Broadband over Power Line: An Overview

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Abstract

Broadband over Power Line (BPL) communication systems can deliver high-speed voice, data and video communications to end-users by transmitting radio frequency energy over existing electrical power lines. Although this technology is not new, the new achievements in deploying BPL has made it more practical in recent years. The existing infrastructure for BPL is the most considerable advantage of this technology. Since electrical power lines have reached mostly all rural areas, BPL technology can provide broadband services in those areas where the use of other technologies like cable or DSL can not be justified economically. BPL is also used in management of power distribution grids by monitoring and facilitating control of them remotely. In this paper a brief history of this technology and a general overview of it will be presented. Also some issues related to the deployment of this technology and the current status of the technology in the world will be addressed.

Introduction

The purpose of power line communications is to use power supply system for communication purpose. The demand for broadband communication is increasing rapidly. According to KOHL group, less than 30% of US residences and 40% of industries use broadband services. However these percentages will be doubled within the next 10 years. Currently, there are several methods to access broadband services. Digital Subscriber Lines (DSL) can provide broadband services mostly in urban areas. Hybrid Fiber Coaxial cable (HFC) is also another alternative which can provide access to broadband services; however its coverage is much more limited than DSL. On the other hand Broadband over Power Line (BPL) can provide a vast coverage for broadband services. This technology can achieve 14 Mbps raw data rate now and it has the potential for up to 200 Mbps in near future, which makes it competitive with cable and DSL technology [10]. Also, considering the already deployed infrastructure for this technology (power lines), the economic aspects of BPL deployment can be justified.

Worldwide Deployment

Many countries including Australia, Austria, China, Finland, Hong Kong, Hungary, Ireland, Italy, Korea, Japan, Netherlands, Poland, and Switzerland are currently studying BPL technology [3]. Internet access via BPL has been archived in Manheim Germany, in Spain by Endesa and Iberdrola (country's leading electric utilities) and also in Chile by Enersis the large electric utility which offers service in Chile, Brazil, Peru, Argentina, and Colombia. In the USA fully operational commercial broadband services are provided in Manassas Virginia and Cincinnati, Ohio [5].

In Canada, Industry Canada monitors related BPL international activities very closely specially regarding to the potential risks of Access BPL interferences with radio-communication services. Furthermore, it has started some early assessments of Access BPL technology in corporation with some other utilities. These assessments are intended to provide a more precise understanding of the technology and its potential risk for interferences. There are currently no specific standards to address the deployment of Access BPL systems in Canada. However, considering lots of similarities between the U.S. and Canadian power distribution systems, Industry Canada proposes technical harmonization with the USA [3].

Background:

Using power lines as a communication medium is not a new idea. The history of power line communications goes back to 1950, when power lines used as a medium to send a control messages. This method, which was called Ripple Control was characterized by using low frequencies (100-900 Hz) giving low bit rates. Also it demanded the use of high power transmitters in the region of 10 KW. This system first provided unidirectional communication used for load control and management of street lights. Bidirectional communication was developed in late1980's and early 1990's. Also use of much higher frequencies and reduction of signal power were become possible since then. During recent years several utilities and companies continued to develop the technology to provide higher bandwidth data transfer across the electric grids in Europe and the U.S. Advances in Power Line Communication (PLC) technology leaded to BPL which now allows transfer of broadband data through power lines. The use of GHz range frequencies is anticipated in near future developments to make the system capable of much higher throughput [1]. (Actually, an almost new vendor, Corridor Systems, has recently succeeded to develop a method to transfer data on medium voltage power lines in the range of 100 MHz to 10 GHz [11].)

Realizing the importance of PLC in access networks, the IEEE Communications Society has formed a Technical Committee in PLC (http://www.comsoc.org/~plc) that sponsors conference sessions, journal special issues workshops and tutorials and promotes the dissemination of technical information on PLC.

