before the potential may be fulfilled, there are various obstacles that must be overcome.CPE is quite costly. According to industry predictions, the price of CPE will reach $500 by the third quarter of 2005 and will drop to $200 by 2007. As a consequence, 1 Mbps service now costs roughly $500 per month on the open market.Slow product rollout to market - Early 2004 was the target date for 802.16 commercial readiness, while early 2005 was the target date for 802.20 with mobility. These time predictions may now be off by a year or more.

DISCUSSION

Overview of North American BPL trials

Many North American electric utility companies have run BPL trials and several are now moving toward deployment. In the absence of BPL standards, utilities are deploying several different technologies, with different ways of carrying data over the electrical grid and different ways of delivering data to the home. The municipal electric utility of Manassas, VA already offers the service to all its customers. PPL has a 60-customer pilot project in Allentown, PA, that is successful, and the utility is looking at ways to make it available to all customers[2]–[4].

Another utility, Progress Energy has taken a two-pronged approach to testing the viability of BPL. The technological phase was successfully completed in mid-2003, and the company is currently undergoing a BPL market test for approximately 500 homes. Ameren is pursuing a pilot that makes them the provider of not only the technology but also customer service. Other utilities conducting pilots include Cinergy, Southern Company, PEPCO, Idaho Power, and Consolidated Edison. Of these, five BPL deployments could be categorized as being “commercial” in that they are charging for the service.

Iberdrola SA, for example, offers BPL service to customers in two Madrid suburbs. Last-mile broadband service (essentially from the distribution pole to the other side of the outlet) is also being used in Finland, Iceland, and Russia. The European Union is seeking to develop a common regulatory framework for the development and deployment of BPL technology throughout its member nations, according to Business Europe.

Higher density of homes per transformer in overseas countries makes their power grids more efficient for BPL deployment. In the U.S. there are 5-6 houses per transformer, requiring more hardware to provision large communities. In Europe and Asia there are 200-300 houses per transformer, requiring much less hardware to service large communities. Europe has had commercial deployments for over two years. The prevailing trend in Europe is for utilitie s to deploy BPL as a “developer” with open access. The big differences are that utilities abroad tend to be less sensitive to capital investments in the telecom market and lower broadband penetration rates to date in Europe present a greater upside.

National Telecommunications & Information Administration (NTIA)

While NTIA recognizes the potential benefits of Access BPL, it also states that FCC must ensure that other communications services, especially Federal Government operations, are adequately protected from unacceptable interference. It states that the Federal Government has extensive operations that potentially could be affected by BPL systems. It notes that there are over 18,000 Federal Government frequency assignments in the 1.7 – 80 MHz spectrum range. NTIA also indicates that it has initiated modeling, analysis and measurement efforts in order to develop means for accommodating BPL technologies while precluding unacceptable interference to Federal Government systems.

Federal Emergency Management Agency (FEMA)

FEMA is supportive of extensively deployed broadband facilities and of a more robust electrical utility infrastructure and states that it appreciates that BPL could be a major factor in achieving these objectives. FEMA indicates, however, that it has become aware that certain distinct approaches to BPL may have the potential to cause interference to its high frequency radio emergency communications system although it has not concluded at this time that there is a material interference problem or that all of the distinct technological approaches to BPL pose a risk of interference. FEMA states that it expects that there may be ways to provide the public with the benefits of BPL without compromising emergency communications.

American Radio Relay League (ARRL)

ARRL expresses concern that Access BPL, if not appropriately restricted, will cause interference to amateur operations. ARRL states that amateurs use very sensitive receivers and high gain outdoor antennas that could be located in close proximity to electric power lines.ARRL contends that entire communities will be affected by radiated BPL emissions. ARRL contends that in an Access BPL system, the power lines would act as an efficient antenna covering an entire city, causing widespread interference to amateur operations. ARRL believes that the potential interference from Access BPL would be so severe as to warrant its exclusion from all bands allocated for amateur use.

Institute of Electrical and Electronics Engineers (IEEE)

In seeking to help realize BPL its potential, the IEEE has begun to develop IEEE P1675™, "Standard for Broadband over Power Line Hardware." The IEEE Power Engineering Society, Power System Communications Committee, has sponsored IEEE 1675. When finished, IEEE P1675 will give electric utilities a comprehensive standard for installing the required hardware on distribution lines, both underground and overhead, which provide the infrastructure for broadband-over-power-line (BPL) systems. It also will include installation requirements for the protection of those who work on BPL equipment and to ensure such systems do not place the public at risk. The standard is targeted for completion in mid-2006[5], [6]. "By turning the local power grid into a broadband conduit, we create another option for universal access to the Internet," says Terrence Burns, Chair of the IEEE BPL Standards Working Group. "This technology offers a neat solution to the 'last-mile' quandary of how to bring information from long-distance fiber optic cables to individual computers without investing in costly infrastructure.

American Public Power Association (APPA)

APPA supports the FCC's general approach to promoting BPL technology and strongly urges the agency to adopt flexible rules that accommodate the various types of BPL technologies being developed. The APPA stated that the FCC should adopt rules that make widespread deployment of BPL a reality.Access BPL equipment consists of injectors, repeaters, and extractors. BPL injectors are tied to the Internet backbone via fiber or T1 lines and interface to the Medium Voltage power lines feeding the BPL service area.6 MV power lines may be overhead on utility poles or underground in buried conduit. Overhead wiring is attached to utility poles that are typically 10 meters above the ground. Three phase wiring generally comprises an MV distribution circuit running from a substation, and these wires may be physically oriented on the utility pole in a number of configurations. This physical orientation may change from one pole to the next. One or more phase lines may branch out from the three phase lines to serve a number of customers. A grounded neutral conductor is generally located the phase conductors and runs between distribution transformers that provide Low Voltage electric power for customer use. In theory, BPL signals may be injected onto MV power lines between two phase conductors, between a phase conductor and the neutral conductor, or onto a single phase or neutral conductor.

Extractors provide the interface between the MV power lines carrying BPL signals and the households within the service area. BPL extractors are usually located at each LV distribution transformer feeding a group of homes. Some extractors boost BPL signal strength sufficiently to allow transmission through LV transformers and others relay the BPL signal around the transformers via couplers on the proximate MV and LV power lines. Other kinds of extractor's interface with non-BPL devices that extend the BPL network to the customers' premises.

For long runs of MV power lines, signal attenuation or distortion through the power line may lead BPL service providers to employ repeaters to maintain the required BPL signal strength and fidelity. 2-1 the basic BPL system, which can be deployed in cell-like fashion over a large area served by existing MV power lines.6 MV lines, typically carrying 1,000 to 40,000 volts, bring power from an electrical substation to a residential neighborhood. Low Voltage distribution transformers step down the line voltage to 220/110 volts for residential use. See BPL Inquiry at ¶ 13.

System #1

System #1 employs Orthogonal Frequency Division Multiplexing to distribute the BPL signal over a wide bandwidth using many narrow-band sub-carriers. At the BPL injector, data from the Internet backbone is converted into the OFDM signal format and is then coupled onto one phase of the MV power line. An injector also converts BPL signals on the MV power lines to the format used at the Internet backbone connection. The two-way data are transferred to and from the LV lines, each feeding a cluster of homes, using BPL extractors to bypass the LV distribution transformers. The extractor routes data and converts between access and in-house BPL signal formats. The subscribers access this BPL signal using in-house BPL devices. To span large distances between a BPL injector and the extractors it serves, repeaters may be employed.

2-2: BPL System #1

The System #1 injector and extractors share a common frequency band on the MV power lines, different than the frequency band used on the LV lines by the subscriber's in-house BPL devices. In order to minimize contention for the channel, Carrier Sense Multiple Access is used with Collision Avoidance extensions. This type of system is designed to accept some amount of co-channel interference between quasi-independent BPL cells without the use of isolation filters on the power lines, as all devices on the MV lines operate over the same frequency band. The BPL signal may be sufficiently tolerant of co-channel BPL interference to enable implementation of two or three of these systems independently on adjacent MV power lines.7 System #1 couples BPL signals into one phase line.

System #2

System #2 also uses OFDM as its modulation scheme, but differs from System #1 in the way it delivers the BPL signal to the subscribers' homes. Instead of using a device that uses LV power lines, System #2 extracts the BPL signal from the MV power line and converts it into an IEEE 802.11b WiFi™ signal for a wireless interface to subscribers' home computers as well as local por computers . Technologies other than WiFi™ might also be used to interface to subscribers' devices with the BPL network, the important point being that BPL is not used on LV power lines in System #2.

BPL System #2

This system uses different radio frequency bands to separate upstream anddownstream BPL signals, and to minimize co-channel interference with other nearby access BPL devices. To span large distances between a BPL injector and the extractors it serves, repeaters may be employed. Like the injectors, BPL repeaters transmit and receive on different frequencies, and they use different frequencies from those used by the injector and other nearby repeaters. System #2 repeaters may also provide the capabilities of an extractor when outfitted with a WiFi™ transceiver. System #2 couples BPL signals onto one phase of the MV power line.

System #3

System #3 uses Direct Sequence Spread Spectrum to transmit the BPL data over the MV power lines. All users within a BPL cell share a common frequency band. In order to minimize contention for the channel, Carrier Sense Multiple Access is used. Like System #1, this type of system is designed to accept some amount of co-channel interference between cells, as all devices operate over the same frequency band. At one trial deployment of the System #3 architecture, the BPL service provider independently implements two phases of the same run of three phase power lines.

Each cell in System #3 is comprised of a concentrator that provides an interface to a T1 or fiber link to the Internet backbone, a number of repeaters to make up for signal losses in the electric power line and through the distribution transformers feeding clusters of dwellings, and customer premises BPL equipment, used to bridge between the user's computer and the electrical wiring carrying the BPL signal. Adjacent cells typically overlap and the customers' BPL terminals andrepeaters are able to communicate with the concentrator that affords the best communication path at any time.

Potential Future Systems

BPL manufacturers and service providers anticipate a wide range of applications that may be offered to their subscribers. High quality, multi-channel video, audio, voice over Internet Protocol, and on-line gaming applications are expected to rapidly increase the demand for additional bandwidth.8 To support the typical subscriber at 1 Mbps, BPL systems are expected to operate at speeds of 100 Mbps or more on the MV power lines in the near future. A number of comments filed in response to the NOI indicate that the BPL industry is already preparing for this growth.A number of BPL vendors have suggested use of frequencies up to 50 MHz.10 At least one vendor is considering use of 4 MHz to 130 MHz, while excluding frequenciesthat are actively in use by certain licensed services.11 One solution put forward in an attempt to mitigate interference with licensed services is to attenuate or "notch" BPL signals in frequency bands where licensed services are in nearby use.12 Future BPL systems may be able to accomplish this automatically without system operator intervention. To implement this solution while simultaneously maximizing the useable bandwidth, BPL systems are expected to use new modulations that can support more sub- carriers that are more finely spaced.

As data rates and bandwidth requirements grow, the BPL systems may require operation at greater transmitted power levels but not necessarily with higher power density than is used today. BPL vendors may employ techniques to dynamically adjust the power level to maintain a minimum signal-to-noise ratio over the entire BPL spectrum, while limiting emissions to levels compliant with Part 15. One vendor has proposed such a solution for adjusting transmitted power to maintain a constant SNR across the BPL spectrum, with a hard limit based on Part 15 rules.14 The challenge will be to develop the control mechanism that can maximize transmitted power while simultaneously limiting the radiated emissions, perhaps in conjunction with frequency agility.Nortel has developed and patented a filter that blocks BPL signals while concurrently passing medium-voltage AC power. The judicious use of such blocking filters will enable optimal segmentation of BPL networks into cells of various sizes having low conducted co-channel interference from neighboring cells. This will enable a greater level of frequency reuse than what is currently available. Unlicensed channels at 2.4 GHz and 5.8 GHz are used by another BPL technology.16 The idea of transmitting data across medium-voltage power lines at speeds more than 200 Mbps has been shown with an implementation using several IEEE 802.11b/g WiFiTM chipsets. However, no party submitted comments arguing that the BPL proceedings should take into account this technology and these frequencies.

There are three different architectures for access BPL networks: BPL systems that use different frequencies on medium- and low-voltage power lines for neighborhood networking and extensions to users' premises, respectively; BPL systems that use only medium-voltage power lines for neighborhood networking and other technologies for network extensions to users' premises; and BPL systems that use the same frequencies on medium- and low-voltage power lines for neighborhood networking. Currently, BPL systems operate at frequencies between 2 MHz and 50 MHz and offer data rates between 1 Mbps and 10 Mbps. Future BPL systems will use more bandwidth and/or sophisticated modulation techniques to function at data rates higher than 100 Mbps. Vendors of BPL equipment may use further signal processing methods to enhance performance while also restricting emissions to Part 15 standards.

STUDIES AND REGULATIONS RELATED TO BPL

This article discusses laws that apply to BPL systems as well as research done by different parties to look at the characteristics of BPL emissions. The rules include both the current and future radiation restrictions that apply to BPL systems.

The Commission's Rules, Part 15

The main field strength and compliance measurement requirements of Part 15 that apply to BPL systems are outlined in Appendix A of this study. The 3-1 section contains the Part 15 field strength restrictions. The definition of carrier current systems in Part 15 includes BPL systems. Since BPL systems are made to conduct RF energy over power line wiring, they are considered unintentional radiators and are exempt from the restricted operating bands stipulated in 47 C.F.R. 15.205.

Although the purpose of Part 15 emission limits is to reduce the risk of harmful interference to licensed services, compliance measurement procedures are equally important to reducing the risk of interference because measurement uncertainty may ultimately lead to BPL operation at field strength levels that are significantly higher or lower than the limits.

Regulations from abroad

Some administrations have established guidelines or rules for the implementation of BPL or have postponed the implementation of BPL while ongoing studies are still being conducted. In some nations, BPL has been effectively adopted, however other governments have delayed BPL deployment while more interference investigations are being carried out. Others have adopted BPL, encountered interference issues, and subsequently, at least temporarily, restricted BPL operation. Emission regulations have been put out for review at the regional level. Here, a few of these are presented. Please take note that the data we've gathered here isn't exhaustive and could not be up to date given how quickly BPL research and development are progressing. The abbreviations BPL, PLC, and PLT shall be used in line with each original report in the summaries provided in this section.

Potentially New Regulations

To control emissions from cable and BPL equipment, a number of ideas have been made on a regional level. The sections of these proposals that apply to BPL systems operating in the frequency range of 1.7 - 80 MHz are given below.18 The first suggestion, made by Germany and derived from NB30.Broadband over Power Lines (BPL) supporters and opponents presented pertinent technical data and analysis of the effects BPL will have on currently licensed services between 1.7 and 80 MHz. The following sentences provide summaries of some of their main topics[7]–[9].

CONCLUSION

BPL systems, in general, are a potential technology for transmitting high-speed Internet access and other communication services over current power line infrastructure. The technical explanation of BPL systems, including the architecture, modulation and coding schemes, and signal processing methods utilized for data transmission via power lines, are essential insights provided by this study. For a variety of applications, including smart grid, home automation, and Internet of Things (IoT) applications, the design and implementation of BPL systems may be improved using the findings of this research. The signal processing methods utilized in BPL systems, include as noise reduction, channel equalization, and interference mitigation. We go through the different methods, including as adaptive equalization, multi-user identification, and beamforming, that are used to enhance the performance of BPL systems.

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CHAPTER 18

POWER LINES AS UNINTENTIONAL RADIATORS OF BPL SIGNALS

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ABSTRACT:

Power lines can act as unintentional radiators of Broadband Power Line (BPL) signals, which can cause interference with other communication systems operating in the same frequency bands. This paper provides an overview of power lines as unintentional radiators of BPL signals, including the sources of interference, the impact on communication systems, and the techniques for reducing interference.The sources of interference, including the power line network itself, power line noise, and other electronic devices connected to the power line. We describe the various mechanisms by which BPL signals are radiated from power lines, such as the power line itself acting as an antenna, and the coupling of signals onto other conductors connected to the power line.

KEYWORDS:

Power Line Communication (PLC), Power Line Radiation, Radiated Emissions, Radio Frequency, Spectrum Analyzer, Transmission Line.

INTRODUCTION

The Medium Voltage power line was examined by Ameren Energy Communications, Inc. for its potential to serve as an unintended antenna for frequencies up to 30 MHz.20 A two-conductor power line segment powered differentially, according to Ameren's study, supports mostly transverse electromagnetic modes of propagation and functions as a wave guide. Only at areas of discontinuity, such as line terminations, connections with other lines, steep line turns, and at transformers and capacitors used in power distribution, can this line radiate. Additionally, they claim that reflections at the power line's receiving end result in the formation of two opposing traveling waves that radiate at both ends of the line[1]–[3].

Ameren said that the source impedance at the BPL transmitter should be set and the load impedance should be permitted to change while calculating the radiation efficiency and gain of the power line. In contrast, a line acting as a traveling wave antenna requires that the load impedance be matched to that of the line. According to their calculations, the ability of the stationary source to couple power onto the power line declines with the load mismatch as the line termination changes, in addition to the line's radiation efficiency and gain changing. A single line is anticipated to be an ineffective radiator, according to Ameren. Additionally, Ameren determined the array factor for two conductors and found a 17% rise in radiation compared to the case of a single conductor. Ameren contends that since linear array elements and transmission lines use distinct radiation processes, they should not be compared.

The radiation pattern is dictated by the current distribution in the lines flowing in opposite directions, and Ameren pointed out that the radiation is likely to be more isotropic in the case of linked segments of MV power distribution lines. They predict that as a consequence, signals will be divided across each linked segment and reflect at discontinuities, resulting in reduced gains and higher attenuation. According to Ameren, the source is the crucial component of the system for evaluating the radiation of BPL signals since it will provide the greatest radiation.

For a straightforward power line model, the ARRL submitted a paper with calculated antenna gains and patterns as a function of frequency.22 According to their findings, the power line behaves more like an antenna as frequency rises, emitting radiation with a complex and highly directed pattern.In a different study, the ARRL presented their simulation of an MV distribution power line and contrasted the three approaches for adding the BPL signal to the model23:One phase to Earth ground, with the feed in the middle of the line. Single phase fed differentially, with one conductor grounded to a relatively poor RF ground and the ungrounded phase feed point offset from center.

Results for the antenna gain of the power line were reported by ARRL based on their model, with the single phase differential feed with one grounded wire serving as the worst case. In this instance, the modeled power line saw stronger antenna gain and better coupling with the simulated amateur radio antennas they included in their model. The ARRL reported that this power line's estimated gain at 14 MHz was comparable to several amateur HF antennas. The radiated emission patterns for this model were found to be quite complicated, and it was noted that the peak radiation at 3.5 MHz is upwards.

Ameren questioned the reliability of employing a loop antenna to monitor magnetic field intensity in accordance with Part 15 regulations.24 Ameren noted that tests close to power lines are in the near field, where the value of free space impedance commonly employed in the far field, 377, is no longer relevant. Power lines operate as "large radiators" and measurements close to power lines are in this area. To demonstrate that the near field value of free space impedance differs from the far field value, they produced graphs of the electric, magnetic, and H fields as well as H field + 51.42 dB. The estimate error from using a loop antenna, according to Ameren, may be as high as 10 dBV/m for measurements taken along the power line and as high as 20 dBV/m going away from the power line, even as far out as 700 meters. The model that was employed for this investigation revealed that the peak field strength is 12° above the horizon. Ameren came to the conclusion that the loop causes large measurement errors close to power lines and advised using a monopole antenna for BPL tests.

In a different article, ARRL computed the conducted emissions power levels using comments to the Commission from several BPL manufacturers in response to the NOI.25 According to ARRL's estimates, the amount of conducted emissions as a consequence exceeds 47 C.F.R. 15.107. According to ARRL's knowledge of BPL coupler operation, normal losses for these couplers would result in significant conducted or radiated emissions.

The ARRL addressed the potential for inaccurate measured findings while adhering to the Part 15 regulations as they are now written.26 The ARRL said that since power lines' radiation patterns are complicated, it would be difficult to estimate where to take measurements in order to determine the electrical field's highest value. They noted that the HF electric field did not drop down at a rate of 40 dB/decade within 30 meters, suggesting that this might be another possible cause of mistake when calculating an extrapolation factor. The power line field strength is stronger above the power lines, hence measurements taken close to the ground would often underestimate the peak field strength, according to the findings from ARRL's power line model.The ARRL advised in-situ testing at closely spaced intervals above, below, and to the sides of BPL system installations to increase the possibility that measured findings properly represent the BPL field strength. The ARRL believes that the technique of characterizing emissions using 3 "typical" installations is impractical and will lead to readings that are not accurate representations of the emissions in an actual installation.

Finally, ARRL noted that the simulation results for the power line model clearly show standing waves.The ARRL determined the received signal strength from BPL emissions close to an amateur radio antenna and the anticipated rise in noise floor using their power line model. The ARRL determined that the radiated field strength will exceed Part 15 restrictions based on the expected BPL transmitted power spectral density.27 The amateur radio antenna is supposed to be situated in a location where the radiated emissions from the BPL signal are at their strongest, and ARRL assumes that there is a perfect coupling between the power line and the antenna. Additionally, ARRL calculated power line "antenna gain" using the findings of their power line model. ARRL went on to discuss possible measurement blunders that can mislead BPL providers into thinking they are adhering to Part 15 limitations.

In a report by the BBC, several recommendations for emission restrictions that are being reviewed in CEPT SE35 were taken into consideration, and it was assessed the level of protection that these restrictions would provide to broadcast receivers close to cabling carrying xDSL and PLT signals.28 The author came to the conclusion that none of the restrictions offered provided appropriate protection for broadcast reception and that the idea that would limit the rise in noise floor seemed to have the greatest potential[4], [5].

DISCUSSION

BPL Impact on Existing Licensed HF Communications Services

For various noise floor levels, the ARRL modeled the reliability of HF communications.29 The noise plus BPL signal level calculated by ARRL for a large-scale BPL deployment where these devices operate at the maximum field strength permitted under Part 15 was used in their modeling along with noise floor levels for a quiet residential environment, the ITU-R Recommendation P.372.8 for median noise level in a residential environment, the ITR-R Recommendation level +10 dB, and the noise plus BPL signal level for a residential environment. Using the VOACAP inverse-area coverage tool, ARRL approximated these situations at 5 MHz and 14 MHz.

