Power Line Communication Technology

L.I. Oborkhale, M.Eng. and O. Shoewu, M.Sc.*

Department of Electronics and Computer Engineering,
Lagos State University, Epe, Campus.

*E-mail: engrshoewu@yahoo.com

ABSTRACT

Power Line Communication and Technology, PLCT for short, is an emerging technology with significant new business potential for both the electricity supply and telecommunications sectors. The liberalization and deregulation of these sectors, currently underway in Nigeria is a major driving force in the development and exploitation of PLCT technology.

Since power lines were devised for transmission of power at 50-60 Hz, and at most 400 Hz, the use this medium for data transmission, at high frequencies, presents some technically challenging problems. Besides large attenuation, power lines are one of the most electrically contaminated environments, which makes communication extremely difficult. Further, more the restrictions imposed on the use of various frequency bands in the power line spectrum limit the achievable data rates. This paper gives a concise overview, summary of limitations, and evaluation of recent trends in Power Line Communication Technology.

(Keywords: power line, communication, technology, frequency, telecommunications, transmission)

INTRODUCTION

This paper is set out to study the use of power line communications in communications engineering, and to examine its advantages to the engineering industry.

Power line communications implies the use of the power supply grid for communication purpose. It is important, however, to observe that already, every building is connected to the power grid and, moreover, practically every room in the developed world and much of the developing world, has power line contact points. The extent of this existing wiring cannot be matched by either the present telecommunications or cable TV wiring. Because of this fact, the use of this network for the transmission of data in addition to power supply has gained a lot of attention.

Power Line Communications and Technology (PLCT) is a rapidly evolving technology, aiming at the utilization of electricity power lines for the transmission of data. The currently available technologies (i.e., wire/cable/fiber optics and wireless/satellite) have not yet given solutions to this critical problem (Surrey, 1996).

It is important to mention that the emerging PLCT technology opens up new opportunities for the mass provision of local access at a reasonable cost. In addition, PLCT can provide a multitude of new services to users which are difficult to implement by other technologies (e.g., remote electricity meter reading, appliance control and maintenance, energy management, home automation, etc.).

All players in the telecommunications and energy sectors will feel the technology and business impact of the implementation of the PLCT technology, strongly. It is an enabler for utilities and others to become important players in building the Information Society, as it provides a new platform for interactive information-based services in local communities (Dixon, 1994).

Power lines connect power generation stations to a variety of customers dispersed over a wide region. Power transmission is done using varying voltage levels and power line cables. Power line cable characteristics and the number of crossovers play an important role in determining the kind of communication technology that needs to be used. Based on the voltage levels at which they transfer power, power lines can be categorized as follows:

1. High-Tension Lines: These connect electricity generation stations to distribution stations. The voltage levels are typically of the order of hundreds of kilovolts and they run over distances of the order of tens of kilometers.

2. Medium-Tension Lines: These connect the distribution stations to pole mounted transformers. The voltage levels are of the order of a few kilovolts and they run over distances of the order of a few kilometers.

3. Low-Tension Lines: These connect pole-mounted transformers to individual households. The voltage levels on these lines are of the order of a few hundred volts and these run over distances of the order of a few hundred meters.

Figure 1 below is a pictorial representation of Power line Networks.

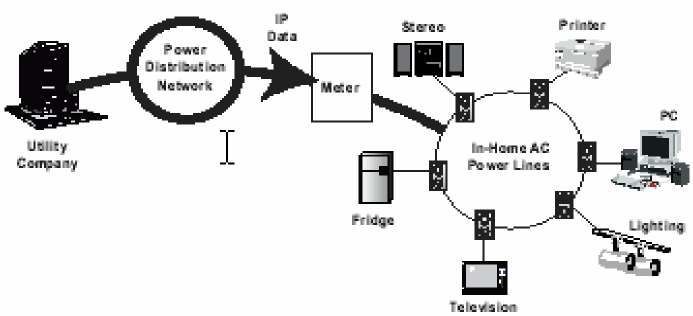

Figure 1: Power Line Networks.

High-tension lines represent excellent carriers for RF energy as we only find open wire equipment with very few crossovers. A transmission power of about 10 watts is often sufficient to overcome distances of more than 1000 kilometers. In the early part of 19^{th} century the first carrier frequency system (CFS) began to operate on high-tension lines in the frequency range of 20 - 900 KHz. During the past, and even nowadays, the main purpose of CFS is to maintain the operability of the power supply.