Advantages of BPL

The major claim for BPL is “the infrastructure is already there”. Therefore there is no need for new major infrastructure as needed for other technologies like HFC or DSL [8]. Another advantage of BPL technology is its vast geographical coverage. Access BPL technology can potentially provide broadband services for rural areas which do not have access to such services now [3]. Where technical and economical issues have limited deployments of cable and DSL, BPL can provide broadband in many underserved areas [7]. Access BPL can also improve competition in broadband field by introducing another alternative for broadband [3]. Another interesting aspect of BPL is its ability to potentially connect all electrical devices in a communicating network [7]. Power lines

reach many unmanned remote locations such as water, oil and gas wells, traffic lights, subways and cars which can take advantage of this communicating network [8]. Having internet connection along power lines also facilitates SCADA (Supervisory Control and Data Acquisition), DSM (Demand-Side Management), and AMR (automated meter reading) applications for utility companies [8]. In summary, BPL can be compared with HFC cable and DSL technology as it is shown in table1.

Comparison	HFC Cable	DSL	BLC
Channel Media	Coaxial Cable	Twisted Pair	Electrical Power Lines
Availability of the Physical Media	Limited availability	More availability than cable.	**The most potentially available media**
Typical Capacity	1 Mbps to 6 Mbps	1 Mbps to 6 Mbps	5 Mbps or higher [7]
Connection Type	Shared	Not-shared	Shared
Security	Uses Encryption	More secure because of having a dedicated connection.	Can Use Encryption
Typical prices per month [7]	$39 to $60	$27 to $49	$28 to $39

Table 1- Comparison between different broadband access technologies

Technology

Basically the idea of Power Line Communication is to modulate a radio signal with data and send it through power lines in a band of frequencies which are not used for supplying electricity. The used frequencies and the encoding scheme have a significant influence on the efficiency and the speed of the PLC service. The encoding scheme which is used in BPL is orthogonal frequency division multiplexing (OFDM). This is a multi-carrier transmission technique which has been recently recognized as an excellent method for high speed data communication.

The history of OFDM goes back to 1960s, but it has become popular recently since integrated circuits, which can perform the needed high speed digital operations, became economically accessible. OFDM is based on the idea of frequency division multiplexing (FDM), which is a technology that uses multiple frequencies to transmit multiple signals in parallel at the same time. However, In FDM 50% of the total spectrum is wasted due to guard bands which are needed between sub-carriers to ensure that they do not overlap.

OFDM is much more spectrally efficient than FDM. It reduces the required bandwidth by squeezing sub-carriers tightly together until they actually overlap with each other. This is accomplished by keeping the sub-carriers orthogonal in the complex domain so that they do not interfere with each other.

The concept of OFDM is shown in figure 1.The generation of orthogonal signals is done by using an IFFT (inverse fast Fourier transform) block. Using OFDM modulation the data is injected onto power lines.

The electric power transmission system basically consists of high voltage lines (greater than 40 kV) medium voltage lines (1 kV to 40 kV) and low voltage lines (110 V or 220 V). The backhaul connections of distribution substation will be provided by standard Telco fiber optic cables. The optical backhaul portion of BPL is closer to users compared to that of HFC users, which makes the available bandwidth of the BPL signal shared by fewer users [5]. However, this architecture facilitates higher bit rates over power lines.