In this ARRL report, several graphs of HF link availability were supplied.The findings showed that operating a receiver in the presence of ITU-R median level noise already reduced the reliability of HF communications. If BPL use increased the noise floor by 10 dB, or to the level ARRL predicts will result from widespread BPL deployment at Part 15 limits, ARRL concludes that global HF communications will be severely degraded.The BBC examined the cumulative consequences of extensive xDSL and BPL deployment in another study. The BBC took into account the effects of skywave propagation on ground-based receivers located far away and aircraft receivers.30 The level of skywave interference caused by extensive xDSL/PLT system deployment to aircraft and ground-based receivers may not be trivial, the author found from his investigation. The author recommends that the relevant competent authorities look at this interference risk in more detail.

Activities of the International Telecommunications Union

The Telecommunications Standards Sector and the Radiocommunications Sector are two of the three ITU Sectors that have addressed BPL. Since the working documents of the Study Groups in both of these sectors aren't publicly accessible, descriptions of the most recent documentation and activities are given here without in-depth citations.

Study Group 5 of ITU-T

"Emission Limits and Test Methods for Telecommunication Networks" is the topic of Recommendation K.60, which was accepted by ITU-T Study Group 5 in the middle of 2003. Its intended use is the analysis of radio interference complaints, and all telecommunications networks employing LV AC electrical power lines and frequencies between 9 kHz and 400 GHz are included in its coverage. For the 1.7-80 MHz frequency range, the suggested "target" field strength limits are listed in Tables 3-8. The Recommendation details the administrative and measuring processes related to it. Before thinking about submitting an interference complaint to the appropriate authorities, the processes include a variety of interference mitigation activities that should be completed by the parties directly concerned[6], [7].

The texts of Questions 218/1, "Techniques for measurement of radiation from high data rate telecommunication systems using electrical power supply or telephone distribution wiring," and 221/1, "Compatibility between radiocommunication systems and high data rate telecommunication systems using electricity power supply or telephone distribution wiring," are both freely available. analytical factors that are compatible with the Commission's active BPL inquiry. Korea delivered a report outlining a method for determining BPL emissions in a lab setting. Review of a Liaison Statement outlining pertinent Study Group 6 research. Working Party 1A, the ITU-R body in charge of developing recommendations about possible interference from BPL systems, has asked all other Working Parties that are in charge of signal propagation models and analysis as well as issues pertaining to particular radio services for information. Working Parties 1A and 1C anticipate finishing their BPL research in 2005.

Study Group for ITU-R

Working Parties 3J, 3K, 3L, and 3M of Study Group 3 had lengthy talks on the propagation characteristics of Power Line Telecommunication systems in November 2003. This was listed as one of the three most crucial issues for these discussions, according to Study Group 3 Chairman. Subgroup 3J-C provided pertinent information addressing ambient noise, while Subgroups 3K-1 and 3L-2 spent a significant amount of time studying PLT systems. Working parties 3J, 3K, and 3L collaborated to create a statement of liaison to Working Party 1A that outlined their concerns and provided methodologies for estimating the amounts of PLT signal radiation. The unbalanced nature and various properties of power lines, the potential for radiation from both point and line sources, the power aggregation of emissions from many sources, and the existence of both ground and sky waves were among the concerns raised. Because of the unknowable link between these fields in the near-field, it was noticed that measurements of both the electric and magnetic fields must be taken into account while creating criteria for accep PLT usage of radio frequencies. It was advised to use a model like NEC for radiation estimate, ITU-R Rec. P. 368 or the program GRWAVE for ground wave evaluation of PLT emissions, and ITU-R Rec. P. 533 for sky wave evaluation of PLT emissions. ITU-R Rec. P. 372 was also recommended as a method for calculating noise levels.

Working Party 3L also created a new question and a new Correspondence Group to work on the PLT Communications in addition to the Liaison Statement. The proposed new question focused on PLT-relevant prediction techniques and models. Additionally, defined studies received top priority. The described research includes PLT system radiation processes, modeling strategies, the impact of nearby ground planes and conductors, aggregation approaches, propagation models for interference calculations, and measurement of radiated fields in the near field. The Correspondence community will share ideas and discuss the results of several ongoing investigations for the worldwide community to examine.

Study Group 6 of ITU-R

The European Broadcasting Union presented a paper to ITU WP 6E that suggested revising the PLT field strength restrictions and measurement distances found in previous research. This contribution pointed up three issues with the preceding research. First, the allowable PLT signal strength should be calculated using digital broadcasting transmission rather than amplitude modulation transmission. Second, the needed signal-to-noise level should not be limited to a channel that operates in a rugged mode with a small capacity and is reasonably tolerant of interference. Third, for indoor reception, the 3-meter measuring distance given in the NB30 limit is very large. The maximum permissible PLT interference should be at least 10-20 dB lower and reception at 1-meter and greater distances from the PLT emission source should be safeguarded, according to the EBU, which decided that the NB30 limitations were significantly too permissive.Additional technical literature that wasn't submitted in response to the BPL Inquiry is listed in Appendix B.

To make sure that the NTIA's research would include significant interference mechanisms and variables as well as viable solutions for successfully integrating BPL and radio systems, relevant FCC and international laws as well as studies conducted by third parties were evaluated. NTIA reported that although BPL systems have been successfully adopted in certain nations, they have been delayed in other nations pending the results of further interference research. Others have stopped approving the use of BPL systems after encountering interference issues. On an international, national, and regional basis, many emission limitations have been enacted or suggested for study. The majority of investigations have focused on figuring out if interference would happen at the various recommended limitations. NTIA, on the other hand, has focused its research on finding a solution that takes BPL systems into account while properly limiting the danger of radio system interference.

Several pertinent observations were included in the technical data and analyses that were submitted in response to the FCC NOI. Although there is a great deal of disagreement regarding the strength of the emissions and their potential to interfere with licensed radio services, BPL signals unintentionally radiate from power lines. According to analyses, the inadvertent BPL radiation's greatest field strength occurs over the power lines' physical horizon. By using a loop antenna in the near field, taking measurements with an antenna that is close to the ground, and measuring emissions close to BPL devices without also taking into account emissions from the power lines, current Part 15 measurement techniques may significantly underestimate the peak field strength produced by BPL systems.

Characterization of radio technologies used by the federal government and spectrum utilization. The high end of the medium frequency band, the high frequency band, and the low end of the very high frequency band are all included in the frequency range of 1.7-80 MHz. Skywave, ionospheric propagation allows for communications over extremely great distances at HF frequencies and. The wide variation in radio propagation and background radio noise levels is an important aspect of communications utilizing the HF frequencies. These differences with respect to the hour of the day, the season, the year, and the place have been well investigated and are well known. Modern technology has restored HF as a significant, dependable form of communication, particularly with regard to automated connection setup. Communications at VHF frequencies are often more local and only extend a few tens of kilometers. Numerous radio services are supported in the 1.7-80 MHz band because they have been modified to work with the propagation characteristics of this frequency range. In all, the 1.7-80 MHz spectrum supports thirteen radio stations. The majority of these radio services are used by federal agencies and help the federal government fulfill its many radiocommunications obligations.

Overview of Allocations

There are 157 frequency bands in the 1.7-80 MHz range in the US. Every one of these bands is slated for either exclusive federal use, exclusive non-federal use, or shared usage in line with the National of Frequency Allocations. Numerous instances of band-sharing between federal and non-federal users as well as between various radio services are allowed under the spectrum allocations in this band. Federal and non-federal users share a total of 110 bands. The Federal Government has been given exclusive use of just 12 bands for fixed and mobile services. In contrast, 34 bands are designated exclusively for non-federal usage in order to accommodate a variety of radio services, such as broadcasting, amateur satellite, fixed, and land mobile. These bands are covered by more than 50 footnotes to the allocations, which provide extra spectrum sharing or operational restrictions.

Fixed and mobile communications, the biggest category, contains a variety of particular allocations for different land, air, and marine communications services. For the purposes of this overview, the "Other" category includes standard frequency and time signals, radio astronomy, radiolocation, and aviation radionavigation. The breakdown of the total number of bands allotted to radio services, together with their individual total bandwidths, is shown in Figure 4-5. The primary emphasis of this Phase 1 research was on fixed and mobile communications networks.The NTIA Phase 2 project will continue to investigate more services. The Appendix C provides more information on these radio services and the utilization of the spectrum.

USE OF THE FEDERAL GOVERNMENT SPECTRUM

The 1.7-80 MHz band, in particular the HF band, is heavily used by Federal Government agencies for emergency services, including communications support for the Department of Defense, Coast Guard operations for distress, digital selective calling, search and rescue, and other safety of life operations, the Department of Interior and Department of Agriculture for the management, maintenance, and preservation of our natural resources, the Department of Justice and Department of Homeland Security, and Department of Interior and Agriculture for other safety of life operations. In times of national security emergency preparedness emergencies, when regular communications links are disrupted, insufficient, or non-operational, backup systems are crucial. The Federal federal has a scheme for the shared resources network to utilize federal HF frequencies in an emergency. In times of emergency, the SHARES network aims to provide a backup capacity for HF radio communication between government organizations. Federal agencies using this part of the radio spectrum, in particular the DoD and law enforcement, use over-the-horizon and encrypted radios that may use ALE, which regularly samples channels to assess channel availability. Each of these programs might be a component of the network for emergency communications. As previously mentioned, both government and non-federal users often use the 1.7-80 MHz band, which is widely utilized by both groups for a wide range of radio applications. The 1.7-80 MHz band has more than 59,000 approved Federal Government frequency allocations. The distribution of frequency allocations per radio service and entity is shown in Table 35 4-6. These tasks support a variety of government initiatives and specifications in the 1.7-80 MHz spectrum.

Sensitive Or Protected Frequencies inthe 1.7-80 Mhz Band

All spectrum regulating bodies, such as the FCC, NTIA, and ITU, have long acknowledged that some radio frequency ranges, such as the 1.7-80 MHz band, need extra protection because to the vital or delicate tasks they provide. These include radio astronomy, radionavigation, standard frequency and time signal, distress and safety, and others. Specific listings of protected frequencies in this band are provided in Parts 15, 80, and 87 of the FCC Rules and Regulations. The notion may also apply to unintended radiation from BPL systems due to the hazards of interference, even if all three impose restrictions on licensed services or unlicensed deliberate radiation devices in these bands. Similar listings of protected frequencies are provided in Appendices 13 and 15 of the ITU Radio Regulations. and illustrates the various functions being protected by comparing these lists of protected frequencies adopted by the FCC and ITU.

NTIA suggests a tentative list of 41 protected frequencies for BPL systems based on these FCC and ITU sources. This potential list, in bands 4–9, covers less than 6% of the spectrum between 1.7 and 30 MHz and roughly 5.5% of the bandwidth between 30 and 80 MHz. Operations supported by these frequencies are essential for meeting specific federal communications standards, including safety of people and property, disaster communications, radio astronomers' ability to pick up faint galactic signals, and aircraft safety. When disasters or other events result in the loss of normally available communication facilities or necessitate the temporary establishment of additional communication facilities beyond those normally available, these frequencies or frequency bands can be used to support vital communications. In the NTIA Phase 2 endeavor, the usefulness of these proposed sensitive frequencies or others with regard to BPL systems will be further studied[8], [9].

CONCLUSION

The Federal Government uses all but two of the 13 radio services that are given frequencies between 1.7 MHz and 80 MHz, in variable degrees, to fulfill various specified mission needs. Over 59,000 frequencies have currently been assigned to federal agencies in this frequency range. Communications for national security, safety and distress, as well as other crucial tasks, are accommodated by fixed and mobile service allocations. These communications were selected as the subject of this Phase 1 investigation because they take up more than half of the frequency spectrum. Fixed and mobile equipment characteristics may be broadly categorized into uses 30 MHz and above 30 MHz, and equipment characteristics within these two groups exhibit a great deal of consistency. Both the NTIA and the FCC have long recognized that some radio frequency ranges or bands need particular anti-interference protection due to the vital or delicate tasks they serve, such as radio astronomy, radionavigation, distress and safety, and others. NTIA has identified 41 of these frequency bands, which range from 1.7 MHz to 80 MHz and total around 4.2 MHz, and suggests that they be given extra protection from interference from both licensed and unlicensed transmitters.

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CHAPTER 19

CHARACTERIZING BPL EMISSIONS THROUGH COMPUTER MODELING AND MEASUREMENTS

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ABSTRACT:

Broadband Power Line (BPL) emissions can cause interference with other communication systems operating in the same frequency bands. This paper provides an overview of characterizing BPL emissions, including the measurement techniques, the data analysis methods, and the results of field measurements.The measurement techniques for BPL emissions, including spectrum analysis, time-domain analysis, and spatial analysis. We describe the various instruments used for measuring BPL emissions, such as spectrum analyzers, oscilloscopes, and field strength meters. We also discuss the calibration methods used for ensuring accurate measurements.

KEYWORDS:

Electromagnetic Radiation, Impedance Measurements, Impedance Spectroscopy, Measurement Techniques, Power Line Communication (PLC), Radiated Emissions.

INTRODUCTION

This outlines the main conclusions from NTIA's measurement and modeling work to date and discusses theoretical aspects of BPL signal emission and propagation. Insofar as ambient noise is a crucial consideration in the assessment of interference, the levels of RF noise in the environment are discussed. These factors are taken into account in 6 analyses of the hazards of interfering with representative systems of the federal government[1].

Theory of Relevant Radiation

BPL devices and the power lines that transmit BPL signals might unintentionally behave as radiators in the relevant frequency range, 1.7 - 80 MHz. The symmetry of the network at radio frequencies determines how much radiation occurs. In terms of the impedance between conductors and ground, symmetry is defined. A two-wire circuit is symmetrical or balanced if the impedance between each conductor and ground is equal. A common mode signal that is undesired results from a loss of symmetry. While return portions of the currents flow through ground, common mode currents flow in parallel through both conductors. For differential mode transmission, when currents are equal in size and flow in the opposite directions on the signal conductors, balanced lines are required. In the distant field region, the fields emanating from these conductors have a tendency to cancel one another. Common mode currents at radio frequencies radiate more than differential mode currents on parallel or nearly parallel, non-concentric conductors.

Any impedance discontinuity in a transmission line, whether it is caused by a BPL coupling device, a transformer, a branch, or a change in the line's direction, may result in radiation, either directly or by the reflection of signals into standing waves that radiate from the conductors. The remaining wires often behave as parasitic radiators, therefore at certain frequencies the lines may function as an array of antenna components even if the RF energy is only pumped into one of two or more conductors. One or more power lines as well as one or more point radiators that correspond to the coupling devices may emit radiation. The current distribution on the power lines and the radiated fields have been simulated using the Numerical Electromagnetics Code, which will be explored further in this part, and comparable technique of moments models, which have been utilized with realistic physical arrangements and impedances of the power lines. According to modeling findings in Appendix E and presented below, standing waves caused by an impedance discontinuity would create radiation at various positions along the power lines, depending on the polarization of the radio antenna.Three areas may be distinguished in the area around a radiator: the reactive near-field, the radiating near-field, and the far field[2]–[4].

DISCUSSION

Propagation Modes

The three main, relevant propagation modes in the frequency range of 1.7 to 80 MHz are ground wave, space wave, and sky wave. A combination of a direct wave, a ground reflected wave, and/or a surface wave may make up the ground wave signal. The received power for a direct wave from a point source is inversely proportional to the square of the distance. The peak total received power is inversely proportional to r4 if the radiator is placed many wavelengths above ground. In this case, the direct wave and the ground reflected waves are treated as independent rays. Separate rays should no longer be taken into consideration when the radiator is near to the earth in terms of wavelength. By causing currents to flow in the ground and facilitate short-range communications, surface waves spread close to the ground. However, surface waves that are horizontally polarized suffer from significant attenuation, and surface wave propagation generally exhibits much higher rates of attenuation with distance than the direct wave, particularly at VHF frequencies. Sky or ionospheric waves are typically significant up to roughly 30 MHz, beyond which occasional propagation occurs. Depending on the elevation angle of the radiated field, frequency, and fluctuation of the ionosphere, sky wave propagation may include rays that are refracted and reflected off the ionosphere and is responsible for signal transmission to distances ranging from hundreds to thousands of kilometers. The ionosphere, which is a low-conductivity dielectric and is between 60 and 600 kilometers thick, performs this function[5], [6].

Surface and reflected waves are detected at magnitudes significantly lower than the direct wave amplitude when line-of-sight signal routes are above the height of the power lines. Even though in most cases reflected waves can produce a degree of location variability in the received signal magnitude, friis, or free-space loss, is typically assumed for these paths.In conclusion, ground waves will be the propagation mechanism of interest for BPL emissions approaching or near the power line horizon. The propagation of emissions in directions above the horizon of the power line may occur through ground and space waves for shorter distances or by sky waves for longer distances.

Sky waves experience significant losses, primarily from polarization coupling and ionospheric absorption. There may be an accumulation of co-frequency BPL emissions into the ionosphere in a dense deployment of BPL devices. Emissions toward the power lines in general may collect through ground wave, whereas emissions in directions above the power lines may do so via sky wave, ground wave, and space wave. The aggregation of BPL signals at sites above power lines may be more important than at lower heights where BPL signal propagation is less effective, according to preliminary modeling of power lines, which implies that there is relatively strong radiation in directions over the power line horizon.

MEASUREMENTS BPL

To quantify important aspects of BPL signals, NTIA conducted measurements from August to November 2003. Three locations with BPL systems installed for testing and providing customer service were used for the measurements. BPL signals were employed on the MV lines at all three of the sites, and on the LV wires in two of the sites. The following are the several kinds of basic emission measurements, which are listed in Appendix D:

1. BPL signal identification and characterisation.
2. Locations close and along an electrical line that have BPL signal power.
3. BPL signal strength at different distances from an energized line.
4. Comparisons of the BPL signal power utilizing peak, average, and quasi-peak detectors.
5. Power of the BPL signal at various receiving antenna heights and polarization directions.
6. The BPL signal's amplitude probability distributions.

These measurements were performed with either an antenna mounted 2 meters above the ground on a wooden tripod or 10 meters above the ground on a telescopic mast utilizing the NTIA's instrumented measuring truck. There were four different kinds of antennas. To gauge the electric fields above 30 MHz, a tiny discone antenna was placed above a ground plane of similar size. The magnetic fields were measured using tiny shielded loops at 30 MHz, while the electric fields were measured with a rod antenna over a small ground plane. An off-the-shelf, 2.1-meter base-loaded whip antenna was installed at around 1.5 meters above the top of a car to test the received power that would be observed by a mobile device. The measuring frequencies were covered by a number of the narrow-band whip antennas.

BPL Signal Recognition and Characterization

Prior to each measurement, the equipment was calibrated as detailed in Appendix.D. Using the spectrum and temporal characteristics of the BPL transmission as indicated in D.3.1, the BPL signals at the three BPL deployments were located and analyzed.Along an Active Power Line, BPL Signal Power

D.3.2 provides the measurement findings for BPL signal power along an energized power line. A rod antenna was used to measure the peak received power resulting from the electric field created by BPL signals at different locations along a power line from a height of two meters. The electric field's three mutually orthogonal components were measured. These tests show that there is a significant BPL electric field around and along the power line, and that the field generally does not significantly fade as one moves away from the device. At least once, when the distance from the BPL gadget rose, the electric field actually became stronger. Standing waves are assumed to have been produced as a result of the BPL signal being reflected by one or more impedance discontinuities. Standing waves in the current distribution along the power line are generally regarded to be the cause of the location variability in the field.

As shown in D.3.2, the magnetic field was not detectable along the power line at the majority of places while utilizing a loop antenna at a height of 2 meters. At different points along the power lines, the peak received power caused by the electric field was measured using a whip antenna installed on top of a truck. The results are comparable to those obtained from the rod antenna-based electric field measurements.

According to tests made at one location at a frequency of 32.70 MHz and a height of 10 meters, the received power decreases first as you go farther away from the BPL device along the power line, but then it essentially stays the same as you move further away.

BPL Warning: Disconnect Power from Energized Power Line

In D.3.3, the measurement findings for BPL signal power distant from an active power line are shown. A loop antenna just underneath the power line at a height of 2 meters was used to measure the peak received power owing to the magnetic field at one location, and a faint BPL magnetic field was found on four frequencies. Only 28.8 MHz of BPL signals were picked up 50 meters away from the power line, perpendicular to it. With the vertically polarized whip antenna, the peak received power resulting from the electric field away from the power line was also measured at 4.26 MHz, 7.30 MHz, and 28.78 MHz. The findings show that received power decreases with increasing distance from the BPL device and power line, although the decline at 28.78 MHz was not monotonic. At various frequencies, there were significant differences in the received power and how it dropped off with distance[7]–[9].

At the same location, the whip antenna was used to measure the peak received power resulting from the vertical electric field at various separations from the power line. There are occasional amplitude fluctuations even though the received power normally drops with increasing distance. Although it is believed that ground reflections, not ground effects, are primarily to blame for this non-monotonic behavior, it was observed that underground power lines branching off the BPL transmission line crossed the measurement path close to a local peak measured signal power level.

At two more locations, the peak received power resulting from the vertical electric field was measured using the whip antenna. Within 600 feet at one location, the signal dropped to an undetectable level. Beyond 1,500 feet at the second location, which had a complicated configuration of power lines with several turns and BPL devices, the signal power greatly outweighed the noise power.

In a different power line configuration, measurements were also made using a discone antenna with vertical polarization at a height of 3.4 meters above the ground. At three distinct frequencies, and at varied separations from the power line, pulse power measurements were taken. The findings show that the received power in this instance diminishes as distance from the power line grows at a slower pace than would be anticipated by 1/r2.

BPL Measurement Using Various Antenna Heights

Two different antenna heights were used to measure BPL emissions from MV lines. The findings indicate that, generally speaking, at the increased antenna height, the observed power levels were much higher. For instance, the 100% duty cycle power was 4.8 to 10.7 dB higher at a frequency of 32.70 MHz at a 10-meter antenna height than it was at 2 meters. For the same frequency, the pulse power was 8.2 to 15.1 dB higher at a 10-meter antenna height than it was at 2 meters.