While in former times speech transmission was dominated, today we have more and more digital data communications due to the rapid progress of overall automation. Through the application of modern digital modulation and coding schemes, a significant enhancement of bandwidth efficiency could be achieved for CFS (Van Der Gracht and Donaldson, 1995).

Medium and low tension lines are characterized by a large number of cross connections and different conductor types (e.g., open over head wire and cable).

Long distance RF signal propagation is seriously hampered in this environment because of high attenuation and impedance matching problems. Around the year 1930, ripple carrier signaling (RCS) began to operate on these lines. These used a frequency range below 3 KHz down to 125 Hz with amplitude shift keying (ASK) modulation technique.

It should be noted that power line communications in the past were utilized for by the Utility Corporations (UCs) in maintaining the seamless power supply (Dutta-Roy, 1999). The UCs generally regarded the power distribution wiring as a "natural" medium for their communication needs, as all-important stations are connected.

Recently, data communications over low-tension lines has gained a lot of attention (Ygge, 1998). This is encouraged by the explosive growth in the telecommunication industry along with advances in digital signal processing, error correction coding, and electronic hardware. Digital devices using low-tension power lines can be categorized based on the bandwidth they use. They are:

1. Low bandwidth digital devices

2. High bandwidth digital devices

THE RELEVANCE OF POWER LINE COMMUNICATION

Power line Technology will open up many new business opportunities for applications and customer services, for both the telecom and electricity sectors in future Nigeria. In this regard, there are various strong, sometimes unique, motivations to consider the PLT-enhanced power line as a very important element of the future Information Society infrastructure. The relevance of powerline communication are discussed below:

- **Power Grid Is Ubiquitous**: The low-voltage power grid has as a unique feature that which constitutes an already existing networked infrastructure to billions of private customers as well as businesses. It is at the same time a large-scale as well as very fine-grained infrastructure: connecting billions of people all over the world, but also even crossing the boundaries of homes and buildings to individual wall outlets and sockets, home appliances and electrical industrial equipment (Redford, 1996).

- **Power grid support communication services:** Although PLC technology is relatively new, both in terms of telecommunication capabilities and commercial equipment cost reductions, it has already been shown that present, relatively limited, data rate transfer speeds are already sufficient for many useful innovative applications. A number of useful services are already feasible with data transmission in the kbps range, while current PLCT speeds are on the order of 10 mbps.

- **Power grid**: The grid is already in place thereby enhancing the cost effectiveness of this technology. Because the power line infrastructure is already in place, it is potentially cheaper than other forms of local telecommunications access, as these will generally require tremendous investment to achieve comparable scale and grain size.

PROTOCOLS FOR POWER LINE COMMUNICATION

Various protocols have been developed for use by low bandwidth digital devices for communication on power lines. Each of these protocols differ in the modulation technique, channel access mechanism (CAM), and the frequency band they use. A brief overview of these protocols is presented in the ensuing discussions.

THE X-10 TECHNOLOGY

The X-10 technology is one of the oldest power line communication protocols. It uses a form of amplitude shift keying (ASK) technique for transmission of information. Although it was originally unidirectional (from controller to controlled modules) recently, some bi-directional products are being implemented. X-10 controllers send their signals over the power line to simple receivers that are used mainly to control lightning and other appliances. Some controllers available today implement gateways between the power line and other media such as RF and infrared (Alvord, 1997).

A 120 KHz amplitude modulated carrier, 0.5 watt signal, is superimposed into AC power line at zero crossings to minimize the noise interference. Information is coded by way of bursts of high frequency signals. To increase the reliability each bit of information is transmitted, which limits the transmission rate to 60 bits per second. This represents poor bandwidth utilization, while the reliability of transmission is severely compromised in a noisy environment. These are the main reasons why this technology has limited applications.

THE CEBus PROTOCOL

The CEBus protocol uses a peer-to-peer communication model. To avoid collisions, a carrier sensed multiple access with collision resolution and collision detection (CSMA/CRCD) protocol is used. The power line physical layer of the CEBus communication protocol is based on spread spectrum technology patented by Intellon Corporation.

Unlike traditional spread spectrum techniques (that is used in frequency hopping, time hopping, or direct sequence), the CEBus power line carrier sweeps through a range of frequencies as it is transmitted. A single sweep covers the frequency band from 100 - 400 KHz. This frequency sweep is called a chirp. Chirps are used for synchronization, collision resolution, and data transmission. Using this chirp technology, a data rate of about 10 KHz can be obtained (Hunt, 1998).