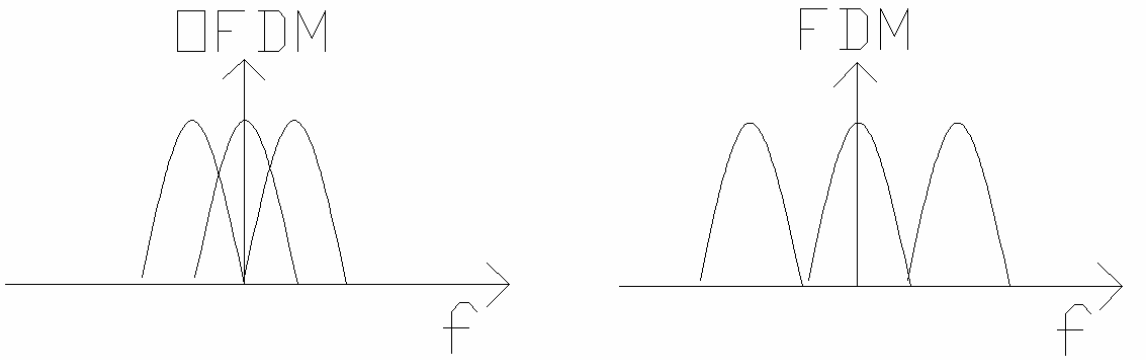

Figure 1 - OFDM spectrum versus FDM: OFDM is much more spectrally efficient than FDM

Depending on the topology, BPL can be categorized into access BPL or in-house BPL. These are discussed next.

Access BPL

Access BPL provides internet and other broadband services like voice (IP Telephony), video, surveillance systems and entertainment (gaming) for homes and offices [4]. In this topology injectors are used to provide an interface between Internet backbone and the medium voltage power lines [3][1]. BPL signals can propagate for 1000 to 3000 feet before they become too distorted and weak. To transmit the signal for a longer distance repeaters are used to regenerate and amplify the signal [2]. Extractors are used to provide an interface between end-users and medium-voltage power lines. Extractors are typically placed at each distribution transformer which provides low voltage electric power for a group of homes in the area. Some extractors amplify the BPL signal strength sufficiently

[1] BPL systems are not used on high voltage power lines yet. This is because; hundreds of thousands of volts of electricity vibrate at an inconsistent frequency which can create interference with the transmitted data [7].

to make the transmission of the signal possible through the distribution transformers. Some others employ couplers to bypass distribution transformers and relay the signal to the end-users [2].

FCC has provided the following definition for Access BPL: “A carrier current system installed and operated on an electric utility service as an unintentional radiator that sends 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.” [6]

Industry Canada has suggested that Access BPL systems can be generally classified as either: (1) an end-to-end system, or (2) a hybrid system [3]. In the end-to-end systems, Access BPL systems use a combination of medium voltage and low voltage lines or only low voltage lines. The BPL signal is injected onto medium voltage lines and is transferred to low voltage lines using couplers or through low voltage transformers and delivered directly to end users [3]. In the case of low voltage only BPL systems, the signal is injected onto the low voltage lines at the transformer or the utility meter directly.

On the other hand, in hybrid systems a combination of power lines and wireless transmission is used. In this scenario the injected BPL signal onto medium voltage lines is extracted and delivered to the end user by using a wireless channel. Recently another scenario has come up which is based on capturing a wireless signal and injection of it to low-power lines to be delivered to the end users [3]. Figure 3 shows an example of an end-to end Access BPL system while a hybrid BPL system.