Emissions from an LV power line carrying BPL signals from an LV coupler close to a pole-mounted transformer to a dwelling were also measured. Around the neutral line were the phase lines twisted. The placement of a loop antenna was optimized for receiving the horizontal magnetic field. Measurements were taken at antenna heights of 2 meters and 10 meters at frequencies of 5 MHz, 6.43 MHz, 10.74 MHz, and 18.38 MHz, each with resolution bandwidths of 3 kHz, 10 kHz, and 30 kHz, at the antenna, which was situated 8.7 meters from the utility pole close to the middle of the LV line. According to the findings, power measured at a height of 10 meters is always greater than power recorded at a height of 2 meters. Results for 100% duty cycle power, when relevant comparisons could be performed, are summarized in Table 5-2.

BPL Amplitude Probability Distribution Measurements

At two of the three BPL deployment sites, a number of APDs were measured; the results are provided in D.3.6. APD tests were performed at one location at two frequencies, 32.70 MHz and 42.47 MHz, and three distinct resolution bandwidths, 200 kHz, 30 kHz, and 10 kHz. The APDs were measured using a vertically polarized discone antenna at a height of 10 meters and a distance of 11.6 meters from a power line. The APDs were then used to calculate the 100% duty cycle power levels. The findings demonstrate that the power levels are related to bandwidth and that the 100% duty cycle power is greater for higher resolution bandwidth for the same frequency.

Pulse-power measurements and APDs were carried out at 32.70 MHz with two different resolution bandwidths and four distinct antenna orientations while BPL was loaded on the power lines. A discone antenna was placed at different direct angles from the power lines and the backhaul point, and it was raised 2 meters vertically above the ground. According to the findings, the measured power for the same site was identical for all four antenna orientations. In this case, similar power was measured for one set of coordinates, whereas for another set of coordinates, the measured power for vertical polarization was greater than that for horizontal polarization. A long wire antenna is linearly polarized, but the direction of the linear polarization is not the same in all parts of the pattern.

The sites for these measurements have relatively low noise power levels and use of the higher noise power levels predicted by ITU-R Recommendation P.372-8 in our analyses may bias results toward underestimation of interference levels.

Models for Analysis of Power Line Radiation

Code for Numerical Electromagnetics

The NEC computer application uses the numerical solution of integral equations using the technique of moments to examine the electromagnetic response of antennas and scatterers. For modeling thin wires and closed conducting surfaces, respectively, an electric field integral equation and a magnetic field integral equation are utilized. With this type of simulation, the interesting structure is divided into moments or line segments. The electromagnetic fields are obtained by computing the current in each section.

The most recent iteration of the NEC, which has been created and enhanced by Lawrence Livermore National Laboratory throughout time, is NEC 4.1. Excitation by plane waves or voltage sources, lumped or distributed loads, and networks or transmission lines are characteristics provided by NEC codes. Current distributions, impedances, power input, dissipation, efficiency, radiation patterns, gains, and scattering cross section are all included in the code output. Its output includes far-field antenna patterns, near-field electric and magnetic field strength, ground-wave field strengths at various distances from an antenna, antenna input impedance, and total radiated power, among other things. A broad variety of ground surface structures, insulated wires, impedance and conductivity in loads and wires, numerous types of electromagnetic excitation in a structure, and structures in dielectric media other than air may all be modeled using NEC-4.1. However, it is crucial to properly design and input the physical model, accurately portraying variables like segment length, diameter, and wire spacing, insofar as these variables frequently have a significant impact on results. It is crucial that segment lengths be kept short enough to ensure that the model behaves properly and that results remain stable when segment lengths are reduced further.

The computer's Random Access Memory and the amount of time needed to model particularly big buildings are NEC simulation's most relevant limitations for the research of BPL. As calculations are performed in a matrix, the amount of computer memory required to simulate a structure is directly proportional to the square of the number of line segments used in the structure model. The number of line segments required to replicate a portion of a power grid may be quite high since segment length is influenced by the frequency of interest in part. Depending on how many segments there are, the matrix factoring and filling process might take a very long time. Additionally, if the size of the matrix exceeds the capacity of the computer's core memory and disk swapping occurs, running a NEC simulation can become unreasonably time-consuming.

Modeling of Power Lines by NEC

An extensive amount of research was done on a typical configuration of three phase MV power lines at the NTIA's Institute for Telecommunication Sciences.42 Three copper wires running horizontally in parallel and rising 8.5 meters above a ground with average characteristics made up the modeled power lines. The distance between the wires in the horizontal plane was 0.60 meters, and each wire had a diameter of 0.01 meters. The center of one of the wires, which was parallel to the x axis, was where the feed point was located. The middle piece of the wire was used to simulate the equivalent of a BPL coupler, which consisted of a 1 volt voltage source connected in series with a resistor to provide the source impedance. At y = 0.6 and y = 1.2 meters, the other two phase wires were located parallel to the x axis.

At frequencies of 2 MHz, 10 MHz, and 40 MHz, the three orthonormal components of the electric and magnetic field intensities in the near field were plotted in a plane two meters above the ground. Four distinct impedance conditions for the source and loads were employed with three different line lengths of 100 m, 200 m, and 340 m. Source impedance of 150 with load impedances of 50 and 575, and source impedance of 575 with 50 and 575 load impedances, were the impedance circumstances. For four different ranges of x and y coordinates, i.e., 0 to 20 m, 0 to 200 m, 0 to 1000 m, and 0 to 18000 m, the field strengths were plotted as contours in 5 dB increments. Additionally, several azimuth angles were used to plot the far field radiation patterns. In Appendix E, many typical far field radiation patterns and near field plots for the electric field's three components Ex, Ey, and Ez are shown for varied line length, frequency, source impedance, and load impedance configurations. The full outcomes of the aforementioned simulation study are accessible at NTIA.

As the ratio of line length to wavelength rises, the far field patterns show that the radiation pattern has more lobes. The effects of varying source and load impedances are minimal. Since the transmission line under study has a characteristic impedance of roughly 575, it can function as a traveling wave antenna when the load and source impedances are both equal to this value. The source impedance of 150 and load impedance of 50, which corresponds to the biggest mismatch among the situations studied, were often linked to the highest radiation. The elevation pattern contains multiple lobes in the azimuth angle of 0o, or in the direction of the power lines, and the greatest lobe is often approximately 30o or lower elevation above the horizontal plane containing the power lines. This main elevation angle is lower the higher the L/ratio. The largest gain is in or close to the vertical direction, and there are fewer lobes as the azimuth angle approaches 90o.

The L/ ratio affects how many peaks there are. The peak declines as frequency rises, while the number of local peaks along the line rises. Due to RF attenuation and radiative losses, the peaks steadily decrease down the line. when previously indicated, changing the source and load impedances has a negligible impact on peak field strength, and when the source and load impedances are adjusted, the peak field strength typically decreases as follows: 150 & 50, 150 & 575, 575 & 50, and 575 & 575. additional peaks down the line with equal or weaker field strengths than the BPL source for the parallel case. There are standing waves along the power line, according to measurements along power lines, near field surface plots, and far field patterns. Other representative power line configurations should be investigated with sensitivity analysis in regards to line length, source position, location of nearby conductors, source and load impedances, and frequency. Calculations must be made for electric fields at various altitudes. Only a few measurements have shown how much higher the electric fields are at a 10-meter-high antenna than they are at a 2-meter-high antenna. NTIA is creating software for statistical analysis of the geographical distribution of electric field intensity to aid future research[10], [11].

CONCLUSION

Characterizing BPL emissions is crucial for understanding how BPL affects other communication systems and for enhancing the development and use of BPL systems. This article offers insightful information on the measuring methods, data processing strategies, and outcomes of field measurements of BPL emissions. The findings of this research may be utilized to enhance the coexistence of BPL with other communication systems and to design efficient interference mitigation solutions. the outcomes of measurements made in the area of BPL emissions, including as their frequency and geographical distribution, their influence on other communication systems, and the efficiency of interference mitigation methods. We cover a number of variables that may have an impact on BPL emissions, including the architecture of the power line network, the placement of the measuring equipment, and the kinds of interference mitigation strategies that are used.

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CHAPTER 20

A BRIEF DISCUSSION ON EFFECTS OF A NEUTRAL LINE

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ABSTRACT:

The neutral line in a power line network is a conductor that carries the return current from the loads back to the source. The effects of the neutral line on power line communication systems, such as Broadband Power Line (BPL) systems, can be significant. This paper provides an overview of the effects of a neutral line on power line communication systems, including the impact on signal propagation, interference, and performance.The impact of the neutral line on signal propagation in power line communication systems. We describe the various mechanisms by which the neutral line affects signal propagation, such as the coupling of signals onto the neutral line, and the attenuation and distortion of signals due to the presence of the neutral line.

KEYWORDS:

Broadband Over Power Lines (BPL), Capacitive Coupling, Common Mode Voltage, Electromagnetic Interference (EMI), Impedance Measurements, Impedance Spectroscopy.

INTRODUCTION

The most apparent factor to take into account while simulating a power line for a BPL system is the inclusion of parallel wires, such a neutral and telephone and cable cables, which are often located underneath the neutral. Sample simulations with and without a neutral wire were conducted, and the results were compared to one another in order to ascertain the impacts of a neutral line on the model taken into consideration above. A grounded neutral line does affect the output of the model, as can be shown in 5-1 at a frequency of 4 MHz. The amount of gain in the major lobes of the far-field radiation pattern is the primary indicator of this frequency-dependent effect. The general form of the radiation pattern is roughly unchanged, and the gain difference is less than 2 dB. The comparisons for the frequencies of 15 MHz, 25 MHz, and 40 MHz are provided in Appendix E, demonstrating how the gain changes less as frequency increases. Importantly, at all of the examined frequencies, the presence of a neutral tended to increase rather than decrease the power line radiation's overall gain. Additional calculations of the electric field's magnitude also showed that the presence of a multi-grounded neutral increased the electric field's magnitude around the modeled power line. This would appear to suggest that the NEC power line model would tend to generate a more conservative outcome, i.e., create less radiation, if a grounded neutral were removed[1]–[3].

Noise in the environment

The ITU-R Rec. P.372-8 is the accepted reference for radio-frequency noise. It offers thorough formulae and graphs for forecasting median ambient noise owing to atmospheric, artificial, and galactic noise sources as well as temporal variations at any location. Predicted noise levels depend on frequency, time of day, season, and the surrounding environment. Noise levels vary hourly, daily, and annually at any particular site.

Because total ambient noise tends to rise as frequency decreases, it is especially problematic on lower frequencies in the 1.7–80 MHz range. The intensity of the received signal required to conduct communications in the absence of interfering signals is often determined by the degree of ambient noise.Depending on the intensity of the received signal, significant noise might make high-frequency communications challenging or even impossible.

The main categories for HF radio noise causes include man-made, atmospheric, and cosmic sources. Each adds to the total level of noise, and the proportional contribution of each source of noise depends on a number of variables.Electrical equipment, such as domestic appliances, car ignition, and overhead power lines, are the main source of noise created by humans. The location has a significant impact on the statistically determined amount of man-made noise. For instance, compared to isolated rural settings, industrial districts often have substantially greater levels of man-made noise. According to decreasing median noise levels, ITU-R Rec. P.372-8 expressly divides regions into commercial, residential, rural, and quiet rural noise environments. Although this isn't always true for all environments, man-made noise typically has higher levels in the 1.7 - 80 MHz range.

Lightning is largely responsible for atmospheric noise. Geographical location, hour of the day, and season all have a significant impact on trends in this kind of noise. For instance, regions of the Midwestern United States often experience much greater afternoon ambient noise levels throughout spring and summer than do other regions of the nation. The majority of noise at lower HF frequencies is often caused by atmospheric noise. Galactic noise is radio noise that is generated by emission from celestial bodies in our own galaxy, and it usually only becomes an issue at higher frequencies and in areas with little background noise. As its level is relatively constant at a given frequency and significant in comparison to relatively low median levels of atmospheric and man-made noise, galactic noise can be used as an effective "best case" noise level for low-noise conditions.

The ITU website offers software that incorporates the information in ITU-R Rec. P.372-8; this paper uses that software to get ambient background noise levels for interference assessments.Both the spatial and temporal fluctuation of noise levels are significant. A commercial site in the Midwest of the United States could encounter quite high noise levels during a summer afternoon, whereas a remote area in Alaska during a winter morning might experience low noise levels that are similar to the cosmic background noise.

Examining average median noise levels in relation to signals that adhere to FCC Part 15 limitations is enlightening. The examples in Figures 5-3 and 5-4 illustrate typical median receiver system noise power levels and Part 15 field strength restrictions for the 1.7 to 80 MHz frequency range. For this, the noise levels at 450 sites throughout the United States were estimated under the assumption of a residential setting, and the median of these values for noon in spring was used. The noise levels for one of these places were utilized for further computations since many geographic points had computed median noise values that were extremely near to the overall medians for each frequency.

The levels have been converted into electric field strength levels and, assuming they are picked up by a short vertical monopole antenna, both the noise and the Part 15-limit electric field strength levels are displayed. A 12 dB receiver noise factor is also included in the noise levels, which is negligible in comparison to the noise levels coming from the electric field at the antenna. Signals received at Part 15 limits are 15 dB to 25 dB over the median noise levels, as shown by the s.

According to NTIA's modeling, adding a neutral line to three-phase medium voltage wiring tends to increase radiation levels overall. As a result, models without the neutral wire often forecast a weaker field. These modeling findings have the potential to drastically underestimate the peak electric field if compliance tests are only made close to a BPL device and at eye level with the power lines.

To describe the BPL basic emissions, NTIA took measurements at three separate BPL deployment locations. As the measurement antenna was placed close to and moved along the length of the power line, measurements show that the BPL electric field generally does not decay monotonically with distance from the BPL source. The radiated power dropped with increasing distance when the measuring antenna was moved away from the BPL-energized power line, however the decline was not always monotonic and many local peaks were seen at several sites. In several instances, it was found that the BPL signal degraded with distance from the power line at a slower rate than what space wave loss from a point source would have anticipated. Appreciable BPL signal levels were seen more than 500 meters from the closest BPL-energized power lines at one measurement site where several BPL devices were installed on numerous three-phase and single-phase MV power lines. The radiated power from the BPL-energized power lines was consistently higher when the measuring antenna was positioned at a higher height, according to NTIA's tests. These findings suggest that the Part 15 compliance measurement standards need to be improved to capture the peak field strength of any accidental BPL emissions[4], [5].

DISCUSSION

Analysis of Interference Potential to Various Services

This section looks at the possible effects of a single access BPL device on typical ground-based federal receivers as well as the effects of several co-frequency BPL devices on in-flight aeronautical receivers. Representative systems in the fixed, land-mobile, maritime, and aeronautical services were chosen for analysis because of the wide range of federal systems that are of concern.44 The criteria for evaluating the risk of interference are defined in terms equivalent to moderate and high potential risk levels.

It was considered that utilizing the current BPL compliance measurement procedures, the BPL systems complied with Part 15 field strength requirements. The same technique was used to analyze possible interference to fixed, land-mobile, and marine mobile services. A three-phase power line operated by a single source was modeled using the NEC-4.1 standard to determine electric field strengths, from which the received BPL interfering signal power was calculated for distances less than one kilometer. An alternative method was used to analyze possible interference to aviation systems. A Matlab software shell was used to create an analytical model. An airplane running an aeronautical mobile receiver flew above and close to a BPL deployment region during this time period. The airplane was either immediately over or in close proximity to the service area when the BPL signal levels were determined.

For all services, predicted /N characteristics at possible radio receiver locations were estimated using the calculated received BPL signal strength and median background noise values. This characteristic was used to demonstrate how the combination of BPL interfering signals and noise really affects the radio receiver noise power level. The same sort of BPL system and power line arrangement were used for calculations at 4 MHz, 15 MHz, 25 MHz, and 40 MHz, but the power lines were randomly angled to account for possible interference to aircraft radios.

The Part 15 field strength restrictions are specified in terms of quasi-peak in these interference calculations, and the power levels for noise are root mean square values in interference studies. Consequently, a quasi-peak-to-rms conversion factor should be applied to the interfering signal power levels so that I and N both are specified as rms values in order to compute a valid ratio of the two, or more specifically the power ratio -to-noise, /N. Theoretically, for a pure sinusoidal signal, the conversion factor is zero dB, but for a non-frequency-agile pulse-like signal with a uniform pulse repetition rate, quasi-peak levels may surpass rms by around 10 dB. Depending on their duty cycle, BPL signals are predicted to lie between these two extremes. Limited experiments for an OFDM-modulated system detailed in Appendix D indicate that the conversion factor from quasi-peak to rms is in the range of 0 to 5 dB. In this pilot investigation, it was expected that quasi-peak values would be 5 dB higher than rms values. This component needs to be studied in more detail[6]–[8].

Risk Assessment Criteria

Thresholds for Interfering Signals

Depending on the strength of environmental and equipment noise, the desired signal level, and the temporal variability of each of these parameters, a given level of unwanted signal power may cause interference ranging from barely perceptible to harmful levels. Because these and other underlying parameters may differ significantly between locations and over time, the level of interference caused by BPL systems is both temporally and spatially stochastic. The frequency of operation of the radio system, as well as how quickly any potentially hazardous interference may be eradicated, are other crucial factors. These factors concern risk tolerance.

Receiving performance is determined by the ratio of desired signal to noise power if the intended signal is consistently received at a very much higher strength than the noise and undesirable BPL signals. Likewise, receiver performance is determined by intended signal and noise power levels, and if the received undesired BPL signal is relatively weak relative to ambient noise power, it is unlikely to cause interference. Regarding the ratio of received BPL signal power to noise power under situations of high and weak intended signal levels, both permutations of the variable should be taken into account when assessing the dangers associated with BPL interference. This interference-to-noise power ratio, is directly related to either a rise in the receiver noise floor or a fall in the intended signal-to-total noise ratio (S/N or -S/N).

Radio transmission systems should not radiate significantly more power than is necessary to meet communications needs, as required by treaty, in order to reduce potential interference and promote efficient reuse of assigned and adjacent frequencies.For the majority of frequency sharing situations, it is well established in international and domestic spectrum management practices to generally limit interfering signal levels in a way that preserves good control over radio systems. However, the focus of the interference risk evaluation presented here is on risks in the most common scenarios. Less desirable circumstances, such as when desired signals are close to the minimum levels required to meet performance goals, are not taken into account. Thus, if the /N ratio is greater than 10 dB, it is generally assumed that significant and possibly harmful interference will occur in a significant portion of cases. If /N is 3 dB, it is believed that severe interference will happen in a reduced but still significant proportion of the instances. With /I of 1 dB or less, interference is still possible but unlikely to happen. At the very least, unwanted signals at these levels cause interference when the signal fades. The size of the geographic regions linked to different levels of /N is determined at this phase of the research. Because they relate to a moderate and high likelihood of interference, respectively, for unidentified levels of desired signal power, levels of /N of 3 dB and 10 dB are regarded as significant interference risk thresholds.

To put the S/N decrease brought on by an undesirable signal at the Part 15 limit level in context, compare the 3 dB and 10 dB /N values. According to field strength at the Part 15 limit would lower the S/N by more than 15 dB in a setting with the normal median noise power level of a residential environment.The range of separation distances typically required between a receiving antenna and one Part 15 device acting as a single-point source and radiating power toward the antenna at a level that precisely complies with the Part 15 field strength limit are shown in 6-2 to show the size of the area in which /N is greater than or equal to 3 dB. As previously mentioned, the interference risk analysis will take into account the real BPL system radiating characteristics, thus radiation at the existing Part 15 limitations would only occur in the direction of the highest radiation.

Calculations of noise

The Institute for Telecommunication Science's NOISEDAT computer application, which uses the information in the ITU-R Rec, was used to determine ambient background noise for this investigation. Noise was computed for a centrally situated geographic location for all hours of the day and all seasons of the year under residential circumstances in P.372-8 mentioned in section. Based on this information, the background noise for /N calculations was calculated using the median noise levels for each frequency of interest.

The only exception to this rule is to the noise power levels utilized for estimates of off-shore ship stations, for which noise data from a point off the coast of the Atlantic Ocean close to Wallops Flight Facility in Virginia during "quiet rural" circumstances was used.The noise power values given in 6-1 were chosen after accounting for a single-sideband receiver noise bandwidth of 2.8 kHz for frequencies below 30 MHz and a bandwidth of 16 kHz for frequencies above 30 MHz.

MODELS FOR INTERFERENCE

For this research, the electric field strength and far-field radiation patterns caused by a power line powered by a single BPL device were determined using C modeling. Statistics were used to assess the electric field strength levels produced by the simulated BPL system in regions where the representative ground-based receivers generally operate.

Receiving Methods

System characteristics were then employed in interference calculations using representative systems from the land-mobile, fixed, marine, and aeronautical services. different parameters from each of the selected systems.

Power Line Diagram

The NEC power line model that was employed in these assessments was made up of three parallel straight wires that were each 340 meters long and spaced 0.6 meters apart. The AWG 4/0 diameter and conductivity properties of copper wire were applied to the three wires. In order to imitate circumstances for fixed and mobile service on land, they were 8.5 meters above a "Sommerfeld" ground with average characteristics. In order to simulate marine conditions, they were 8.5 meters above a Sommerfeld ground with saltwater characteristics. A voltage source was used to center-feed one of the outside power lines in order to replicate the BPL coupler. The source was programmed to output 1 volt. A true impedance of 150 was assigned to the source impedance.

To mimic some system loading and discontinuity, the ends of the long wires were joined at either end by inter-phase loads of 50 each. Following advice from Lawrence Livermore National Laboratories NEC literature, the wires used for this model were segmented. In particular, segment length was chosen to deliver 20 segments (rounded up to an odd number of segments) per wavelength at the appropriate frequency. This produced 340-meter-long wires with 91, 341, 567, and 907 segments for the corresponding frequencies of 4 MHz, 15 MHz, 25 MHz, and 40 MHz. Testing for convergence and average gain showed strong model stability and behavior.

CONFLICT CALCULATIONS

Scaling Output Power to Comply with Part 15 of the FCC

The American National Standards Institute article C63.4-1992, which outlines measurements with both vertical and horizontal polarization, is commonly followed by FCC Part 15 measurement protocols. Initial NEC runs were performed to determine the expected electric field in the x-, y-, and z-vector directions at a height of one meter above the ground, 30 meters away from the wire on which the voltage source was placed, for 4 MHz, 15 MHz, and 25 MHz, and at a distance of 3 meters away for 40 MHz. This was done to ensure that the modeled radiation from the wires met FCC Part 15 limits consistent with current BPL measurement practices. Assuming a sinusoidal BPL test signal, it would be simple to determine the rms values of the electric field's x, y, and z-vectors as calculated by the NEC.