LONWORKS TECHNOLOGY

LonWorks is a technology developed by Echelon Corporation and provides a peer-to-peer communication protocol, implemented using Carrier Sensed Multiple Access (CSMA) technique. Unlike CEBus, LonWorks is a narrowband spread spectrum modulation technique using the frequency band from 125 KHz to 140 KHz. It uses multi-bit correlator intended to preserve data in the presence of noise with a patented impulse noise cancellation.

HIGH BANDWIDTH DIGITAL DEVICES

High speed data communication over low-tension power lines has recently gained a great deal of attention. This is fueled by the unparalleled growth of the Internet, which has created accelerating demand for digital telecommunications. High bandwidth digital devices are designed to exploit this market. More specifically, these devices use the existing power line infrastructure within the apartment, office or school building for providing a local area network (LAN) to interconnect various digital devices.

It has to be noted that the existing infrastructure for communications like telephone lines and cable TV has very few outlets inside buildings. By use of gateways between these and Power line LANs a variety of services can be offered to customers. Some of the applications include high-speed Internet access, multimedia, smart appliances/remote control, home automation and security; data back up, telecommunications, entertainment and IP-telephony (Hunt, 1998).

High bandwidth digital devices for communication on power line use the frequency band between 1 MHz and 30 MHz. In contrast to low bandwidth digital devices, no regulatory standards have been developed for this region of the spectrum. Devices using this unlicensed band need to be compliant with the radiation emission limits imposed by the regulatory bodies. It should be noted that internationally agreed, distress, broadcast, citizen band, and amateur radio frequencies also occupy this portion of the spectrum. Hence, the technologies being developed for high-speed digital communication over power lines should have the ability to mask certain frequency bands for future compatibility. The section that follows gives a brief overview of power line channel characteristics in the frequency band between 1 MHz and 30 MHz (Van Der Gracht and Donaldson, 1985).

CHARACTERISTICS OF POWER LINE

Power lines were originally devised for transmission of power at 50-60 Hz, and at most 400 Hz. At high frequencies, power line is very hostile for signal propagation. In this section a brief overview of channel characteristics will be given (Sweet, 1997).
High bandwidth digital devices communicating on power line devices need to use powerful error correction coding along with appropriate modulation techniques to these impairments. In the following discussion, the OFDM modulation scheme and its application over power line shall be previewed.

ATTENUATION

High frequency signals can be injected on to the power line by using an appropriately designed high pass filter. Received signal power will be maximum when the impedance of the transmitter, power line, and the receiver are matched. Dedicated communication channels like Ethernet have known impedance, thus impedance matching is not a problem. However, power line networks are usually made of a variety of conductor types and cross sections joined almost at random. Therefore, a wide variety of characteristic impedances will be encountered in the network. Further, the network terminal impedance will tend to vary both at communication signal frequencies and with time as the consumer premises load pattern varies. The impedance mismatch would result in a multipath effect resulting in deep notches at certain frequencies (Hunt, 1998). In a typical home environment the attenuation on power line is of the between 20 dB to 60 dB and is a strong function of load. Figure 2 shows the attenuation characteristics of a sample power line channel. Note the deep notches at 11, 13.5, 15 MHz created by the multipath effect.

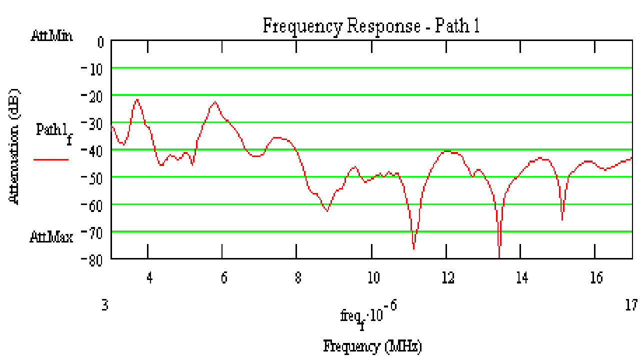

Figure 2: Attenuation Characteristics of a Sample Power Line Channel.

NOISE

The major sources of noise on power line are from electrical appliances, which utilize the 50 Hz electric supply and generate noise components which extend well into the high frequency spectrum. Apart from these, induced radio frequency signals from broadcast, commercial, military, citizen band, and amateur stations severely impair certain frequency bands on power line.