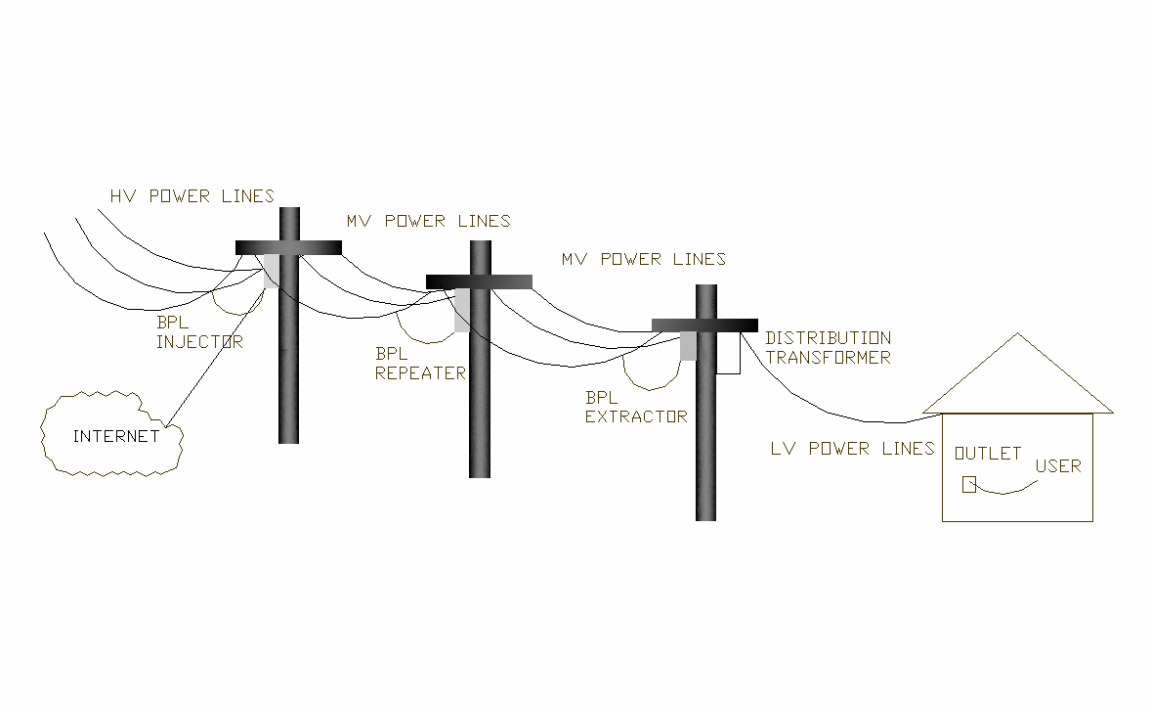

Figure 2- Access BPL System

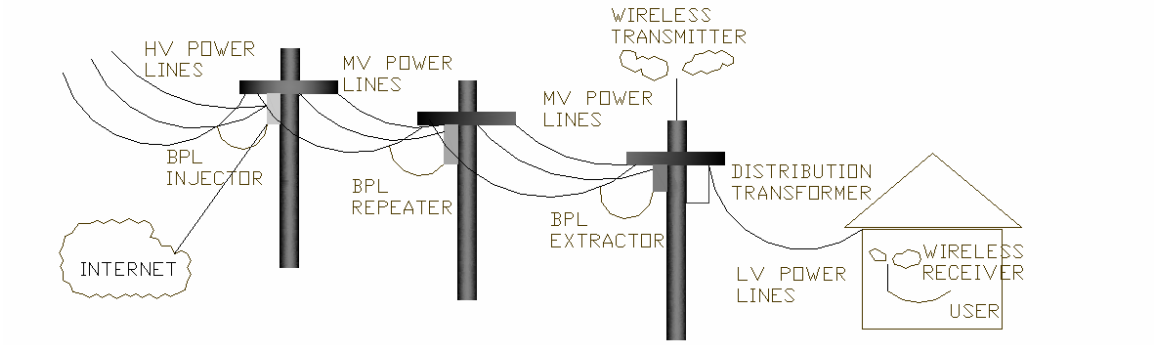

Figure 3- Hybrid BPL System

In-house BPL

FCC has defined In-house BPL as follow: "A carrier current system, operating as an unintentional radiator, which sends radio frequency energy by conduction over electric power lines that are not owned, operated or controlled by an electric service provider. The electric power lines may be aerial (overhead), underground, or inside the walls, floors or ceilings of user premises. In-house BPL devices may establish closed networks within a user's premises or provide connections to Access BPL networks, or both. "[6].
This application occurs within a building where both end of the communication link located. The distance between communication ends is typically less than 100 meters [4]. This system is attractive because no extra wiring is needed within the building. Networking and sharing common resources such as printers are the main applications of this technology [3].