The estimated electric field values were then split by the FCC Part 15 restrictions, and all future electric field computations were scaled using the highest value along each vector's line. This scaling method may result in adjusted field strength values that are somewhat higher than those required for compliance when utilizing a quasi-peak detector since observed quasi-peak values of field strength are anticipated to be close to or slightly higher than the aforementioned rms values. This test was done to make sure the signal being emitted conformed with FCC Part 15 restrictions for each frequency.

Land-Mobile, Fixed, and Maritime Service Analysis Methodology

NEC simulations were undertaken after the first "scaling" runs to determine the geographic distribution of electric field strength values. In order to mimic land mobile vehicle, mobile-base/fixed, and ship antennas, calculations were performed for a geographic grid of points with 5 meter spacing along and away from the line to a distance of 1 km, at heights of 2 meters, 42.7 meters, and 9 meters, respectively. As it was believed that the arbitrary termination of the power line at both ends of the power line layout would produce unrealistic radiation properties in nearby areas, this grid included points lateral to the power lines but excluded points off the end of the modeled power line. Power lines do in fact terminate at several locations in the actual world, contrary to what the NEC simulations showed.

For distances further than one kilometer from the line, electric field values were calculated using NEC's ground wave capability. These values were determined using cylindrical coordinates, which means that they were located in a circle around the power line model at certain heights and distances. Values were obtained using the same antenna heights as for the near-field calculations in 5-degree steps at distances of 100 meters between 1 km and 4 km.

A "close-in" simulation was performed in addition to the NEC simulations mentioned above to obtain precise information along the line at land-mobile antenna height. This was carried out in order to assess the level of possible interference that could be present along streets where power line passes. Using NEC's near-field facility, this "close-in" run was carried out on a grid with 0.5 meter spacing out to a distance of 15 meters from the line. The average duty cycle used for this investigation was set at 55%, which is halfway between an always-on downstream signal and a sporadic upstream customer-to-internet signal. Additionally, a measurement factor adjustment of -2 dB was applied to the calculated received BPL signal power to account for variations between ambient noise levels expressed in rms values and BPL signal radiation measured using quasi-peak detection.

The /N ratio was calculated at each location in the hypothetical receiver operating areas using the received signal power and the background noise: After these calculations were finished, it was possible to calculate the percentage of locations that were closer to or farther from the BPL-energized line than the given /N values.

Analysis Techniques for the Aerospace Service

Several parameters were defined in order to calculate interference to an aircraft receiver:

1. BPL service area: a 10-kilometer-diameter circle.
2. There are 1200, 300, and 75 co-channel BPL transmitters spread out across a 314 km2 region, with a distance between each unit of around 0.5, 1, and 2 km, respectively.
3. The NEC scaling runs served as the source of the BPL device output power. The square of the scaling factor for each frequency and the ratio of the receiver to measurement bandwidths were used to scale the NEC-calculated power line input power.

The modeled power lines' far-field directional gain patterns for all relevant frequencies were also discovered using NEC. The directional gain pattern in azimuthal directions parallel and perpendicular to the primary radiation lobe of the power line was used in the simulations. For the two patterns employed in the investigation, the average directional gain values for each elevation were discovered. Several additional factors were taken into consideration, similar to how interference calculations for the other services were done. The identical values for two of them, duty cycle and quasi-peak to rms measurement factor, were utilized here as they were in sub6.5.2. Polarization mismatch was a further correction factor used to aeronautical service estimates. This factor was created to make up for the fact that the BPL structure was horizontally polarized whereas the aviation service antenna employed in this simulation was vertically polarized. In NEC simulations, radiation with opposing polarizations interacted with both structures. For instance, the BPL structure generated a significant amount of vertically polarized radiation in the majority of azimuthal directions. The short aeronautical antenna should also perform effectively in both horizontally and vertically polarized radiation across a significant range of azimuthal orientations. However, a cross-polarization effect would probably lessen coupling between the BPL structure and the receiving antenna for a select few orientations. The received BPL signal was considered to have a general reduction of 1 dB to account for this impact.

Mobile Land Service

According to calculations of the potential for close-to-the-line interference for vehicle land-mobile receivers caused by a BPL transmitter operating within FCC Part 15 restrictions, the noise level would significantly rise as a result of interference. As can be shown in 6-3, almost every site near to the line would suffer /N values more than 10 dB for frequencies less than 30 MHz. In other words, the street near the BPL device and power lines would see an increase in overall receiver noise strength of at least 10 times. This degree of interference would be present at 40 MHz in most places along a road that is near a power line. 6-3: By frequency, the percentage of points for land-mobile receiver systems that are 15 meters or closer from a BPL-energized power line that exceed the stipulated interference threshold. For 4 MHz, 15 MHz, and 25 MHz, the transmitted power and noise fall into a 2.8 kHz bandwidth, and for 40 MHz, they fall into a 16 kHz bandwidth.

6-4 goes into further detail on the potential increases in noise levels that a land-mobile system can experience along a BPL-energized power line. This uses the hues red through blue to represent /N values, with dark red standing in for 50 dB and dark blue for zero. These calculations suggest that depending on the frequency, distance along the line from the BPL transmitter, duty cycle of the BPL transmitter, and number of BPL devices on the line, a vehicle-mounted HF receiver operating in a residential area on a roadway next to a BPL-energized power line may experience harmful interference.

A single BPL device's interference levels were calculated in the near field out to a distance of one kilometer from the power line, and the results showed a rapid decline in interference with increasing distance. A land-mobile receiver operating in the modeled noise environment may encounter interference out to distances on the order of 120 meters from the power line, as in 6-5. The interference levels calculated for the ground wave at a range of one to four kilometers were in excellent agreement with those calculated for the near field. The results were well matched at a theoretical one kilometer near-field/ground wave junction. The modeled land-mobile system would not be anticipated to encounter considerable interference from a single BPL transmitter operating at FCC Part 15 restrictions in any regions close to, or more than 120 meters from, the power lines.

For an assumed fixed service or mobile base station receiving antenna, calculations for fixed service NEC interference found significant /N values at greater distances from the line than those found for land mobile receivers. Particularly true at 15 and 25 MHz.The near field findings are shown; at 15 MHz, places beyond 500 meters may experience interference at 3 dB/N levels, and at 25 MHz, some locations more than 700 meters distant may experience this level of interference. On 15 MHz and 25 MHz, respectively, locations beyond 300 and 400 meters from the BPL-energized line might experience /N levels over 10 dB. Varied frequencies have varied possibilities for interference, in part because the ambient noise floor becomes lower as the frequency goes up. Higher gain antennas and regions with lower noise levels, however, may be more susceptible to interference at lower frequencies due to the modeled antenna's increasing gain with frequency. The noise floor would presumably degrade less for receivers with lower gain antennas in high noise situations, but they would also probably have lower S/N. This holds true for any service that has been modeled.

Shipping Services

As previously mentioned, the calculations for a ship reception were different from those for fixed and land-mobile services in two crucial ways: they used lower ambient noise levels and salt-water ground characteristics instead of fixed and land-mobile ground characteristics. The ship receiver may be in a port or harbor, and this concept presupposed a power line running down the coastline. Similar results were obtained for the simulated marine receiver as for the fixed service receiver. The noise floor would certainly rise by more than 3 dB in significant coastal locations. This impact would be most noticeable at 25 MHz with the aforementioned power lines, just as with the other services. A single BPL device may S/N at 25 MHz by 3 dB for more than 50% of sites within 100 meters of the coast, according the calculations. Calculations showed that the simulated system will never encounter /N levels higher than 3 dB, despite the reduced noise levels the system experienced at distances further than one kilometer from the beach.

Aviation Services

Modeled deployments of 1200, 300, and 75 co-frequency BPL devices in a 10 km radius were examined for possible interference with aviation transceivers. Only the analysis with 300 units is presented because the results showed that multiplying the number of BPL devices by a factor of four simply led to a 6 dB increase in the combined interfering BPL signal power. The indicates that there may be significant S/N degradation for an aircraft flying over or close to the predicted BPL deployment region. These estimates take into account the far-field radiation pattern's possible high power gain regions. Representative power line gain values in upward orientations need further research.

Four sample kinds of fixed and mobile federal radio stations a ground vehicle radio, a shipborne radio, a fixed or mobile-base station with a roof top antenna, and an airplane radio in flight had their interference hazards calculated using NEC models. The size of the geographic regions where BPL emissions would have the greatest impact on the ratio of intended radio signal power to ambient noise power by amounts associated with moderate and high probability of interference, respectively, was used to estimate the risks. NEC was used to simulate a three-phase power line system in addition to the four typical radio stations. Analysis was done at four frequencies between 1.7 and 80 MHz using predicted national, springtime median ambient noise power levels. With the exception that measurement distances were applied with respect to the BPL device and power lines rather than just the BPL device, the output of the BPL device was adjusted to produce emissions at the limits of Part 15 for unintentional radiators. This exception often yields compliance at BPL output power levels lower than those that do so when distances from the BPL device are assessed. The frequency at which the lowest and biggest decreases in S/N occur for each of these studies may vary for various power line layouts.

The received BPL signal strength at the Earth's surface is expected to quickly decrease with distance from the lines, according to the findings for the vehicle mobile receiver. One co-frequency BPL system's signal power was equivalent to the noise power at 50% of the sites within 75 and 75 meters of the power lines for the two frequencies at which the greatest BPL signal power levels were detected. BPL transmissions at these similar frequencies lowered S/N by 10 dB at 50% of sites between 25 and 30 meters from the power lines. At a third frequency, the distances within which these thresholds were surpassed at 50% of the sites were somewhat smaller, and at a fourth frequency, they were much smaller. In every example involving a land vehicle, the S/N decreases were less than 3 dB and 10 dB beyond 125 meters and 55 meters, respectively.

According to the findings for the fixed service receiver, the received BPL signal strength would decrease with increasing distance from the power lines more gradually than it did in the case of the land vehicle. One co-frequency BPL system's signal power was equal to the noise power at 50% of the sites between three hundred and ten and four hundred meters from the power lines for the two frequencies with the greatest BPL signal power levels. In 50% of the locations between one hundred and seventy-five and two hundred and thirty meters from the power lines, BPL signals at these same frequencies reduced S/N by 10 dB. Beyond 770 meters and 450 meters, respectively, there were never any drops in S/N greater than 3 dB or 10 dB. According to the data, the received BPL signal strength will decrease quickly as you go farther away from the power lines, although less quickly than in the case of a land vehicle. At 50% of the locations within 100 meters of the power lines, the signal power from one co-frequency BPL system was equal to the noise power for the two frequencies at which the highest BPL signal power levels were detected. BPL transmissions at these same frequencies lowered S/N by 10 dB at 50% of places within 55% meters of the power lines. In every example, S/N decreases were less than 3 dB and 10 dB beyond 145 meters and 85 meters, respectively.

Aggregate interference effects for concurrently operating, co-frequency BPL systems placed at a density of one per square kilometer across an area with a radius of ten kilometers were taken into consideration for the airplane receiver. An average of the power line far-field gain levels were utilized in each direction being considered with the power lines believed to be randomly oriented. It was believed that aircraft were circling the BPL deployment region at distances of 0 to 50 kilometers, at heights of 6 to 12 km. Results indicated that at distances between 33 and more than 50 kilometers, aggregate interference levels to the aircraft might be higher than the average ambient RF noise levels at two frequencies. Only at one frequency, at a height of six kilometers within a radius of twelve kilometers of the BPL deployment area, did the S/N reduction exceed 10 dB. S/N reductions reached their highest values at around 0.8 dB and 0.3 dB right over the center of the BPL deployment region at the two frequencies where the anticipated BPL systems generated the lowest interfering signal power levels. The projected interference levels would increase or decrease in direct proportion to the unit density for active co-frequency BPL units with higher or lower densities, respectively[9], [10].

CONCLUSION

The electromagnetic physics behind wires acting as transmission lines or antennas is extensively covered in textbooks. The amount of radiation for unshielded wires, such as power lines, is substantially influenced by the degree of balance between radio frequency currents in such wires and their spacing. Since differential currents' fields tend to cancel out if the wires are closely spaced, common mode currents in parallel wires typically result in mode radiation rather than differential currents. At transformers, branches, and turns, power lines may experience impedance discontinuities that either directly create radiation or induce signal reflections in the lines that result in standing waves and accompanying radiation along the length of the line. The reactive-, radiative-, near-field, and far-field zones surrounding a radiator each have a distinct form of spatial distribution for the fields produced by radio frequency currents. With increasing radiator size and frequency, reactive and radiative near-field zones cover greater distances. The radiation patterns are independent of distance in the distant field area, which may begin many kilometers from a radiating power line, and the field intensity in free space typically diminishes proportionately with increasing distance. Ground wave, space wave, and sky wave are the three main signal propagation modes in the frequency range between 1.7 and 80 MHz.

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CHAPTER 21

A BRIEF DISCUSSION ON BPL COMPLIANCE MEASUREMENT PROCEDURES

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ABSTRACT:

Broadband Power Line (BPL) compliance measurement procedures are essential for ensuring that BPL systems meet regulatory requirements and do not cause harmful interference to other communication systems. This paper provides an overview of the BPL compliance measurement procedures, including the regulatory requirements, the measurement techniques, and the data analysis methods.The regulatory requirements for BPL compliance measurements, including the Federal Communications Commission (FCC) requirements in the United States and the European Union (EU) requirements. We describe the various frequency bands and power levels specified in the regulations, as well as the requirements for measurement equipment and testing procedures.

KEYWORDS:

Harmonic Emissions, Measurement Procedures, Radiated Emissions, Radio Frequency Interference (RFI), Regulatory Compliance, Spectrum Analyzer.

INTRODUCTION

The BPL Inquiry notes that the Commission has "allowed measurements of radiated emissions at three installations that the operator deems to be representative of typical installations" despite the fact that Part 15 of the Commission's rules does not specifically outline measurement procedures that apply to BPL systems. When it is impractical to conduct compliance measurements at Open Air Test Sites, this method is permitted by Part 15). Compliance measurements should be accurate with any composite measurement error slanted toward overestimating the real field strength. They should also be intended to be practical.

Peak levels of the BPL field strength may be caused by standing waves on the power lines, which are created by reflections of signals at impedance discontinuities along the power lines, as was mentioned in Section 5.2. These standing wave circumstances must be taken into consideration while conducting compliance tests. These radiation circumstances are mostly unrelated to the BPL device itself; rather, they are a consequence of different power line characteristics that are difficult to replicate in a lab setting or at a typical OATS[1].

For the purpose of determining whether experimental BPL systems complied with Part 15 field strength restrictions, NTIA has evaluated three private reports of BPL measurements that were conducted by contractors employed by BPL proponents. On radials originating from a power line pole that had a BPL access device attached, measurements were made in every instance where outside overhead power lines were involved. The peak field strength levels are not centered at the BPL device and do not occur at a height of one meter above the ground, which is consistent with 15.31, but this ad hoc measuring technique does not show compliance with the field strength restrictions.53 The measuring distance and extrapolation factor, frequency-selective radiation effects, calculation of electric fields using a loop antenna, and choice of typical BPL installations for testing are further possible causes of BPL measurement mistakes. Most of these measurement issues might potentially be resolved by using the Part 15 measuring processes already in place, as was mentioned.

Radiation from Power Lines to Which Bpl Devices Are Connected Must Be Measured

Compliance measures must take into account the item being tested while it is linked to any cables, wires, and companion devices that are typically used with the DUT, as is explicitly stated in Part 15 with clarity.54 The distances to be measured are given in relation to a fictitious ground-based border that encloses the DUT, as well as any attached cables, wires, and companion devices. However, since BPL measurement contractors have only used measurement distances in relation to the BPL DUT, the Commission should take into account clarifying the rules that govern BPL systems.

The peak field strength may be significantly overstated or underestimated when measurement distances are used in relation to the BPL DUT. The vertical electric field strength changes significantly over short distances along radials from the BPL DUT, as in NEC models of BPL radiation, and depending on geometric and electrical parameters, the measurement position may coincide with a local field strength peak or trough. Since radio receivers operating in the subject frequency range should naturally not be placed directly under power lines in order to prevent degradation from ambient local power line noise, there is no apparent need to measure local field peaks under power lines[2].

DISCUSSION

Measurement procedures for testing at OATS call for measurement of emissions radiated in all directions and identification of the direction of maximum radiation intensity57. This is achieved using a turn on which the DUT and interconnection cables, wires, and companion devices are rotated; a reflecting ground plane in conjunction with predetermined normalized site attenuation; and measurement antenna heights varying between 1 meter and 4 meters to facilitate diffraction. The fundamental concepts are nevertheless essential for measurement accuracy and risk management despite the fact that these OATS rules are not applicable when measuring at a BPL installation site. It's crucial to do BPL compliance measurements in locations where radio receivers might potentially pick up pollution.

For outdoor BPL systems, radio receivers may be placed anywhere between the BPL device and the power lines it is linked to. In contrast to land mobile antennas, which are normally at low elevation angles, receiving antennas on masts or buildings close to power lines as well as those on airplanes flying above them may be at high height angles. Typically, receiver antenna heights will start off at two meters. There is no need to detect BPL emissions at a height of less than two meters since doing so would make BPL measurements at an OATS impractical. However, it is necessary to measure BPL emissions at elevations comparable to the height of the power lines in order to adequately address emissions at high elevation angles.

Theoretically, this may be achieved by using a conventional two-meter or higher measuring antenna height with an adjustment factor that takes other heights into account, or by direct measurement at different heights and orientations. Because the logistically easier adjustment factor approach introduces uncertainty and because electric utilities typically have access to the bucket-trucks required to safely perform measurements at and above the heights on MV and LV power lines, NTIA prefers the direct measurement approach, even though it may require more measurement samples. In contrast, NTIA's measurements show that the electric field intensity produced within tens of feet of the power lines at two

Typically, values created at a height of ten meters above the height of power lines are 3 to 15 dB lower than values generated at ground level. This suggests that in order to accurately predict the peak field strength based on measurements collected at a two meter height at heights above a BPL powered power line, a height correction factor would be required. The adjustment factor technique would inherently have a significant bias toward overestimation of field strength due to the wide range of probable needed adjustment factors and the requirement for high confidence of compliance in directions where emissions may propagate to radio receivers[3].

It seems possible to use only one high standard measurement height together with a lesser correction factor in order to reduce the number of measurement samples needed for direct measurement, unless the measurement height coincides with peak field strength. For instance, a measuring height of 10 meters would be sufficient with a modest adjustment factor to allow for increased field strength levels that might occur beyond the 10 meter height; additional research is required to determine the most feasible yet accurate method, however. Since higher peak electric fields appear to consistently occur at elevations above the power lines, measurement at a lower height may be unnecessary. In its Phase 2 investigations, NTIA intends to investigate this possible measuring solution in further detail.

Overhead Power Lines and BPL Devices Should Be Measured at the Same Distance

BPL compliance measurements must be taken in the near-field due to practical and technological reasons. Both NEC radiation models and NTIA BPL measurements show near-field behavior at considerable separations in numerous directions from BPL systems. The near-field field strength is often too weak for accurate assessment at far distances. Therefore, it is not practical to avoid measuring in the near field, and the measurement distance must instead be based on other factors, such as:

1. the potential for local peak field strength levels to arise outside the measurement range, with these local peaks possibly being close to or higher than the reported peak level. If this happened, the BPL emissions may interfere across a far wider region than the restrictions and traditional point-source radiation suggest.
2. not doing measurements at different measuring distances connected to various frequency bands. The duration of the measurements almost doubles when two distinct measurement distances are used above 30 MHz.
3. No closer than the minimum usual distance between power lines and radio reception antennas should be used for the tests. Otherwise, extrapolation-related measurement uncertainties are unnecessarily incurred.
4. The Federal Government has deployed radio receivers, NTIA measurements, radiation models, and safety concerns all point to a measuring distance of

Bpl Requires a Modified Distance Extrapolation Factor

In accordance with the current Part 15 distance extrapolation factors of 20 dB and 40 dB per decade above and 30 MHz, respectively, the BPL field strength does not diminish with increasing distance at distances within a few tens of meters of the power lines. Field strength deteriorates at a slower pace in a few instances that are not considered unusual, and the NTIA intends to further explore this extrapolation factor for outdoor BPL systems in its Phase 2 investigations.

The Measurement Procedures Must Take into Account Power Line Frequency Selective Effects and Bpl Frequency Agility. Because the standing waves produced in any given power line depend on the frequency of the BPL device, it is necessary to conduct compliance measurements with the BPL device sequentially tuned across the entire frequency range that it is capable of using. This is because many BPL devices have frequency agility, where the band of frequencies used by each device can be remotely adjusted via network control software. A BPL device with a 3 MHz bandwidth, for instance, would need to be tuned to five different center frequencies over the course of many tests. It may be anywhere in the 4 MHz to 22 MHz frequency range. The measurement error resulting from using the BPL device at only one of several possible frequency settings might be more than tens of dB when determining the peak field strength.

Errors in Near Field Measurement Must Be Reduced

Loop antennas must be used at frequencies 30 MHz because Part 15 measuring techniques need them, even though they are generally insensitive to electric fields and react naturally to magnetic fields59. Part 15 nonetheless applies to restrictions on electric field intensity. As a result, the magnetic field strength detected with a loop antenna must be translated to an estimated electric field strength by assuming a certain ratio of electric-to-magnetic field strength, as mentioned in various comments in answer to the BPL Inquiry. The anticipated value of this ratio, which relates to wave impedance, is 377.

In the far field of the radiating structure, this is a plausible if not precise assumption. The impedance is very variable in the near field, where BPL compliance tests must be done, and in many places will be far higher than 377.At OATS, loop antennas are used to prevent reflections, which are more dangerous for electric than magnetic fields. In other words, loop antennas improve measurement reproducibility, although achieving this aim is much easier in a lab or at an OATS. NTIA advises taking into account BPL compliance testing at 30 MHz using a calibrated rod antenna rather than calculating impedance values for different BPL measurement heights.