Electric appliances can be divided into three categories based on the nature of noise they produce in the high frequency bands. They are:

1. Single impulsive noise
2. Periodic impulsive noise
3. Continuous impulsive noise

The most common impulse noise sources are triac-controlled light dimmers. These devices introduce noise as they connect the lamp to the AC line part way through each AC cycle. These impulses occur at twice the AC line frequency as this process is repeated every ½ AC cycle. Figure 3 shows the periodic impulsive noise caused by a dimmer on powerline.

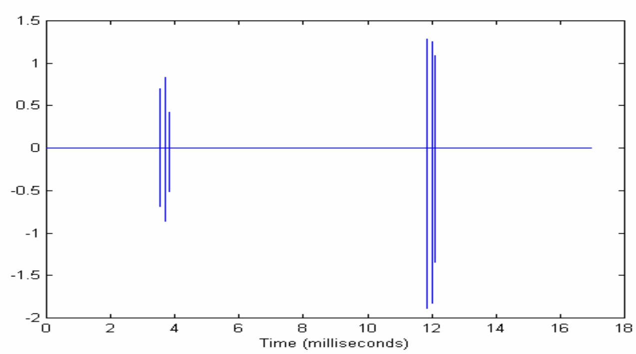

Figure 3: Sample of Periodic Impulsive Noise Created by Dimmer.

This kind of noise is produced by a variety of series-wound AC motors. These motors are found in devices such as vacuum cleaners, drillers, electric shavers, and many common kitchen appliances. Communtator arching from these motors produce impulses at repetition rates in the several kilohertz range. Continuous impulsive noise is the most severe of all the noise sources.

OFDM MODULATION

The choice of modulation scheme is dependent on the nature of physical medium on which it has to operate. Modulation schemes for use on power lines should have the following desirable properties:

1. **Ability to over come non-linear channel characteristics**: Power lines have very non-linear channel characteristics. This would make equalization very complex and expensive, if not impossible, for data rates above 10 Mbps with single carrier modulation. The modulation technique for use on power lines should have the ability to overcome such non-linearity without the need for a highly complicated equalization.

2. **Ability to over come multipath spread:** Impedance mismatch on power lines results in echo signal causing delay spread of the order of 1ms. The modulation technique for use on power line should have the inherent ability to over come such multipath effect.

3. **Ability to adjust dynamically:** Power line channel characteristics change dynamically as the load on the power supply varies. The modulation technique for use on power lines should have the ability to track such changes without involving large overhead or complexity.

4. **Ability to mask certain frequencies:** Power line communications equipment use unlicensed frequency band. However it is likely that in the near future various regulatory rules could be developed for these frequency bands also. Hence it is highly desirable to have a modulation technique that could selectively mask certain frequency bands. This property would help in future compatibility and marketability of the product globally (Sweet, 1997).

A modulation scheme that has all these desirable properties is Orthogonal Frequency Division Multiplexing (OFDM) (Dulta-Roy, 1999). OFDM is generally viewed as a collection of transmission techniques. When applied in wireless environment it is called OFDM. However in a wired environment the term Discrete Multi Tone (DMT) is more commonly used. OFDM is currently used in the European Digital Audio Broadcast (DAB) standards. Several DAB systems proposed for North America are also based on OFDM. OFDM under the name DMT has also attracted a great deal of attention as an efficient technology for high-speed transmission on the existing telephone networks (e.g. Asymmetric Digital Subscriber Loop or ADSL).

THEORY OF OPERATION

The basic idea of OFDM is to divide the available spectrum into many narrow-band, low data-rate carriers (or subcarriers). To obtain high spectral efficiency the frequency response of the subcarriers are overlapping and orthogonal, hence the name OFDM. Each narrowband subcarrier can be modulated using various modulation formats where BPSK, QPSK and QAM are commonly used.

If the subcarrier spacing is chosen much smaller than the coherent bandwidth of the channel, the channel transfer function reduces to a simple constant within the bandwidth of each subcarrier. In this way, a frequency selective channel is divided into may flat fading subchannels, which are much easier to equalize. The need of equalization is completely eliminated by using differential modulation technique. Differential modulation improves performance in environment where rapid changes in phase are possible. OFDM can be implemented equally well with coherent modulation and demodulation to maximize the signal to noise ratio. This approach is preferred for performance-oriented systems, like point to multipoint licensed radios where the highest bit rate per hertz is most important. A schematic block diagram of OFDM is shown in Figure 4.