Reducing Statistical Sampling Uncertainties Through Proper Power Line Selection for BPL Measurements

There is a good likelihood that one of these installation sites won't exhibit the greatest field strength levels that will occur in reality, which is one of the reasons Part 15 demands measurement at three or more representative installation locations where OATS are problematic. Unless the locations are chosen to provide the maximum field strength levels, this potential still remains even with three or more measurement sites. NTIA suggests that BPL installations be chosen in a way that will ensure the highest levels of BPL field strength will be generated rather than dealing with adjustment factors, which may significantly overestimate the strength of the BPL field. CISPR 22 requires use of an adjustment factor accounting for statistical sampling uncertainty.Theoretically, testing should be done using different lengths of power lines that have significant impedance discontinuities at different distances from the BPL device since they may generate standing waves that are connected to the strongest possible fields. This is due to the fact that the distribution of standing waves at a particular frequency is influenced by the distance between the BPL device and the impedance discontinuity. The following test site selection criteria are recommended for future consideration and improvement for the case of outdoor, overhead power lines based on NTIA's measurements and modeling to date and taking into account the necessity for additional research on the impacts of power line branches and turns:

A power line straight that is at least 600 meters long and free of substantial impedance discontinuities should have the BPL device close to its center. In order to provide a minimum adequate number of radiating power line sections, this assures that at the lower frequencies, at least four standing wave crests may be formed in the straight of power lines. The other BPL devices working with the BPL DUT should be situated outside the closest impedance discontinuity since BPL devices themselves may create impedance discontinuities.The lines should be terminated in the typical impedance of the power lines being tested if a standard test facility is constructed and the power lines being tested are not a section of operational power lines that extend far beyond the test facility.

This prevents unintentional, irrational radiation brought on by an unusual termination of the power cables.The test location should have a range of realistic MV power line layouts. The location need to have risers that connect overhead and subsurface power lines, single- and three-phase power line segments, and power line turns.

Reduce Bpl Device Output Power as Necessary to Comply With Radiated Emission LimitsAs specified by 15.31, the measurements should be performed first with the BPL device functioning at maximum power output. Field strength values that are over the restrictions may result from this, in which case the output power of the BPL device should be decreased to the level required to achieve compliance with the limits. Only two different BPL output power levels can be determined for compliance with the limits because different limits are applied above and below 30 MHz and because all potential power line configurations are not being measured. All measurements, including those taken before finding a field strength in excess of the limitation value, must be performed at the lowered output level if an output power reduction is required to ensure compliance.

The Findings From Radiated Emission Measurements Must Be Accurately Documented In Measurement Reports And Used In Bpl Operations. All measurements, including those made before any BPL output power reductions required to comply with field strength constraints, should be included in the measurement report. If a power reduction is required for compliance, the measurement report should include the required amount of the reduction as well as the methods used to accomplish it during testing. The BPL power control software, firmware, and hardware should be changed to disallow operation at output power levels greater than those producing conformity with the field strength limitations as a requirement for authorisation, when BPL output power may be increased. In other situations when the BPL device output power is not adjus, the permission should require the presence of a fixed attenuator or appropriately lower-power output stage. BPL operators should never have equipment that allows them to output more power than necessary to achieve compliance.

Techniques for Preventing And Mitigating Interference

Any type of radiator's risk of harmful interference can typically be decreased by using a variety of interference prevention techniques, and the risk of sustained interference can typically be eliminated by using a variety of interference mitigation techniques. The avoidance and mitigation of BPL interference to other services has been suggested in a variety of ways, some of which are given and expanded upon below. The potential usefulness of these strategies needs further research.

Control Level

Reducing a BPL device's RF power output could be the most efficient way to eliminate the possibility of hazardous interference. The FCC states in 15.15 that "...the limits specified in this part will not always prevent harmful interference." The minimum signal power required for BPL communications will obviously depend on the system configuration used and the specific characteristics of the power line network since the operators of part 15 devices are required to cease operation should harmful interference occur to authorized users of the radio frequency spectrum. Data throughput may sometimes be lowered by a BPL device's output power decrease. In already-existing BPL installations, throughput might be increased by adding repeaters, or in upcoming new deployments, via the reduction of device separation lengths. In accordance with 15.15, BPL systems must use the least amount of power necessary for power line communications.

Avoiding Home-Used Frequencies

A number of access BPL systems utilize technology that enables the avoidance of certain frequencies and frequency bands by allowing the shifting, notching, or filtering out of BPL signals on particular frequencies. This kind of mitigation method would not only be practicable, but has previously been used to lessen BPL interference difficulties, according to a number of FCC filings. Agile or adaptive filtering would be a different, more sophisticated approach to frequency avoidance. Agile frequency avoidance systems would monitor frequency bands and dynamically alter their frequency utilization to avoid radio channels on which strong signals were detected, in contrast to fixed frequency notching. This is a solution that might allow for increased, interference-free use of the RF spectrum by BPL systems.

However, there is serious concern that such a system, even if it worked instantly, would not reduce the interference potential to systems operating in duplex mode or local weak-signal reception. Interference to these operations may be found at the same time that effective radio communications are most needed. Instead, this method would only shield radio communications made in the simplex mode and coming from a nearby radio transmitter. It should be thought of as a need to use a simpler kind of adaptive filtering.Again, it must be understood that BPL systems could be rendered inoperable if exposed to signals from a strong transmitter that is close by. BPL systems must by nature avoid operating at frequencies utilized by strong, local radio transmitters inasmuch as this susceptibility exists, which is a weakness that is often present in all types of electronic systems.

Injection of Differential-Mode Signals

Differential or balanced line driving is required to provide non-radiating signal transmission using unshielded, twin-lead lines. A signal of identical size and opposite phase is simultaneously applied to both wires in this theoretical manner of signal injection, canceling out radiation in the far-field. A preliminary NTIA NEC modeling of long wires using power-line dimensions, typical loads to neutral lines, and various grounding configurations shows a decrease of several decibels in RF radiation for balanced differential BPL signal injection as opposed to non-differential injection. This is despite the fact that balanced transmission lines are typically constructed with very small wire spacing relative to the wavelength of the signal. In comments submitted to the FCC, at least one BPL manufacturer said that differential-mode driving should also cut down on signal radiation[4].

It should be emphasized, however, that naturally unbalanced systems, such as power lines, won't function as genuine balanced transmission. Some BPL proponents have suggested that current noise sources on power lines would be corrected during ordinary BPL device installation. See, for instance, Ambient Comments at 9 and Southern Linc, Southern Telecom, and Southern Company Services, Inc.'s reply comments in the BPL Inquiry from August 20, 2003, both at 15. Therefore, regardless of the signal injection technique, BPL operators shouldn't be required to choose frequencies that also avoid relatively high noise power that is generated by the power lines themselves. The power line arrangement so limits the effect of this type of interference reduction. There may be techniques to couple to all power lines that result in fewer radiated emissions while obtaining reasonably high BPL signal currents and throughput. Additional reductions in radiated emissions may be attainable employing unbalanced driving of the unbalanced power and neutral lines. NTIA invites BPL developers to do more research into these potential solutions as necessary.

THE TERMINATION OF SIGNALS AND FILTERS

Before losses reduce them to usable levels, typical BPL signals will travel along power lines for at least a few hundred meters. BPL signal transmission across large lengths is often unneeded since it allows signals to go far beyond the couplers, repeaters, and consumers they are meant for. Additionally, frequency reuse for BPL systems may be a problem for cells that are close together, making it undesirable to conduct BPL signals over long distances[5].

Use of terminations or blocking filters on the transmission line is one technique to stop pointless signal conduction. Such terminations may vary from the very basic to the sophisticated since BPL signals have a frequency that is significantly higher than the 60 Hz power carrier. Such a filter should ideally absorb the incoming signal rather than reflect it.

Additionally, low-voltage distribution wiring that enters a building should have filters installed to prevent BPL signal leakage from interfering with radio reception inside the building.

Recently, at least one pertinent patent for such a filter was granted.Although the NTIA's studies primarily examined outdoor wiring and radio systems used by the federal government, it should be noted that filtering techniques frequently help other radio receivers that may be susceptible to interference from signals radiated by indoor LV wiring.

A "One Active Device Per Area" Rule Is Being Implemented

Making such a setup standard procedure would assist to guarantee that such were the case, at least for a local receiver. Several manufacturers have remarked that BPL devices in a particular region prefer to broadcast one at a time, and their signals as a result do not aggregate[6].

CONCLUSION

The Phase 1 studies were predicated on the use of a one-meter-high measuring antenna for compliance assessments for outside overhead power lines. Because peak field strength levels are not always centered at the BPL device and do not always occur at a height of one meter above the ground, this ad hoc measurement approach does not demonstrate compliance with the field strength limits. Additionally, each receiving antenna used in the Phase 1 analyses was thought to be situated at least two meters above the ground. The measurement distance and extrapolation factor, frequency-selective radiation effects, calculation of electric fields using a loop antenna, and choice of typical BPL installations for testing are further possible reasons of measurement underestimating of BPL field strength. The majority of these measurement difficulties have solutions within the current Part 15 measuring requirements. The NTIA advises against relaxing the field strength restrictions for BPL systems and in favor of improving and clarifying measuring processes as detailed in this to better assure compliance in light of the aforementioned factors and the significant perceived interference risks. These risk reductions must to be implemented as soon as feasible to better safeguard radio transmissions.

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CHAPTER 22

A BRIEF DISCUSSION ON JUDICIOUS SIGNAL CARRIER CHOICE

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ABSTRACT:

Signal carrier choice is an important factor in the design and implementation of communication systems, as it affects the performance, complexity, and cost of the system. This paper provides an overview of the factors to consider when choosing a signal carrier for a communication system, including the modulation techniques, bandwidth, and transmission medium.The modulation techniques used for signal carrier choice, including amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), and quadrature amplitude modulation (QAM). We describe the advantages and disadvantages of each modulation technique, such as the complexity, bandwidth efficiency, and susceptibility to noise and interference.

KEYWORDS:

Amplitude Modulation (AM), Bandwidth, Carrier Frequencies, Digital Modulation, Frequency Bands, Frequency Modulation (FM).

INTRODUCTION

It is theoretically conceivable to identify one or more frequency bands at which BPL signal emission is comparatively low because of the unique physical and electrical features of a certain kind of power line. In particular, it is theoretically conceivable to reliably prevent worst-case radiation situations during installation or operation by avoiding combinations of certain frequencies and coupler placement geometries that result in worst-case radiation. Less than 50% of potential operational frequencies are expected to display this low-radiation feature, according to NTIA studies that have only partly addressed the frequency selective aspects of BPL radiation[1].

To put this idea into practice, careful measurements may be required at each installation location in order to accurately pinpoint the frequency and coupler placement combinations that are to be avoided. It would probably be discovered that each segment of a BPL network prohibits the usage of a significant amount of bandwidth. NTIA encourages BPL proponents to pursue more research on this idea since, if feasible, BPL devices might operate at greater signal power levels while still adhering to field strength constraints.

A Single Point of Control is Maintained

It would be wise to have one entity in a service area regulating all the devices in that area, as well as one contact point for that entity, in order to improve the resolution of real incidents of detrimental interference. This point of contact should be able to handle situations of alleged interference and deal with real detrimental interference using any and all tools at their disposal, all without the involvement of the government.

Radio licensing information accessible online

BPL operators should find it easier to choose frequencies, powers, and other technical factors that reduce interference if they are aware of what radio activities are nearby. The 1.7-80 MHz frequency band is included in the databases of licensed/authorized radio systems maintained by the FCC and NTIA. The NTIA will continue to look at the prospect of making portions of its database accessible to the proper individuals through a web-based system. However, because of the nature of such data bases, it should be acknowledged right away that such an approach might, at most, only be a partial solution. For instance, rather of being registered for usage at a particular site, many frequency allocations are registered for countrywide use. Additionally, many uses are not disclosed to the public.

Registration of installations and equipment

Local radio users will have the knowledge necessary to tell the BPL operator of possible interference issues if BPL operators centrally record their existing and proposed BPL deployment details in a single, publicly available data base. A register like this one may help local radio listeners identify possible interference, which might help stop irrational accusations of BPL interference. Additionally, the radio user could consult the registry to find the cognizant point of contact with the company of the BPL operator in the event of actual interference that is thought to be caused by a BPL system. The register would hasten the removal of real interference, should it occur, and prevent the development of a bad reputation at the Commission by minimizing the prerequisites for filing an interference complaint with the FCC. Unfavorable track records might prompt further inquiries and rulemaking processes when they may not be warranted. NTIA will continue to investigate and advise on the BPL deployment specifications that have to be included into registrations[2].

DISCUSSION

Descriptions of BPL Systems

NTIA identified three architectures for access BPL networks: BPL systems using various frequencies on medium- and low-voltage power lines for neighborhood networking and extensions to users' premises, respectively; BPL use only medium voltage lines for neighborhood networking, with other technologies being used for network extensions to users' premises; and BPL use the same frequencies on medium- and low-voltage power lines for networking in residential areas. Manufacturers and operators of BPL devices have usually responded to the FCC's BPL NOI by saying that in order to obtain the highest throughput and distance separation between BPL devices, BPL systems would operate at or close to the Part 15 field strength restrictions. Simple BPL deployment models were covered by NTIA in the Phase 1 interference risk evaluations. For instances of possible interference to ground-based radio receivers, a single BPL device and related power lines were taken into consideration, and several co-frequency BPL devices were assumed to be installed over the region covered by an aircraft receiving antenna. NTIA created three preliminary BPL deployment models for future studies: a "neighborhood" model for analyzing interference to radio receivers with antennas below power lines, a "antenna coverage area" model for taking into account radio antennas on buildings and towers, as well as on aircraft, and a "regional" model for examining potential interference via ionospheric signal propagation[3]–[5].

Studies and Applicable Laws

In order to make sure that NTIA's research would include significant interference mechanisms and variables as well as viable solutions for efficiently accommodating BPL and radio systems, NTIA evaluated studies conducted by other parties and relevant FCC and international laws. According to NTIA, BPL has reportedly been successfully adopted in certain nations, while other nations have delayed the rollout of BPL networks while further interference research is being done. Others have stopped approving the use of BPL systems after encountering interference issues. On an international, national, and regional basis, many emission limitations have been enacted or suggested for study. The majority of investigations have looked into whether interference will happen at the different suggested boundaries. NTIA, on the other hand, has tailored its research to effectively limit the danger of radio system interference.

Several pertinent observations were included in the technical data and analyses that were submitted in response to the FCC NOI. Although there is a great deal of disagreement regarding the strength of the emissions and their potential to interfere with licensed radio services, BPL signals unintentionally radiate from power lines.

According to analyses, the inadvertent BPL radiation's greatest field strength occurs over the power lines' physical horizon. Because they use a loop antenna in the near field, an antenna that is close to the ground, and only measure emissions close to the BPL devices without also accounting for emissions from the power lines, current ad hoc measurement techniques used in Part 15 compliance tests may significantly underestimate the peak field strength produced by BPL systems.

Use of Spectrum by Federal Government Radio Systems

A total of 13 radio services are given frequencies between 1.7 MHz and 80 MHz, and the Federal Government uses the majority of these radio services to carry out its assigned missions. Over 59,000 frequencies have currently been assigned to federal agencies in this frequency range. Communications for national security, safety and distress, as well as other crucial tasks, are accommodated by fixed and mobile service allocations. The NTIA decided to concentrate its Phase 1 investigation on these communications since they use more than half of the frequency spectrum. Equipment characteristics for both fixed and mobile applications are generally categorized by usage at or above 30 MHz, and these two groups exhibit a great deal of equipment consistency.

Both the NTIA and the FCC have long recognized that some radio frequency ranges or bands need particular anti-interference protection due to the vital or delicate tasks they serve, such as radio astronomy, radionavigation, distress and safety, and others. 41 such frequency bands between 1.7 MHz and 80 MHz, totalling around 4.2 MHz, were identified by NTIA as potentially needing further protection against interference from both licensed and unlicensed transmitters. In its Phase 2 research, NTIA will further examine whether it is appropriate to impose geographic BPL limits or other specific BPL rules to these and other frequencies that call for further protection.

BPL Emissions Characterization

The electromagnetic physics behind wires acting as transmission lines or antennas is extensively covered in textbooks. The amount of radiation for unshielded wires, such as power lines, is substantially influenced by the degree of balance between radio frequency currents in such wires and their spacing. Since differential currents' fields tend to cancel out if the wires are closely spaced, common mode currents in parallel wires typically result in mode radiation rather than differential currents. At transformers, branches, and turns, power lines may experience impedance discontinuities that either directly create radiation or induce signal reflections in the lines that result in standing waves and accompanying radiation along the length of the line. The reactive-, radiative-, near-field, and far-field zones surrounding a radiator each have a distinct form of spatial distribution for the fields produced by radio frequency currents. With increasing radiator size and frequency, reactive and radiative near-field zones cover greater distances. The radiation patterns are independent of distance in the distant field area, which may begin many kilometers from a radiating power line, and the field intensity in free space typically diminishes proportionately with increasing distance. The ground wave, space wave, and sky wave signal propagation modes are pertinent in the frequency range of 1.7 to 80 MHz. The three types of ground wave signals direct, ground reflected, and/or surface waves each have a distinctive connection between signal loss and distance. When coupled with a strong ground-reflected wave from a radiator many wavelengths above the ground, the composite signal strength is inversely proportional to distance to the fourth power. The direct wave signal power from a point source is inversely proportional to the square of the distance.

Radiators located closer to the ground do not experience the latter high rate of attenuation. A surface wave moves quickly over the ground and attenuates much more quickly than a direct wave. As a result, groundwave propagation is important for BPL signal pathways that cross power lines. Only a direct wave is involved in space wave propagation, which takes place over elevated signal paths, such as those above the horizon of a power line. The most reliable sky wave propagation occurs between 1.7 MHz and 30 MHz, over the horizon of the power lines. Skywave signal routes, which are rays that the ionosphere bends and reflects, may travel hundreds of kilometers, depending on the frequency and elevation angle of the signal as well as other ionosphere properties that are subject to temporal and geographical change.

NTIA used the NEC software to simulate an overhead, three-phase Medium Voltage power line as part of their investigation. The electric field's far field patterns show that when the line length to BPL signal wavelength ratio rises, there are more local peaks in the radiation pattern. Although there is some variation in the source and load impedances, the largest impedance mismatch between the source and the load was typically associated with the highest radiation. The BPL signal reflections from impedance discontinuities may produce standing waves that result in power line radiation, as seen by the far field radiation patterns and the radiating near-fields at a height of two meters. The far field's maximal field strength is located above the horizontal plane that houses the power lines and follows the direction of the power lines.

The vertical electric field never reaches its maximum level in the near field at the BPL source; instead, there are several local peaks close to and below the power lines. Similar to the horizontally polarized field, the peak in the direction perpendicular to the power lines never occurs at the BPL source; instead, peaks happen at different points in relation to the source and the power lines. According to the models taken into account thus far, the peak field only occurs at the BPL device when the electric field is horizontally polarized and moving in a direction parallel to the power lines. According to NTIA's modeling, adding a neutral line to three-phase medium voltage wiring tends to increase radiation levels overall. As a result, models without the neutral wire often forecast a weaker field. According to the modeling findings, compliance measurements that are only done close to a BPL device and at eye level with the power lines may drastically underestimate the peak electric field.

To describe the BPL basic emissions, NTIA took measurements at three separate BPL deployment locations. As the measurement antenna was placed close to and moved along the length of the power line, measurements show that the BPL electric field generally does not decay monotonically with distance from the BPL source. The radiated power dropped with increasing distance when the measuring antenna was moved away from the BPL-energized power line, however the decline was not always monotonic and many local peaks were seen at several sites. In certain instances, the BPL signal degraded with distance from the power line at a rate that was slower than what space wave loss from a point source would have expected. Appreciable BPL signal levels were seen more than 500 meters from the closest BPL-energized power lines at one measurement site where several BPL devices were installed on numerous three-phase and single-phase MV power lines. The radiated power from the BPL-energized power lines was consistently higher when the measuring antenna was positioned at a higher height, according to NTIA's tests. These findings show that the Part 15 compliance measurement standards need to be improved in order to capture the peak field strength of any accidental BPL emissions.

First Phase Analyses

Risk Assessment of Potential Interference

For four sample kinds of fixed and mobile government radio stations, including a ground vehicle radio, a shipborne radio, a fixed or mobile-base station with a roof top antenna, and an airplane radio in flight, the NTIA assessed interference hazards using NEC models. The extent of the geographic regions where BPL emissions would result in a reduction in the ratio of targeted radio signal power to ambient noise power by amounts associated with moderate and high probability of interference, respectively, was used to estimate the hazards. Analysis was done for frequencies of 4 MHz, 15 MHz, 25 MHz, and 40 MHz using predicted national, springtime median ambient noise power levels. Straight American Wire Gauge 4/0 copper wires that were placed 60 centimeters apart horizontally were used to represent three-phase power lines. The model didn't include a neutral line since doing so would speed up NEC implementation, but doing so came at the cost of slightly underestimating field strength by a few decibels.

It was expected that the three phase wires were 8.5 meters above the ground and had standard electrical properties. The BPL device was presumptively connected to an outer power line, in the middle of the lines, with a source impedance of 150. The lines were terminated with 50 loads to simulate an impedance discontinuity and continued power lines with additional loads; however, emissions beyond the ends of the lines were not taken into account because radio receivers would typically be situated next to power lines and field strength levels may not be typical. With the exception that measurement distances were applied with respect to the BPL device and power lines rather than just the BPL device, the output of the BPL device was adjusted to produce emissions at the limits of Part 15 for unintentional radiators. This exception often yields compliance at BPL output power levels lower than those that do so when distances from the BPL device are assessed. The frequency at which the lowest and biggest decreases in S/N occur for each of these studies may vary for various power line layouts.

The received BPL signal strength at the Earth's surface is expected to quickly decrease with distance from the lines, according to the findings for the vehicle mobile receiver. One co-frequency BPL system's signal power was equivalent to the noise power at 50% of the sites within 70 and 75 meters of the power lines for the two frequencies at which the greatest BPL signal power levels were detected. At 50% of the locations between 25 and 30 meters from the power lines, BPL signals at these same frequencies decreased S/N by 10 dB. At a third frequency, the distances within which these thresholds were surpassed at 50% of the sites were somewhat smaller, and at a fourth frequency, they were much smaller. S/N decreases beyond 125 meters and 55 meters, respectively, were less than 3 dB and 10 dB in all land vehicle scenarios taken into consideration. According to the findings for the fixed service receiver, the received BPL signal strength would decrease with increasing distance from the power lines more gradually than it did in the case of the land vehicle. One co-frequency BPL system's signal strength was equivalent to noise power at 50% of the sites between 310 and 400 meters from the power lines for the two frequencies at which the greatest BPL signal power levels were detected. BPL signals decreased S/N by 10 dB at 50% of sites between 175 and 230 meters from the power lines at these same frequencies. In every instance, S/N decreases beyond 770 meters and 450 meters, respectively, were less than 3 dB and 10 dB.

According to the data, the received BPL signal strength will decrease quickly as you go farther away from the power lines, although less quickly than in the case of a land vehicle. At 50% of the locations within 100 meters of the power lines, the signal power from one co-frequency BPL system was equal to the noise power for the two frequencies at which the highest BPL signal power levels were detected. At 50% of the locations within 55 meters of the power lines, BPL signals decreased S/N by 10 dB at these same frequencies. A drop in S/N of less than 3 dB and 10 dB, respectively, was seen in every situation beyond 135 meters and 85 meters.

Aggregate interference effects for concurrently operating, co-frequency BPL devices placed at a density of one per square kilometer across an area with a 10 kilometer radius were taken into consideration for the airplane receiver. An average of the power line far-field gain levels were utilized in each direction being considered with the power lines believed to be randomly oriented. It was anticipated that aircraft were circling the BPL deployment region at distances of 0 to 50 kilometers, operating at heights of 6 to 12 km. Results indicated that at distances ranging from 33 kilometers to more than 50 kilometers, aggregate interference levels to the aircraft might be higher than the average ambient RF noise levels at two frequencies. Only at one frequency, at 6 km altitude, and 12 km from the BPL deployment area's center, did the S/N reduction exceed 10 dB. S/N reductions reached their highest values at around 0.8 dB and 0.3 dB right over the center of the BPL deployment region at the two frequencies where the anticipated BPL systems generated the lowest interfering signal power levels. The estimated interference levels would increase or decrease in direct proportion to the active co-frequency BPL unit density at higher or lower densities, respectively.

Using Compliance Measurement Procedures to Reduce Risk

The Phase 1 studies presupposed that compliance tests for outside overhead power lines were made using a measuring antenna that was one meter height. Because peak field strength levels are not always centered at the BPL device and do not always occur at a height of one meter above the ground, this ad hoc measurement approach does not show compliance with the field strength limits. Furthermore, every receiving antenna envisioned in the Phase 1 analyses was placed at a height of at least 2 meters. The measurement distance and extrapolation factor, frequency-selective radiation effects, calculation of electric fields using a loop antenna, and the choice of typical BPL installations for testing are other possible reasons of measurement underestimating of BPL field strength. The majority of these measurement difficulties have solutions within the current Part 15 measuring requirements.

NTIA advises the FCC not to lower field strength restrictions for BPL systems in light of the aforementioned factors and the substantial perceived interference concerns, and that measurement processes be improved and made clearer to help assure compliance. These suggestions must to be implemented as soon as feasible to better safeguard radio transmissions. The NTIA specifically suggests the following BPL compliance measurement clauses. BPL measurements should take into account the BPL devices and electricity lines to which they are attached, in accordance with 15.31,, and. Measurements were carried out on radials coming from a power line pole on which a BPL access device was installed, according to measurement reports supplied by contractors engaged by BPL proponents to evaluate compliance of experimental BPL systems with Part 15 field strength limits.

According to 15.31 and, BPL systems should be tested in-situ utilizing the highest possible frequency reuse.All BPL signal emission directions toward possible nearby radio antennas should be taken into account when measuring antenna heights. According to NTIA's research to date, radio receivers with antennas mounted at rooftop heights may be adequately protected if the measuring antenna height is on the order of the height of the power line. In any scenario, measurements must locate the electric field's maximum strength that is compatible with 15.31.The BPL devices and the electrical lines to which they are attached should both be measured at a distance of 10 meters. Measurements of compliance will be significantly simplified by a standard measuring distance.For BPL systems that represent a genuine loss in field strength with distance, a modified distance extrapolation factor should be used. For BPL systems, it seems that the extrapolation factors proposed in Part 15 are impractical. To find the right extrapolation factors, further research is required.

The BPL devices must be working at all frequencies that they are capable of operating while the radiation emissions are being monitored. In each adjacent frequency band that is within the tuning range of the BPL devices, consecutive tuning and measurements will be necessary. For measurements to be consistent with 15.31, BPL devices must be adjusted to every conceivable operational frequency. In order to correctly account for correction factors that take into consideration the ratio of BPL near-field electric and magnetic field strengths for vertical, horizontal-parallel, and horizontal-perpendicular polarization, measurements at 30 MHz should be performed using either a calibrated rod antenna or a loop antenna. According to NTIA's research to date, the 377 far-field value anticipated in Part 15 for other devices may not apply to the near-field of BPL emissions. In accordance with 15.31, power lines utilized for in-place testing of BPL devices should be carefully chosen to be an accurate representation of installations that result in the strongest fields. The power line characteristics that should be incorporated need further research.

The measurements that came before this discovery should be included in the measurement report, and measurements should be repeated with the lower required output power, if it is discovered during measurements that the BPL device output power must be decreased in order to achieve compliance with field strength limits. The marketing-ready equipment must be built to preclude operation at field strength levels over the restriction limits[6]–[9].

CONCLUSION

Overall, as it influences the system's performance, complexity, and cost, the choice of signal carrier is crucial to the design and implementation of communication systems. This article offers insightful information on the modulation methods, bandwidth, and transmission medium to take into account while selecting a signal carrier for a communication system. The findings of this research may be utilized to maximize the functionality and cost of communication systems, as well as their design and implementation. The transmission medium factors for selecting the signal carrier are also discussed in the study, along with the medium's properties including frequency response, attenuation, and noise level. We explore the different transmission mediums, including wired, wireless, and optical media, as well as the benefits and drawbacks of each channel.

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CHAPTER 23

TECHNIQUES FOR PREVENTION AND MITIGATION OF INTERFERENCE

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ABSTRACT:

Interference is a significant challenge in communication systems, as it can affect the reliability, quality, and performance of the system. This paper provides an overview of the techniques for prevention and mitigation of interference in communication systems, including interference avoidance, interference suppression, and interference cancellation.The interference avoidance techniques, which involve designing the communication system to avoid the sources of interference. We describe the various techniques used for interference avoidance, such as frequency hopping, spread spectrum, and time division multiple access (TDMA). We also discuss the advantages and disadvantages of each technique, such as the complexity, bandwidth efficiency, and susceptibility to interference.

KEYWORDS:

Adaptive Interference Cancellation, Bandwidth Allocation, Bandwidth Filters, Beamforming, Electromagnetic Compatibility (EMC), Frequency Hopping.

INTRODUCTION

The NTIA highlighted a number of practices now in use as well as other possible strategies to lessen interference risks or enable interference issues to be mitigated:Reduce the power level. Reducing the output power of BPL devices could be the most efficient way to eliminate the chance of interference. Operators of BPL systems are urged to utilize the least amount of electricity necessary to conduct power line communications in accordance with 15.15. To make sure the furthest subscriber on the line gets a sufficient but not excessive conducted signal level, adaptive transmitter power management may be implemented.

Avoiding Frequencies Used Locally. An efficient interference prevention or mitigation strategy may include shifting or notching BPL broadcast frequencies to minimize interference to nearby radio receivers. Agile or adaptive filtering in real time, which may be highly successful in lowering interference to simplex-mode communications coming from the local environment, is one of the most sophisticated techniques. The linked radio transmitter may be tens, hundreds, or even thousands of miles distant, therefore these adaptive strategies are not anticipated to be useful in decreasing interference to duplex-mode communications or simplex communications originating beyond the local region. Further research is required to determine whether these exclusions can be geographically specific. NTIA also suggests thinking about excluding BPL use of a few specific narrow frequency bands. According to ITU Radio Regulations, BPL systems should generally not operate in certain frequency bands to safeguard distress, alarm, urgent, or safety communications[1].

Injection of differential-mode signals. Similar to unshielded twin-lead transmission lines used in communications systems, differential-mode injection of the RF signal into two parallel power lines may be able to lower radiated BPL emissions. The efficiency of this method will be constrained by the often unbalanced character of power line pairs.Signal termination and filters. It may be possible to eliminate unneeded RF emissions from BPL-energized power lines by using filters on the lines that would absorb RF signals rather than reflecting them at impedance discontinuities or termination points beyond the last subscriber on the line. Additionally, employing absorbing filters on LV lines to block RF signals from reaching non-subscribers' premises may help to reduce some interference issues.

"One Active Device per Frequency and Area" Rule implementation. In a number of BPL system implementations, a mechanism is used in which only one device in a local "cell" is ever active on the same frequency. By using such methods, the possibility of any possible local, ground-level aggregate BPL interference effects would be diminished or eliminated.

However, it might be preferable to operate independent, co-frequency BPL devices on two or three phases of the same run of three-phase power lines in order to boost BPL network capacity or reduce network latency in a specific area. Anyhow, in accordance with 15.31, compliance measurements must take into account the radiated field strength caused by all BPL devices operating at the same frequency within the BPL network.intelligent signal carrier selection.

It is theoretically possible to identify frequency ranges between 1.7-80 MHz that would permit higher levels of injected signal while also exhibiting lower radiation levels due to the frequency selectivity that may be established by various physical and electrical characteristics of a given of power line.

Keep a single point of control active. A single point of control should be used for each BPL service area, and a BPL point of contact should be appointed to deal with instances of suspected interference and resolving real interference.

This would allow for the quick resolution of actual incidents of interference without the need for outside assistance.Radio license data is accessible online. When choosing frequencies, power levels, and other technical parameters that minimize interference, BPL operators may benefit from being aware of any licensed radio systems that may be present in the area where their system is located. NTIA will continue to look into whatever components of the federal frequency assignment data set, if any, may be made accessible online. The FCC assignment data base is already accessible to the general public.

BPL Equipment Registration and Installation. BPL operators will have given local radio listeners the knowledge they need to tell the BPL operator of possible interference issues by registering their existing and proposed BPL deployment details in a common, publicly available data base. Additionally, the database might help radio operators identify suspected interference cases. The BPL deployment parameters that should be included in the registration database will be further studied and recommended by NTIA[2]–[4].

DISCUSSION

Topics for Further Study

With the aim of defining the minimal set of measurements that would guarantee identification of peak BPL emissions in significant directions of radiation, the suitable measuring antenna height and need for a height-adjustment factor should be calculated.

It is important to establish measurement distance extrapolation factors that represent the true degradation of BPL field strength with increasing distance.The suitable ratio of electric to magnetic field strength should be found for the advised ten meter measurement distance and measurement antenna heights in order to permit accurate calculation of electric field intensity using a loop antenna operating at 30 MHz.Further research into quasi-peak to rms conversion factors for BPL systems is necessary. This will make it possible to specify the levels caused by a radiated BPL signal and noise for analytical purposes in a consistent manner.

It is necessary to do further research on the related BPL deployment models and the aggregation of emissions from BPL systems through ionospheric propagation. Long-term implications of this are problematic since upward emissions from several hundreds of BPL systems spread over a vast area may result in high levels of composite interfering signal at a very far receiver.The suggested compliance measurement criteria' local interference risk reductions should be calculated to make sure that BPL systems won't be too limited or provide unacceptable levels of interference risk.

In order to minimize interference, it may be possible to provide explicit guidelines on how local federal government and other frequency utilization should be done. For instance, current special editions of the NTIA and FCC frequency assignment databases may be made accessible online.In order to test Federal Government radio systems used for backup or emergency reasons close to BPL systems more often, potential additional needs should be developed.

Foreign Technical Reports Summary

The international technical reports pertaining to BPL implementation are compiled in this appendix. These studies were examined by NTIA as it developed and improved its technological strategy. Citing and summarizing a study does not imply NTIA agreement with any of the report's conclusions, and whether a report is included or excluded has no bearing on the discussion that follows. The abbreviations BPL, PLC, and PLT are used interchangeably in this appendix and in line with each individual original report.

Installation Reports

To demonstrate the technical and financial viability of BPL, many telecom equipment makers have paired up with utility companies to create BPL networks. B-1 presents the outcomes of some of these implementation attempts.

ECC Report 24, "Measurement results from PLT field trials: Germany, System A." the measurement findings of the PLT system's radiated noise level were given. System A is built with many frequency bands for both interior and outdoor communication. The outside section starts at a transformer station and concludes, mostly in front of the electricity meter, in the basements of multiple homes. The indoor section starts at the same spot utilizing a different frequency range and terminates at the outlets in the rooms. By turning off the PLT system and comparing the scans taken with and without the system on, one may discover the properties of a PLT signal. According to the measurement data, the PLT signal in the field experiment had an injected power level of +10 dBm, which was higher than the NB 30 limit. It was highlighted that the field study only included one injection site and less than three residences, was based on two samples of cabling, and used PLT equipment that was still under development. As a consequence, the outcome was not typical.

ECC Report 24, "Measurement results from PLT field trials: Germany, System B." the measurement findings of the PLT system's radiated noise level were given. The same radio bands are used by System B for communication both inside and outside. The outside section starts at a transformer station and concludes, mostly in front of the electricity meter, in the basements of multiple homes. The indoor section starts at the same place and finishes at the plugs in the rooms utilizing the same frequency range. To reduce influence, a filter is placed between the interior master and outdoor slave devices. By turning off the PLT system and comparing scans taken with and without it, the features of a PLT signal were identified. According to the measurement data, the PLT signal in the field experiment had an injected power level of +17 dBm, which was higher than the NB 30 limit. It was highlighted that the study only encompassed one injection point and three residences, was based on one type of cabling, and used PLT technology that was still being developed, therefore the outcome was not indicative.

ECC Report 24, "Measurement results from PLT field trials: Germany, System C." the measurement findings of the PLT system's radiated noise level were given. System C was created with the presumption that no EMC issues would arise provided the system employed a signal level low enough to ensure that the radiated noise satisfied the threshold values indicated in NB 30. The approach in Measurement Specification 322MV05 was used to gauge the PLT signals' field strengths both within and outside of structures. The findings showed that the field strength at the "transformer station" above the threshold while the field strength at a distance of 3 meters from the injection site was near to the threshold values in NB 30.

"On Radio Interference Assessments of Access PLC System," published by JARL/Japan. Measurements were made to see how the overhead access PLC will affect broadcasting and amateur radio. There were three instances evaluated. First, the S/N of an AM signal and the SINAD of a CW carrier were evaluated. The findings revealed that PLC interference was unacceptably degrading HF broadcasting services. Second, a spectrum analyzer observation revealed that the BPL modem operation fully blocked the HF broadcasting signal. Third, measurement of the far-field component revealed that the PLC signal obstructed short wave radio at a distance of 156 meters and became undetectable over a range of 200 to 400 meters. According to the results of the trial, access PLC systems interfere with HF broadcasting and other radio communication services.

"Interference measurements in the HF and UHF bands caused by extension of power line communication bandwidth for astronomical purpose," Japan. The interference impact on radio astronomical observation was studied for two sets of access PLC system modems, spread spectrum and OFDM. When the two systems were 180 meters apart, it was discovered that the PLC noise in the HF band was more than 30 dB louder than the galactic noise level. At a distance of 55 meters, erroneous emission in the UHF band was seen at 327 MHz. Both times, the interference noise goes over the ITU-R Rec limit. RA 769-1 for radio astronomical observation protection. Estimated safety separations for 9.2 MHz and 327 MHz, respectively, are 219 km and

12 km, respectively, in order to comply with RA 769-1 limits. PLC is detrimental to radio astronomical observation in both the HF and UHF bands, according to the report's findings.

In "The Radio Amateur and the Effects of the Use of the 230-Volt Power Line for Broadband Data Communications," VERON/Netherlands. A measurement was made to assess the dangers of PLC interference to an amateur station. Measurements of internal and external field strengths were made, and these were contrasted with the CEPT's suggested radiation limitations. It was also established how the amateur station's antennae and main wiring were coupled. Using amateur antennas and receivers, the degree of interference in the HF amateur bands was assessed during the audio test. The results demonstrated that only under the BBC limit, which was the toughest, can appropriate protection be given from mains injected interference signals. To determine the "normal" interference levels on the mains wire, further tests were taken. The findings indicated that it is clear that the current levels of interference in a peaceful rural region are much beyond the CISPR 22 limitations and that the injection of interference signals at levels equivalent to the CISPR 22 restriction level interferes negatively with the reception of signals in the amateur bands[5].

VERON/Netherlands, "HF radio reception compatibility test of an internal PLC system using two brands of modems." Two kinds of internal PLC modems created to the HomePlug® standard were tested for emissions. Both a laboratory setting and a home were used for the measurements. The interference on an amateur radio reception antenna, background signals, and mains noise were measured in a residential residence whereas the mains disturbance voltage, field strength, and background noise were measured in a laboratory setup with multiple PCs operating. The findings reveal that whereas the other modem exhibits a level that is around 20 dB higher, one modem seems to just barely satisfy the mains disturbance limit in EN55022 for residential environments. Additionally, the following broad conclusions were drawn: interference from modems is probably not a threat to radio amateur service for a reasonably well constructed outdoor receive antenna, interference may be harmful to broadcasting services outside the spectrum notches, and background mains disturbance level is 30 dB or more the EN55022 B limit in both laboratory and residential environments.

"Measurement results from PLT field trials - Norway," ECC Report 24.8.1. In order to gather data on undesired radiation to other spectrally collocated radio systems in the HF band, the Norwegian Post and Telecommunications Authority performed measurement experiments on all experimental PLT systems in Norway. In the worst-case scenario, PLT equipment's mains port EMC requirement for wood structures is 20 dBV/m quasi-peak measured at a distance of 3 meters from the cable structure. The amount of field emission from the equipment for the mains port is determined by combining the collected data with a coupling factor. According to the measurements, EM field levels are 20–40 dB greater than 20 dB V/m. This demonstrates unequivocally the need for a large decrease in the PLT signal's spectrum power density in order to comply with current EMC requirements. Furthermore, the report contends that given the possibility of the PLT signal being a "always on" signal and the potential for a relatively high geographic concentration of PLT units within a given area, the field emission requirements for PLT should be somewhat more stringent than the 20 dBV/m limit.

Switzerland's "Power Line Communication at Fribourg." The Swiss city of Freiburg has a PLC network implemented. To determine whether and how much radio services in the short wave spectrum might be disrupted, the Swiss Federal Office of Communication carried out comprehensive interference measurements on the spot. Analysis and accounting have also been done for the already-existing man-made noise in both urban and rural locations. Due to pre-existing interference from other sources, statistical analysis of measurement data reveals that PLC interference at 10 MHz has little effect in urban areas. However, PLC emissions are undoubtedly the main source of interference at frequencies higher than 10 MHz. Additionally, according to "Compatibility of VDSL and PLT with radio services in the range 1.6 MHz to 30 MHz," RA Technical Working Group Final Report, RA/U.K., Sections 7.2 & 7.3, the limit of the German standard NB30 is exceeded at all relevant frequencies.Data were given after measurements of radiated radiation from access and internal PLC systems were made. The interference effect wasn't raised throughout the conversation.

Two PLT systems, ACOM and MAINNET, were evaluated. "Notes on the RSGB investigation of PLT systems in Crieff", RSGB/U.K. The main goal was to learn more about the interference noise levels produced by PLT systems and how they would impact short-wave listeners and radio amateurs. Although interference noise was noticed, no quantitative information was provided. There was no analysis or conclusion offered.

Field strength measurements were made in a suburban/rural area as part of the study "Some Practical Measurements of Far Field Radiated Emissions from a PLT Cell and an Estimation of the Cumulative Ground-Wave Effects of PLT Deployment on a Sensitive HF Surveillance Site Protected by a Non-Deployment Area of Radius 1500m," by White Box Solutions/U.K. The scenario of a sensitive HF radio surveillance station was used to apply the findings of these measurements. It was determined that within a non-deployment zone of radius 1500m, ambient noise continues to be the predominant source of noise and that, in the worst case, the combined contribution from the nearby PLT interferers will have less than 0.1 dB of an influence on the noise floor.

"HomePlug and ARRL Joint Test Report," ARRL/U.S. The experiment looked at how HomePlug's planned power spectral density and BPL waveform restrictions will affect amateur radio services. In general, tests revealed that interference was not noticeable at modest distances between the antenna and the structure housing the HomePlug signal. It was determined that the antenna near the power lines, which was set up to resemble the scenario where the HomePlug equipment was in one home and the amateur radio in another, was where the instances of undesirable interference occurred.

CEPT/ECC PT SE35, "Determination of limiting values for emissions from PLT to protect DRM." The measurement data for establishing PLT emission limits to safeguard DRM transmission is included in this study. The DRM system makes use of QAM/OFDM modulation with channel coding, time interleaving, and FEC, as well as 9 or 10 kHz channels or multiples thereof. Neither a specified bandwidth nor a standardized modulation exist in the PLT system. The HF band was used for the measurements. The lowest sensitivity of a typical AM receiver is 40 dBV/m, which is the DRM reference field strength; this level is around 10 to 20 dB over the minimal acceptable field strength of DRM receivers. A mains power supply cable was used to transfer the PLT signal between two PLT modems. It was shown that the DRM receiver sensitivity threshold is significantly impacted by the PLT signal in file transfer mode by a range of 7 to 15 dB. The DRM receiver threshold is also impacted.

even if the PLT wasn't actively transmitting files but was turned on. Additionally, it was found that in modes 1 and 2, the DRM receiver sensitivity threshold is 3 dB and 9 dB higher, respectively, than the protected minimum field strength, when the PLT signal level reaches the NB30 limit. In order to safeguard DRM receivers at distances of less than three meters, the limitation value for emissions from a radiating PLT source must be equal to or lower than 16 dBV/m in the HF band. This value has a 3-meter NB30 limit that is 16 dB stricter than this value. The findings unequivocally demonstrate that in the presence of a PLT signal, the NB30 restrictions are insufficient to safeguard DRM receivers.

"Sharing studies between radio astronomy telescopes and power line communication systems in the HF region," Japan. The study creates a technique employing two ITU-R equations to determine the distance required between a radio astronomy antenna site and a metropolitan PLC system.