OFDM modulation is generated using a Fast Fourier Transform (FFT) process. M bits of data are encoded in the frequency domain onto N subcarriers (M=N x B where B is the number of bits per modulation symbol. B=2 for QPSK). An inverse FFT (IFFT) is performed on the set of frequency carriers producing a single time domain OFDM "symbol" for transmission over a communication channel.

The length of time for the OFDM symbol is equal to the reciprocal of the subcarrier spacing and is generally a very large time compared to the data rate. After this a cyclic prefix is inserted by simply copying the last part of the time domain waveform and prepending it at the start of the waveform. The use of cyclic prefix is two fold. It makes the Inter Carrier Interference (ICI) zero even in the presence of time dispersion by maintaining orthogonality. It also acts like a guard interval removing Inter Symbol Interference (ISI).

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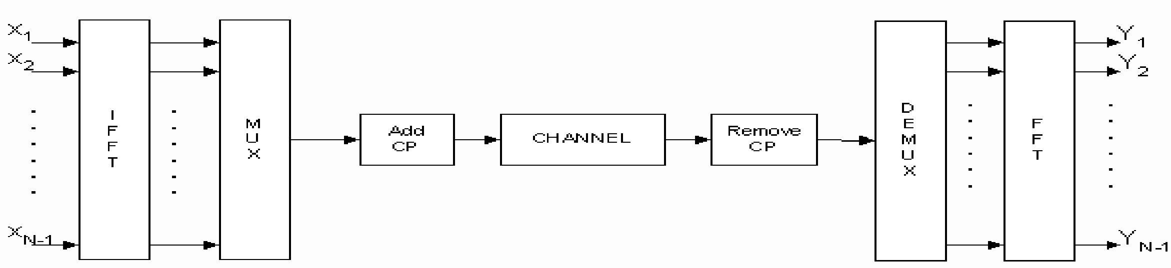

Figure 4: Block Diagram of OFDM System.

OFDM signals are demodulated by first removing the cyclic prefix from the time domain signal, and then performing an FFT on each symbol to convert the frequency domain. Data is decoded by examining the phase and amplitude of the sub carriers.

ADVANTAGES OF OFDM

Here are some of the advantages of OFDM:

1. Very good at mitigating the effects of time-dispersion

2. Very good at mitigating the effect of in-band narrowband interference

3. High bandwidth efficiency

4. Scalable to high data rates

5. Flexible and can be made adaptive; different modulation schemes for sub carriers, bit loading, adaptable bandwidth/data rates possible

6. Has excellent ICI performance

7. Does not require channel equalization, and phase lock of the local oscillators.

DISCUSSION

There are three main reasons why exploitation of PLCT to date has been limited to "narrow band". Research into high speed and high frequency PLCT systems has been contemplated for a long time: AT&T carried out preliminary evaluations already in 1923. It is only in recent years, however, that complex modulation techniques have been developed which are able to manage high speed digital services within such an onerous environment as the power line.

Standards such as CENELEC's which identify frequencies employed for PLCT to 148 kHz restrict the capability to deploy modern voice or data systems. Furthermore, this has reduced the incentive to investigate potential higher value PLCT systems.

For limited applications it is not always easy to build the business case for this technology application; the current market, legal and technical changes, and uncertainties clearly add to this. Therefore, investigation of PLCT has to date been limited to narrow band applications, which are primarily targeted at reducing operational costs of the power supply utility (e.g. power line telemetry).

CONCLUSION

The emerging PLCT technology opens up new opportunities for the mass provision of local access at a reasonable cost. In addition, PLCT can provide a multitude of new services to the users which are difficult to implement by other technologies (e.g., remote electricity meter reading, appliance control and maintenance, energy management, home automation, etc.).

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ABOUT THE AUTHORS

Lawrence Oborkhale is a Lecturer in Electronic and Computer Engineering at Lagos State University. He received his M.Eng. in Electrical Engineering from the University of Benin and a B.Eng. from the University of Ilorin. He is a member of IEEE and the Nigerian Society of Engineers. His area of interest is communications and digital electronics. He has written a number of papers in digital communications.

O. Shoewu, M.Sc., B.Sc.(Hons), MNSE, serves as a Lecturer at the Lagos State University. He earned his M.Sc. and B.Sc. from the Lagos State University and the University of Lagos in 1992 and 1995, respectively. He is presently a postgraduate student working towards a Doctoral degree in Electronics. His research interests are in the areas of electronics, computers, and communications technology.

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