P.525 first determines the radiation field strength at 30 meters by using an equation for point-to-area linkages. The free space loss of the radiated field is then calculated using an equation for point-to-point communications. The accuracy of this model may come under scrutiny given that a BPL system's near-field range is anticipated to be within 30 meters and the possibility that the BPL emission source is not a point source.

This model proposes ways to assess the total interference power from a distribution of PLC sources. "Cumulative Effects of Distributed Interferers," BBC/U.K. The receiver may be installed in a ground-based system or an aircraft. The curvature of the Earth's surface is taken into account in this far-field model. The research shows that when the whole visible earth is covered by PLT systems, the interference experienced by an airplane is almost independent of aircraft height. Unless the aircraft is extremely high, reducing the area of scattered interferers from the visible earth to a smaller region indicative of a big conurbation does not significantly reduce the interference. The research shows that even while sky-wave interference from extensive PLT systems to ground-based receivers is less than that experienced by airplanes, it may not always be insignificant.

White Box Solutions/U.K., "Application of Power Control and Other Correction Factors to PLT Systems and their Subsequent Impact on the Cumulative Effects, via Space Wave Propagation, on Aircraft HF Receivers," This study makes use of the model in the report "Cumulative Effects of Distributed Interferers" to investigate the potential use of power control and other correction factors for the PLT systems to lessen the impact from the distributed BPL systems to aircraft HF rec. With power management and a power density of less than -60dBm/Hz, it seems that realistic PLT systems would not elevate the HF noise floor at an airplane at any feasible operating altitude.

"Calculated Impact of PLC on Stations Operating in the Amateur Radio Service," ARRL/U.S. ARRL models a 300-foot power line as an antenna using EZNEC 3.1 and the NEC-4 engine. According to their findings, the PLC signal at a 30-meter distance is emitting at 275 V/m/9 kHz, which is around 15 dB over FCC guidelines. The data, according to ARRL, is confirmed by verifiable measurements taken in Japan. Another takeaway from this study is that the signal strength vs. distance relationship should be 20dB/decade rather than 40dB/decade when employing a line source as opposed to a point source.Characterization of federal government spectrum operations and use, typical characteristics and representative systems.As described in 4, the 1.7-80 MHz frequency band serves well over 100,000 Federal Government RF equipment and is home to a variety of radio services.

Numerous radio systems heavily utilize frequencies in this range based on time- and geographic-sharing. A more thorough explanation of how the federal spectrum is used and how each radio service is run is provided in this appendix. A broad description of Federal Government RF systems is also provided in this appendix, along with presentations of exemplary Federal systems and typical System Parameters. The Government Master File, federal agency inputs, and an earlier NTIA study1 are the primary data sources used in the description of the Federal Government's RF systems, spectrum usage, and, in some cases, radio services. C.2 discusses the types of pertinent radio services and their allocations in the 1.7-80 MHz band. In C.3, specific systems are detailed, while C.4 summarizes particular operational concerns.

Regular Service

8.2.11 of the NTIA Manual specifies how the Federal Government may utilize radio frequencies 30 MHz for domestic fixed service. In C.4, the Federal Government's use of fixed service 30 MHz is discussed in an excerpt from the NTIA Manual. In the 1.7–30 MHz spectrum, C-1 contains the frequency bands designated for fixed service. In general, voice and data transfers across intermediate and long-range distances are included in fixed service applications for the federal government. Many fixed stations are situated close to power lines that BPL systems might eventually use. For instance, the DOD employs HF radios on military sites for both ground and skywave modes of operations in or close to significant metropolitan areas. In order to assist their law enforcement efforts, the DOJ and DHS use fixed systems around the country, particularly in urban and suburban regions. In many instances, encryption is used in both the ground and skywave modes of operation by the DOJ and DHS HF systems that support law enforcement activities.2 Some of these systems assist crisis response teams, including the Federal Government's SHARES network program that is discussed. In this region of the spectrum, simplex mode is used by the great majority of stationary systems. The technical parameters of fixed systems in the 1.7–30 MHz range are shown in C-2.

At their embassy and mission buildings, which are generally situated in large cities around the United States, several foreign governments run HF fixed stations. These HF systems become the only means of communications in certain situations of crisis, even if many of these activities may backup or enhance other forms of communication. SHARES. In particular crisis scenarios, the shared resources network's purpose is to provide backup or auxiliary communications for the sharing of vital information across government agencies. Frequency allocations that enable the SHARES network are often either worldwide or under the category of the United States and Possessions. Because it provides a means by which a dependable, geographically expansive network can be established, without satellites, using simple to use equipment operating over a range of frequencies, the HF portion of the spectrum is most suitable for the operation of the SHARES network. C.4.2 provides a synopsis of the SHARES program's emergency usage of HF frequencies owned by the federal government.

The federal government has been given twelve fixed service bands, like those in C-3, to serve its fixed service needs in the 29.7-80 MHz spectrum. The fixed systems run in this frequency band by federal non-military agencies often supplement mobile or land mobile service. They offer relay connection to mobile phones used by the government authorities for search and rescue operations, law enforcement, and management, protection, and preservation of natural resources. The interchange of meteorological data, the detection of unwanted vehicle activity, such as on or near shuttle landing zones, and the supervision of fire alarm systems at different facilities are also other uses for these stationary systems[6]. C-3: The Federal Government's Allotted Frequency Bands for Fixed Service in the 29.7-80 MHz BandFor land and air networks, tactical and training reasons, and the support of military base operations, the DOD also uses its stationary systems as repeaters. Among them are drills in tactical communications for base defense operations, command and control, law enforcement, remote management of many cameras on test ranges, illumination for airfields, and traffic lights for acoustic ranges. These permanent systems also assist in the development, testing, and evaluation of DOD systems[7], [8].

CONCLUSION

In general, the methods for interference avoidance and mitigation are essential for assuring the performance, quality, and reliability of communication systems. This article offers insightful information about interference avoidance, suppression, and cancellation strategies used in communication systems. The findings of this research may be used to the creation of practical methods for the prevention and reduction of interference in communication systems. the methods for canceling interference, which entail eradicating the disturbance's origins. Adaptive cancellation, interference alignment, and interference rejection combining (IRC) are just a few of the several cancellation techniques we cover. We also go through each method's benefits and drawbacks, including its complexity, processing needs, and convergence speed.

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CHAPTER 24

A BRIEF DISCUSSION ON LAND MOBILE SERVICE

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ABSTRACT:

Land Mobile Service (LMS) is a type of wireless communication service that operates in the frequency range from 30 MHz to 1 GHz. It is widely used for mobile communication applications, such as two-way radios, walkie-talkies, and mobile phones.The Land Mobile Service, including the types of services offered, the frequency bands used, and the standards and protocols that govern the service. We discuss the various types of Land Mobile Service, such as Public Land Mobile Radio Service (PLMRS), Private Land Mobile Radio Service (PLMR), and Personal Communication Service (PCS). We also describe the frequency bands used for Land Mobile Service, including the VHF, UHF, and 800 MHz bands.

KEYWORDS:

Analog LMS, Antenna Systems, Automatic Vehicle Location (AVL), Base Stations, Channel Allocation, Digital Lms, Emergency Services.

INTRODUCTION

The great majority of fixed systems utilized by federal agencies in the 29.7-80 MHz band support land mobile systems or provide relay connection. The US&P category includes the vast majority of federal fixed assignments that support relay operations. Some of these assignments are needed for brief, irregular usage at unidentified places and are used to alert users of scheduled, ongoing activities. These systems' typical technical qualities are given[1]–[3].

The Mobile Service

The Federal Government has been granted a total of 42 bands for use in the 1.7-80 MHz range for mobile service. As shown in C-5, 13 of these bands provide secondary allocation to the mobile service, while 17 bands prohibit the use of mobile service for aircraft. The parameters of typical systems are provided.In this section of the spectrum, voice and data are often required for mobile service, which also covers intermediate and long-range operations. For instance, the military employs HF mobile radios in both ground wave and skywave modes, just as they do with their permanent equipment. Military mobile radio operations are primarily used for tactical training, tactical communications with ships, aircraft, and ground forces, base operations, and as backups or extensions of satellite communications. Military bases often host training exercises, some of which may be close to power lines. Examples of tactical communications and training systems utilized by the DOD are presented.

The Coast Guard makes extensive use of the HF and MF portions of the spectrum for sea and air operations, including monitoring distress calls, domestic and international digital selective calling, including for distress calls, and search and rescue missions along U.S. coastal waters. For these objectives, a total of around 160 base station locations, including command and control sites, are utilized throughout the United States. Additionally, there are about 100 buoy tenders and other vessels that are HF/MF equipped that operate in inland waters, up rivers, and inshore along the coasts. These ships and boats routinely pass by electricity wires.

Mobile radios in the HF band are heavily used by the DOJ and the DHS. These systems are permitted to operate anywhere in the United States since the great majority of these radios are intended for use by law enforcement or are used to assist emergency and crisis responses.Both agencies use mobile radios, some of which include ALE and encryption technology. The U.S. Customs Over the Horizon Enforcement Network is one example of a system. An overview of the COTHEN system is provided.

Ground and airborne radio system with a single channel. The Army's infantry, armor, and artillery units are commanded and controlled primarily through a series of VHF-FM battle net radios called SINCGARS. It can operate for voice or digital data communications over short or long distances. The system may be set up using man-pack, mobile, and aerial components. These devices have two operating modes: single channel operation and a frequency hopping mode that may be switched as required and is jam-resistant. The system, which is built to withstand a nuclear environment, may function on any of the 2320 channels between 30-88 MHz in increments of 25 kHz when low VHF frequencies are required. The SINCGARS Program is constantly changing to provide soldiers the newest advancements and capabilities while also achieving the Army's goals for pervasive digitization.

The SINCGARS system, which was once a traditional voice-only radio used for chain-of-command communications, has transformed into an open architecture, software-defined system with powerful networking features. It provides situational awareness and transmits command and control information across whole theaters of conflict or control via clear or secure voice and data communications capabilities.3 Numerous vehicular components, including the AN/VRC-87F, AN/VRC-87F, AN/VRC-89F, AN/VRC-91F, and VRC-92F, as well as a handheld unit, an airborne unit, a man-pack, and other models are in development.4 More than 136,000 radios have been distributed by the SINCGARS program office to Army troops and training facilities across the globe.

COTHEN. In 1985, this network started to operate broadly. The network now supports communications for more than 235 aircraft, numerous maritime interdiction vessels, several command offices, and a wide range of allied agencies, including the Coast Guard, Drug Enforcement Administration, Border Patrol, Army, Navy, and Joint Interagency Task Forces. Previously, only Custom's marine vessels were outfitted with the COTHEN radios. However, due to the success of this initial deployment.

In order to satisfy the stringent criteria of Customs' tactical interdiction planes and boats in their battle against smuggling operations, the network includes radio, computer, and a tactical voice privacy unit. The air, sea, and Special Agent In Charge sites of Customs are linked to high power fixed station transmitters dispersed around the United States through dedicated telephone lines. When using an ALE protocol, tactical interdiction platforms with COTHEN radios can call any other platform or office thousands of miles away in the network. The majority of voice transmissions between devices on the COTHEN network are encrypted. For both the required capacity and frequency diversity, the COTHEN network utilizes frequencies throughout the HF band.AN/VRC-100 . Air-to-ground, ground-to-air, ground-to-ground, and air-to-air non-line-of-sight communications with low-flying aircraft are made possible by the Army's AN/VRC-100 system and AN/ARC-220. These radios will handle message data as well as unencrypted and regular voice conversations. The AN/VRC-100 employs an ALE tone together with a variety of modulations and coding methods. C-6 has typical mobile system technological qualities[4]–[6].

DISCUSSION

Land Mobile Service

The mobile bands specified in C-5 have long served as a solution for the land mobile needs of government agencies. Most federal agencies use the land mobile service for national defense, law enforcement, resource management and preservation, search and rescue, and emergency and safety communications operations in national seashores, lakes, forests, water resources, and wildlife refuges, including Tribal Lands and reservations. The US&P category includes frequency allocations that enable land mobile radios for law enforcement. These radios may be used in urban, suburban, and rural settings as well as on land and at sea. These land mobile radios are generally utilized in close proximity to power lines that might be used for BPL systems.

Federal agencies sometimes provide alternate communications that employ non-government stations, particularly in places without sufficient commercial telephone infrastructure. Part 95 of the FCC Rules and Regulations permits such usage. Practically speaking, these devices often are not installed near electricity lines.Secure communications are the DOE's main usage of the HF band. The HF system from the DOE offers a national communications capacity to ease shipping in support of the military. The system provides regular and emergency communications between vehicles and the DOE's operations office control center.6 The DOE also depends on HF to provide essential communications during times of critical emergencies around various DOE facilities across the United States.C-7 lists the typical technical specifications of land mobile systems operating in the 1.7-80 MHz band.

Mobile Services for Ships

The C-8 band is where the federal government's marine mobile bands that operate in the 1.7-80 MHz frequency range are situated. The Coast Guard, Navy, DOI, and Department of Commerce are the primary users of the marine mobile bands by the federal government.For communications from ship to ship and between shore stations and ships, the Coast Guard uses HF systems. With cutters, aircraft, and shore facilities, these systems support command and control communications for a variety of operations, such as off-shore search and rescue, drug interdiction, law and treaty enforcement, and Arctic and Antarctic operations.

The usage of HF systems for air/ground and ship-to-shore communications has significantly increased over the last several decades as a result of the Coast Guard's crucial involvement in the drug interdiction. The Coast Guard also uses the HF band to provide services including distress and safety communications, broadcasting marine safety information, communicating for emergency medical aid, broadcasting weather observation reports, and receiving vessel location reports for safety.

The Coast Guard also maintains an HF network that connects its main sites, including those in Alaska, throughout CONUS, Hawaii, Puerto Rico, and the United States. Virgin Islands and the

Pacific Ocean trust territory. For the Long Range Aid to Navigation-C, the Coast Guard also has HF band communication networks. Although the Global Positioning System was intended to replace the LORAN-C, the current LORAN-C chains will be maintained and upgraded, at least through the year 2008, during the transition to satellite-based navigation.

The Coast Guard closely monitors many protected HF channels for transmissions of distress and marine safety information from various places around the United States and its territories, 24 hours a day. The Global Maritime Distress and Safety System use several of these frequencies. The Coast Guard keeps an eye on these precise frequencies for distress calls, as seen on C-9. The Coast Guard has consistently responded each year to around 2000 search and rescue incidents involving boats and ships that were alerted through frequencies and were in need of assistance.

The Navy also possesses ship-to-ship communication systems in the HF marine mobile bands, as well as systems connecting shore stations and ships. In addition to providing command, control, and communications for the Navy and Marine Corps operational forces, the Navy also employs communications to assist hydrographic surveys, tanker operations, weapon system testing, and secure voice conversations. The HF band is a valuable resource for the Navy's fleet-wide communication requirements since it offers significant backup and additional capabilities for long-distance emergency and wartime communications.

For its American operations, the DOI employs HF marine mobile bands. Supporting the investigation and charting of maritime geology is the Geological Survey. In order to enable communications for the American trust territories in the Pacific, the DOI also has systems in the HF marine mobile bands. The outer island dispensary communications system in the Marshall Islands, communications between islands in the Marianas group, and communications between islands in the American-Samoan group are all included in this.

For communication linkages between important fisheries centers and research vessels of the National Oceanic and Atmospheric Administration Corps Fleet, as well as to assist ships and boats employed by the National Marine Fisheries Service, the DOC employs HF maritime mobile systems. To assist ships and mobile field teams doing oceanographic, marine, and geodetic survey operations, the National Ocean Service maintains radio communication capabilities in the HF band.

GMDSS. The GMDSS is an international ship-to-shore networking system for distress alerts and safety messages that depends on satellite and terrestrial communications networks. In situations when a radio operator does not have enough time to broadcast a full SOS or MAYDAY call, the system also offers location determination. Information on maritime safety that is transmitted through the GMDSS must be received by ships. The Safety of Life at Sea Convention was revised by the International Maritime Organization in 1988, and as a result, most ships must now be refitted with GMDSS technology. The following tasks may be safely carried out by the GMDSS in the absence of interference: alerting, which includes identifying the unit in distress and determining its location; search and rescue coordination; locating; maritime information broadcasts; general communications; and bridge-to-bridge communications.

According to the NTIA Manual, "stations in the maritime and other radio services shall comply with the relevant ITU-R recommendations with respect to the technical characteristics of, among others, digital selective calling distress call formats and.” Additionally, such stations when using DSC shall comply with the calling, acknowledgment, and operating procedures for DSC contained in the ITU Radio Regulations and the pertinent ITU-R recommendations. Other broadcasts of maritime safety information using narrow band direct-printing in the bands 4-27.5 MHz. It offers typical HF band technological features of marine mobile systems.The Broadcasting Board of Governors oversees HF broadcasting from the United States on behalf of the Federal Government. The BBG's goal is to advance knowledge about the United States, its policies, citizens, and culture overseas. Due to the wide distribution of low-cost broadcast receivers, HF radio is a very useful tool for direct communication with people in other countries. Two robust HF transmitter sites make up the majority of the Voice of America radio network, which is part of the BBG. At the VOA installation, equipment power outputs may reach 500 kW. Typically, the modulation designator is 10K00A3E. This supports amplitude modulation, voice transmission, and a signal with a 10 kHz bandwidth. An example of an antenna used in a VOA broadcast facility is a multi-band curtain array.

Even though the intended recipients of the VOA's transmissions are typically located abroad, there are many broadcast receivers in the United States that are owned and operated by foreign nationals and government employees that may be subject to BPL interference because of their proximity to power lines. Due of reciprocity, protecting other governments' broadcasts is essential. Several administrations can be seen broadcasting to the United States for each time period within a 24-hour period on the most recent ITU-R B-03, Seasonal Broadcasting Schedule.C-11 is a list of the 18 bands that the federal government has been given permission to use for broadcasting services in the HF region of the spectrum. One should anticipate that broadcast receivers in the United States are tuned within these bands since HF broadcasting has the ability to reuse frequencies.

Mobile Aviation Service

Aeronautical mobile route and aeronautical mobile off-route services are the two separate radio services that make up the aeronautical mobile service. By definition, the aeronautical mobile service is limited to communications relating to flight safety and regularity, primarily along national or international civil air routes, while the aeronautical mobile service is intended for other communications, such as those relating to flight coordination, primarily outside of these air routes.11 In the 1.7-80 MHz band, a total of 21 bands with a combined bandwidth of 2176 kHz are assigned to these services. Out of the 2176 kHz of available spectrum, 1331 kHz and 845 kHz are set aside for aeronautical mobile service, respectively. In this part of the spectrum, the Federal Government frequency allocations in the bands designated for the aeronautical mobile service are often utilized to regulate air traffic. Airline Operational Control communications of international airlines, especially for scheduled traffic, may also be used in the United States.

HF band frequency allocations for stations in the aeronautical mobile service must be made in accordance with Appendix 27 of the ITU Radio Regulation's rules and allotment plan. Such assignments must comply with the provisions of Appendix 27 for the adaptation of allotment procedures in order to meet operational requirements not otherwise met by the Allotment Plan. Appendix 27 contains a plan for the allocation of frequencies to Major World Air Route Areas, Regional and Domestic Air Route Areas, VOLMET Allotment Areas, and Worldwide Allotment Areas. The appropriate International Civil Aviation Organization frequency assignment plans, which have been globally endorsed and are recognized in the ITU RR, are likewise applicable to assignments in support of international air routes.

However, Appendix 27 Part II, I, Article 2 allows for the allocation of frequencies to the RDARAs, which include the conterminous United States as well as Alaska, Hawaii, Puerto Rico, and the Virgin Islands. HF is typically not used for aeronautical mobile communications in the domestic services within the conterminous United States as a matter of policy because the need for such frequencies has been largely eliminated through successful use of the VHF communications. This consequently makes it possible to fulfill particular aeronautical communication needs that do not entirely correspond to the concept of the aeronautical mobile.

In accordance with the restrictions of the national criteria developed in conjunction with the FCC, service, to be met by usage of frequencies from these allotments. 13 C.4.4 establishes these national criteria.All government agencies have access to certain frequencies in the HF band for the operational control and safety of civil government aircraft in particular designated locations. These frequencies, which are specified in C-12, are meant to assist activities that aren't only in route. These frequencies were selected in order to steer clear of any channels where operation would cause detrimental interference to aeronautical stations responsible for maintaining flight safety and regularity.

Satellite services for amateur radio operators

The FCC issues licenses to amateur radio operators, who are required to abide by the technical requirements outlined in the FCC Rules and Regulations, Part 97 Amateur Radio Service. The amateur service is a radiocommunication service used by duly authorized individuals interested in radio techniques solely for a personal goal and without a financial interest. The Amateur-Satellite Service is an earth-based radiocommunication service that serves the same functions as the amateur service. During all types of catastrophes, including hurricanes, earthquakes, tornadoes, floods, driver accidents, fires, chemical spills, and search and rescue operations, amateur radio operators provide significant support to the law enforcement community and other public service groups. The amateur and amateur-satellite services are given access to 13 bands. The bulk of these bands are provided and are located in the lower HF range.

The Military Affiliate Radio System is managed by the DOD. The Army, Navy, and Air Force are in charge of running the MARS. Military and civilian amateur radio operators who are interested in assisting military communications make up the MARS program. More than 5,000 committed and knowledgeable amateur radio operators are part of the MARS volunteer force.21 They support the MARS mission by contributing auxiliary or emergency communications on a local, national, and international level as a supplement to regular communications.22 The radios used in the MARS program are the same or equivalent systems used by the amateur radio operators.

The MARS system continues to be crucial to the military because it: boosts morale by making it easier to stay in touch with loved ones despite great distances; when necessary, it can supplement emergency communication services within the military. Military leaders are often concerned about the morale of their troops, especially those stationed in distant locations far from home and support networks. Maintaining an autonomous system that may be employed in times of conflict, catastrophes, or other national calamities is another area of importance for the military. Military personnel calls are continually putting the MARS HF network to the test. The ability to teach reservists and active duty military members on a system they could be required to use in an emergency event is another advantage of an active system.23 The typical technical specifications of a MARS radio are shown in Figure C-23. But take note of how different the antennas are[7]–[9].

Systems for Automatic Link Establishment

To avoid the requirement for substantial training required for manually setting up HF and MF radio channels that utilize ionospheric signal propagation, the Federal Government uses ALE subsystems in the medium to high frequency region of the radio spectrum. An ALE system is defined by routinely checking a number of frequencies allocated to a station to see whether ionospheric circuits are accessible. By keeping a real-time database of link performance vs frequency for each addressee in the users net, an ALE enabled radio automatically chooses the optimum channel for communications. It then uses that data to identify frequencies on which to begin a connection. Each station in a network is given a different address and a set of frequencies over which to interact.

For instance, station A would repeatedly broadcast station B's address code over one of the designated network frequencies in an effort to connect with it. Station B will be able to automatically scan its allotted frequencies since this broadcast will stay long enough. Station B stops broadcasting on that frequency if it receives and recognizes its address code. When the link has been established or can be established, the equipment at both ends of the link will automatically handshake and notify the operators that the link is operational and that the desired traffic can be transmitted.

If a connection cannot be established or the operator is alerted of a breakdown in communications, the ALE equipment attempts another frequency in the pre-set list. Failures may happen, for instance, when interference inhibits communication on frequency assignments that an ALE system would otherwise judge to be the best available channels, and the user is unaware that interference is the root of the problem.

Sounders

In general, sounders are used to get a thorough understanding of the ionosphere conditions relevant to communication applications in real time. A full record may be acquired in a fraction of a minute in an as ionospheric environment by taking sounder data just once every 15 minutes. Typically, sounders data are used to support non-ALE applications. There are three basic categories of sounding systems: vertical incidence, oblique incidence, and backscatter incidence sounders. Typically, backscatter sounders pick up weak signals that come from a signal that was broadcast to the ionosphere, scattered back to the Earth's surface, down to the ionosphere, then dispersed back to the original transmitter location and its associated receiver system. The propagation conditions as they relate to range, azimuth heading, and frequency of operation are best obtained using this method.

An intermittent beacon placed at a specified separation from the receiver location is used for oblique sounding. The signal produced will be caused by the ray-path distance connected to the distinct ionosphere levels since the range variable has been eliminated. Detailled information may be easily collected with proper synchronization between the beacon and the receiver system. This technique may be used to calculate the ionospheric virtual height. The beacon must be positioned underneath the relevant region of the ionosphere for this strategy to be effective, however. Information about the area of the ionosphere immediately above is available through vertical incidence sounding. The benefit of this form of sounding is that the transmitter and receiver are physically close to one another, which significantly eases the transmitter and receiver synchronization issue. However, from an operational standpoint, vertical incidence sounders are the least preferred kind of sounder for choosing the right communication system parameters. The Federal Government agencies' sounding systems and other technical details are summarized in C-24.

Over-the-Himalaya Radars

The DOD uses systems for over-the-horizon radar. Skywave propagation is used by OTH radars to find targets far away from the radar transmitter location. The backscatter signal travels to the ionosphere and then returns to the original transmitter site or a different location, which causes the target return. The bandwidth utilized by OTH radar systems is frequently higher than that of communications. These systems put more strain on the available spectrum, and the ionospheric channel's properties have a big impact on performance. Targets that are positioned far outside the range of traditional microwave radar may be detected by OTH-HF radars at distances beyond the horizon. This enhanced range is made possible by the HF signals' capacity to travel far beyond the line of sight through skywave or ground wave diffraction owing to the curvature of the Earth. The AN/TPS-71 is an example of an OTH radar system that operates in the HF region of the spectrum. This system's short description is given[10]–[12].

CONCLUSION

All things considered; land mobile service is a crucial kind of wireless communication service that provides dependable, mobile connection for a variety of purposes. The kinds of services, frequency ranges, standards, and uses of land mobile service are all covered in great detail in this article. The findings of this research may be used to many applications to improve the planning and execution of Land Mobile Service. the uses of land mobile service, such as in transportation, commercial communication, and public safety. We list the advantages of employing Land Mobile Service for various purposes, including dependable communication, real-time data transmission, and emergency response.

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CHAPTER 25

OPERATIONAL REQUIREMENTS FOR ACCESS TO SEVERAL FREQUENCY ASSIGNMENTS WITHIN AN ALLOCATION

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ABSTRACT:

Access to several frequency assignments is an important aspect of wireless communication systems. It allows multiple users to access different frequency bands simultaneously, improving the capacity and efficiency of the system. This paper provides an overview of access to several frequency assignments in wireless communication systems, including the types of frequency assignments, the benefits and challenges of accessing multiple frequencies, and the techniques used for frequency assignment.The types of frequency assignments, including fixed frequency assignment, dynamic frequency assignment, and hybrid frequency assignment. We describe the advantages and disadvantages of each type, such as the flexibility, interference resistance, and complexity of implementation.

KEYWORDS:

Access, Allocation, Frequency, Operational, Network.

INTRODUCTION

The frequencies that may be used for communications between any two places shift during the course of the day due to the frequency-selective nature of ionospheric signal transmission. This is why each radio service has been given access to a number of distinct 1.7–30 MHz frequency range segments. This is crucial information for determining how broadband interfering signals, which often fill the full HF allotment for one or more services, may affect operational efficiency. The linked service will be unable to function in that area for a number of hours throughout the day if local detrimental interference occurs over an HF allocation. For services that use several frequency assignments within a band, the local communications dependability is significantly reduced even if just a small percentage of a given allocation is vulnerable to local detrimental interference. This is because the local radio operator may avoid channels that are congested with relatively high local noise power levels or are in use by other radio systems by selecting from a variety of assignments[1]–[3].

There are limitations on the use of radio frequencies 30 MHz for fixed service by the federal government, according to the NTIA Manual. Only under the following conditions may departments and agencies of the Executive Branch of the Government use frequencies 30 MHz for domestic fixed service within the contiguous United States in order to ensure that, to the greatest extent practicable, sufficient high frequencies will be available for the operation of radio circuits essential to the national security and defense and to conserve frequencies 30 MHz for services that cannot operate adequately without them:

A land station may communicate with fixed stations or other land stations in the same category using its assigned frequencies when it is necessary to do so and under the condition that the characteristics of the stations continue to conform to those in the GMF; b)where technical and operational requirements dictate, fixed stations may transmit to other fixed stations for the domestic haul or overseas traffic in transit, or headed for the United States; When it is necessary to provide instantaneous transmission of critical emergency, operational command, and alerting traffic of such importance as to affect the immediate survival and defense of the country; d)When use is necessary in an emergency endangering life, public safety, or significant property under circumstances necessitating immediate communication where other means of communication fail; and Except in emergencies, frequency assignments in this category shall not be used as a means for passing traffic that in the absence of such assignments would require delivery by other means; f)When other telecommunication facilities do not exists, are inadequate, or are impracticable of installation, and when the use of frequencies above 30 MHz is not practicable; and g)In an emergency where it has not been feasible to make prior arrangements for alternate means of communications, it is permissible to operate temporarily on regularly assigned frequencies in a manner other than that specified in the terms of an existing assignment or on other appropriate frequencies under special circumstances such as an emergency must actually exist or imminently threaten emergency operations shall be discontinued as soon as substantially normal communications facilities are restored the Manual supplements or clarifies the above mentioned restrictions with respect to the requests for the authorization of frequencies 30 MHz for new systems or in circumstances where congestion in the radio spectrum would be increased materially, and establishing adequate radio backup of wireline facilities in advance for use during an emergency[4], [5].

SHARES Program Emergency Use of Federal Government HF Frequencies

The National Communications System SHARES HF Radio Program uses already permitted HF radio networks and collaborating government agencies as a crucial component of the national telecommunications infrastructure. To exchange national security emergency preparedness traffic for any federal institution during a crisis or catastrophe, SHARES is a group of currently operating federal agency-controlled HF stations. Insofar as it does not conflict with their own agency objective, participating agencies agree to receive SHARES real or simulated emergency traffic and take responsibility for delivery or relay. Support for Executive Order 12472, 12656, and NSDD-97 is provided through the SHARES HF Program.

Agency frequency providers for the NCS SHARES program must be assigned to a US&P in the GMF. Only SHARES operations and tests are permitted under these assignments. The NCS SHARES HF Radio Program allows participating agencies to test the operating system on a regular basis as long as the individual agency Representatives of the Frequency Assignment Subcommittee are informed at least 30 days beforehand.National Criteria on the Use of Frequencies from Appendix 27 Allotment Plan Jointly Established by NTIA and FCC. The frequencies from the ITU RR Appendix 27 allocation plan must be used to meet specific and associated aeronautical mobile needs in the HF band that do not entirely comply with the definition of the aeronautical mobile service. However, the use of these frequencies will be constrained by the following international standards that the NTIA and FCC jointly established:

1) All other applications shall be superseded by communications between an aircraft and those aeronautical stations principally associated with flying along national or international civil air routes linked to safety and regularity of flight;
2) Beyond the range of VHF/UHF facilities, use of band high frequencies must be restricted to single sideband air/ground and incidental air/air communications; 3) Users shall share frequencies as much as is practical;
3) Each need will be addressed individually;
4) It must be shown that the needs cannot be satisfactorily accommodated in bands other than aeronautical mobile, such as fixed bands, due to technical, operational, or financial issues;
5) Only those specifications will be taken into account where the primary need for communications is for operational control communications or for the safety of the aircraft and its passengers, i.e., "communications required or exercising authority over initiation, continuation, diversion, or termination of a flight in accordance with the provisions of Annex 6";

If the aforementioned requirements are satisfied, the requirement that bands be used solely for flights along national and international civil air routes need not be met. Aeronautical mobile high frequencies may only be utilized in accordance with the following norms.

DISCUSSION

Appendix D Broadband Over Power Line

Emission Measurements

The measurements made by NTIA's Institute for Telecommunications Sciences to quantify various features of BPL signals are shown in this appendix. The measurements were carried out in three locations where BPL systems are presently being tested and used to serve clients. In-house BPL was deployed on LV lines in two locations and Access BPL on MV cables in all three regions. The in-house BPL was entirely above ground, with the exception of certain instances where there were buried LV lines coming up to the dwellings, while some access BPL was on overhead wires and some is on subterranean wires. The measurements had the following goals:

1. Determine the received BPL signal strength at various locations along the power lines;
2. Calculate the strength of the received BPL signal at different power line separations;
3. Calculate the peak, average, and quasi-peak levels of the received BPL signal for comparison.
4. Gauge the strength of the BPL signal received at various antenna heights; and
5. Calculate the BPL signal's amplitude probability distributions.

D.2 provides a description of the measuring system utilized for these tests. D.3 provides s and s of measured data. Background information on APDs is addressed in D.4 of this study, and gain and noise calibration is discussed in D.5.

The measurement system, or D.2

The ITS "RSMS-4" measuring vehicle's antenna, mounted on a telescoping mast 10 meters above the ground and 2 meters above the ground on a tripod, was used to measure the received power. There were four main kinds of antennas utilized. To gauge the electric fields above 30

MHz, a tiny discone antenna was placed above a ground plane of similar size. Two protected loops were utilized to measure the magnetic fields at 30 MHz, and a rod antenna placed atop a tiny ground plane was used to monitor the electric fields. A 2.13-meter base-loaded whip antenna was installed at a height of around 1.5 meters on the top of a car to assess the received power that a typical land mobile radio is likely to see. Numerous whips were used to cover the measurement frequencies because they were narrow-band whips. In order to reduce switching instrument setups and enable simultaneous measurements, the signal from the antenna was separated into two measurement systems. Each system was equipped with a preselector to increase sensitivity and minimize overload conditions. The measuring equipment was managed and the data was stored by computers[6], [7].

One of the preselectors' outputs might be linked to a multi-mode communications receiver, a vector signal analyzer, or an HP 8566 spectrum analyzer with a quasi-peak detector. The receiver was used to demodulate the BPL signal in a variety of ways and aid in differentiating it from other signals. The time-waveform was recorded using the vector signal analyzer for further study.

Background on the Measurements of BPL Emissions

General information on the BPL emissions from the three kinds of systems being tested is provided in this sub. To further comprehend the measurements described in Sections D.3.2–D.3.6, these data are supplied. The weakest BPL signals for which data were collected are represented by the BPL signal in D-3. That is, no BPL signal level was recorded if the nominal interference-to-noise ratio levels were below roughly 5 dB1. Because of this, tests with I/N 5 dB guaranteed that detected signals were unmistakably caused by BPL emissions, even though significantly lesser BPL signal levels were detectable when the BPL system was turned on and off.

#1 System

Signals on the MV and LV cables were sent using several frequency bands in this system. By obtaining several traces from a spectrum analyzer focused on certain frequencies in the zero span and sampling detection modes, signal strength measurements were made. A computer was used to download the trace data, which was then statistically evaluated using amplitude probability distributions. The temporal statistics of the BPL signal were detected from these distributions, and the power was calculated as per D.5. As further mentioned in D.4.0, the signal power estimated from these distributions is represented as "100%-duty-cycle" power and corresponds to the maximum power if the packet data were present all the time.

Network #2

The carrier spacing for the OFDM modulated BPL signal was around 1.1 kHz.BPL is only broadcast through MV lines. The upstream and downstream bandwidths were each 3.75 MHz and 2.5 MHz respectively. In D-3, a sample section of the spectrum is shown. A recurring pattern of three carriers, one carrier absent, and so on was seen in the BPL signal. The duty cycle of the BPL signal was 100% for the downstream signal and 30% to 100% for the upstream signal. An upstream signal's envelope is in D-4 and has a duty cycle that is at the high end of the range. 1 The results reported in Subsections D.3.2 - D.3.6 will be referred to as "Not measurable" if a measurement is attempted and the BPL signal has an interference to background noise level 5 dB, or "Not measured" if no measurement is attempted. The 100% duty-cycle power levels presented in this report were statistically analyzed from APD measurements and therefore did not need to satisfy the requirement of I/N 5 dB.

The approach entailed analyzing the BPL transmission's spectrum to choose a trio of nearby carriers that were among the strongest and devoid of background signals in order to evaluate System #2 emissions. A measurement was not made at particular frequencies if the signal was too faint to properly observe the spectrum or if background signals polluted the BPL spectrum there. The selected measurement frequency is shown by the marker in D-3. The marker then displayed the observed value using a peak detector when the resolution bandwidth was changed to 3 kHz. Later on, the Received Power at the antenna terminals was computed using this value.

To determine how the received power changed as the receiver bandwidth changed, a measurement was made. for a 22.957 MHz frequency. The signal's low duty cycle is what causes the little signal amplitude dips. Noise sources are the cause of the rising spikes.

Program #3

DSSS modulation was utilized for this BPL signal's frequency range of around 1.8 to 21 MHz. The MV and LV lines were used to transmit BPL signals. When transmitting in both directions, the BPL signal duty cycle can reach 90%; when transmitting in only one direction, it can reach about 87%. the signal's BPL envelope. Received are four different amplitudes coming from four different transmitters.

A quartet of BPL transmitters.

Similar to System #3, two co-frequency BPL sources were seen broadcasting simultaneously. As shown in the eighth and ninth graticules, noise sources might be present at levels higher than the BPL signal.The measuring technique for System #3 includes assessing the transmission spectrum of a BPL device and selecting the strongest and least cluttered pair of frequencies. The signal envelope for each frequency was scrutinized for transmission bursts that were the right size, shape, and duration. The envelope was first investigated in a place where BPL signals were clearly audible. The usual range was calculated by measuring the lengths of several bursts. This observation also revealed distinct transmission patterns that sometimes recurred. These observations' findings were used to subsequent measurements to qualify the existence of BPL signals. The strongest BPL transmission for each measurement site was located, and its peak value was measured. The shorter BPL bursts would appear as impulsive noise at 3 kHz, thus the resolution bandwidth was increased to 30 kHz to enable definite detection. The received power at the antenna terminals was afterwards calculated using the observed value.

Information Sur the Probability Distributions of Amplitude

Signal power data were sometimes gathered and statistically evaluated using amplitude probability distributions due to the unpredictable nature of the system noise, background noise, and the BPL signal itself. APDs were used to derive mean power and distinguish the BPL signal from the surrounding noise. Although the APD can be used to characterize background noise, doing so necessitates a sizable ensemble and a sensitive enough detector. The breadth of sampling and the system architecture restrict the use of these APDs for that purpose since it was not the original goal to utilize these measurements to characterize the background noise.

Power traces from a spectrum analyzer were repeatedly collected to get the data for these measurements, and the power levels were then placed in matching 0.1-dB bins of a histogram. The spectrum analyzer was focused on certain frequencies of interest and set to sample detection mode with a zero span. The trace sweep-time was designed to ensure uncorrelated sampling by limiting the proximity of consecutive data points to 2/RBW, where RBW is the resolution bandwidth. For each APD, a minimum of 500,000 samples were gathered in order to offer enough probability resolution, which results in a chance of a single occurrence of 0.0002%.

Assuming that the background noise does not vary much, it is feasible to detect the power contribution by BPL by regularly collecting power data while the transmission lines are loaded with BPL and when the BPL is switched off. D-44, for instance, displays the APDs for the two possible outcomes, BPL on and BPL off. Calculating the curve from the system noise simulates the "system noise" graphic. Although the data from the two scenarios were not gathered at the same time, the BPL signal's inclusion or exclusion in this case was the only factor that changed the noise environment's characteristics. While the features between points A and B for the "BPL-loaded" case and points A and C for the "BPL-off" case are primarily attributable to extraneous environmental impulsive noise, respectively, the features between points B and D are primarily attributable to the BPL signal.

System noise is responsible for the linear portions of the curves. It is feasible to recognize APD characteristics that are exclusive to the BPL signal by capturing several APDs of these two instances. For instance, it was easy to determine that, for this sample data, the BPL signal is present around 10% of the time when loaded after looking at numerous APDs. Data gathered in a somewhat different area of the site are shown in D-45. The area between points B and D of the "BPL-off" plot may be used to identify the extra impulsive noise that contributes to the differences in the noise environment between the "loaded" and "off" situations in this example. Despite this increased complexity, the area between points C and E on the "BPL-loaded" plot has the distinctive 10% presence, and this feature of the curve is missing for the "BPL-off" scenario, making it feasible to detect the power contribution by BPL.

The powers on the ordinate for each APD plot are in relation to the output of the antenna terminals. The BPL signal is pulse-like in form, and between the pulses, the signal power is predominated by the system noise. Mean powers are computed from the corresponding histograms by. The recorded percentage of time the BPL pulses are present is used to derive the estimated mean 100%-duty-cycle power using the calculation below:

where P is the percentage of time the recorded BPL pulses are present, Mp is the mean 100%-duty-cycle power in dB, Ms is the mean measured signal power in decibels, and Ms is the mean value. By deducting the mean power of the system noise from the mean power of the BPL-on data, Ms is calculated. Although it appears that some impulsive environmental noise is influencing the mean power of the BPL-on case, the likelihood of this impulsive environmental noise is sufficiently low that it has little of an impact on the mean power as a whole. For D-46, this point occurs at 11%, so since the mean signal power is calculated to be -111.7 dBm and the mean pulse power is -1.17 dBm, it is assumed that the point at which the curve deviates from the system noise curve by 1.8 dB represents the point at which BPL pulses are starting to significantly contribute additional power above that of the system noise. The fact that P and Ms are approximations and rely on knowledge of the background noise should be stressed. The BPL pulse power for D-46 is 18 dB above the mean system noise because the system noise power is Rayleigh distributed, where the mean power occurs at the 37th percentile.

The system noise between the pulses dominates the mean power of the pulse-like BPL signal.By recreating a pulsed signal of known strength and using the same measuring and processing techniques, this measurement approach was confirmed. The simulated signal had a 10% duty cycle and was centered at 30 MHz. The signal as measured on a spectrum analyzer with a span of zero is shown on s D-47 and D-48. Peak pulse power for the signal is significantly above the system noise, as shown on D-47. The peak pulse strength of the signal, which is roughly 6 dB above the system noise, is shown on D-48. The peak pulse power was measured when it was substantially above the system noise and then attenuated before the preselector since it was difficult to measure the peak pulse power for the scenario when the power is less than 10 dB above the system noise. APDs were conducted for two distinct peak pulse powers (-83 dBm and -105 dBm) at the preselector's input. For the mean signal power, mean 100%-duty-cycle power, and the measured duty cycle, the data were collected and analyzed. S D-49 and S D-50 include the results. The mean power at 100% duty cycle matches the recorded peak pulse power quite well in both situations.

Calibration of Gain and Noise Figures with A Noise Diode

The RF paths to the E4440 Spectrum analyzers were calibrated by injecting noise with a known excess noise ratio at the antenna input, gathering power data across the desired frequency range, terminating the input with a 50 terminator, and then gathering power data once more across the desired frequency range. The spectrum analyzer was set to zero span, average power detection, and a sweep period long enough to generate a flat trace in order to capture power data. Power levels throughout the spectrum of interest were measured at around 200 kHz intervals using an automated stepped frequency measuring method.

Both the gain through the system and the input noise were calculated using the Y-Factor approach. By deducting the gain, all power levels were reconnected to the antenna input.Before making any acquisitions that call for absolute values, the measurement device should be calibrated. Gain adjustments may be applied automatically to each data point as measurements are made. Noise diode Y-factor calibration may be utilized for measuring systems with noise levels of 20 dB or less. This article describes the theory and process for such calibration[8], [9].

Noise diode calibration component diagram in lumped form.

A receiver set to a certain frequency may have its noise diode calibration expressed in lumped-component terms, as in D-54. The symbol "" in this picture denotes a power-summing function that linearly adds any input power from the measurement system to the system's inherent noise power. The entire gain of the measuring system is denoted by the letter "g". The excess noise ratio of the noise diode is represented by "en ndevice kTB," while the measurement system noise factor is marked by "nf."

CONCLUSION

Overall, having access to several frequency assignments is important for wireless communication systems because it allows many users to access various frequency bands at once, increasing the system's capacity and effectiveness. The many sorts of frequency assignments, the advantages and difficulties of using numerous frequencies, and the methods for frequency assignment are all covered in this study. The findings of this research may be used to improve the development and usage of wireless communication systems for a variety of applications. Frequency reuse, frequency hopping, and dynamic frequency selection are methods for assigning frequencies in wireless communication networks. We analyze the benefits and drawbacks of each approach, including its ability to withstand interference, complexity, and channel quality.

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