Technical Challenges and Research

The main concern about BPL technology is the radio frequency interference (RFI) that it creates. According to American Radio Relay League (ARRL), BPL systems produce Radio Frequency Interference within 75 meters for mobile radio and 150 meters for fixed radio [9]. To reduce the potential RFI, BPL providers need to reduce the transmission power which consequently increases the number of required repeaters and the cost of the system [5]. Some vendors claim that they have overcome this issue by using adaptive techniques to notch out the interfering signals in power lines. On the other hand,

Motorola has used a completely different approach to solve this problem. It uses BPL only on low-voltage power lines and provides the backhaul wirelessly. According to Motorola, because it uses only low voltage power lines, the system is less susceptible to interferences [10].

Moreover, power lines were initially created to deliver electrical power at 50Hz to 60Hz and behave like low pass filters. Broadband data, which are transmitted at much higher frequencies, must overcome several obstacles to get through power lines. Attenuation of high frequency components in power lines is a major concern. On a common power line in the USA, the signal should be amplified at a distance much less than a mile, which makes the use of repeaters necessary every 1000 feet to a mile [9]. Communication signals also encounter several levels of noise on power lines that are generated by connected electrical appliances [9]. Furthermore, impedance mismatching of connected appliances can result in considerable loss at particular frequencies (nulls).The location and the depth of these nulls change according to the number and type of the connected devices to the power network [4].

Currently, there are two proposed schemes to overcome these issues: using adaptive OFDM modulation or using multi bit rate OFDM modulation. In both methods good knowledge of channel characteristics is needed. However, power line channel is has wide sense stationary properties (channel characteristics slowly change). Therefore, adaptive schemes provide a good solution because the channel needs to be estimated less frequently. By loading fewer bits at most affected frequency bands, the total throughput can be improved. This is a beautiful advantage of multi bit rate OFDM.

In Ryerson University, ADROIT group currently focuses on developing better solutions for BPL by using adaptive and multi bit rate OFDM. In this scheme the bit rate of each OFDM sub-carrier can vary based on the channel characteristics. Therefore the sub-carriers with the least attenuation can deliver the most bit-rate. In other words, by increasing the bandwidth of the sub-carriers with better channel characteristics, the throughput can be increased. The concept of multi rate OFDM is shown in figure 4.

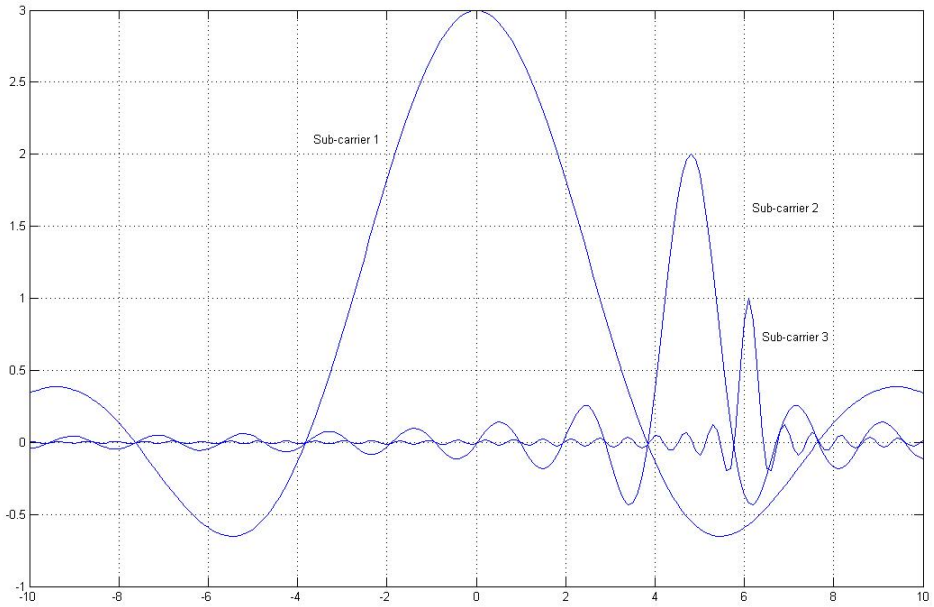

Figure 4- Frequency diagram of Multi Rate OFDM
Higher bit-rate can be obtained on the sub-carriers with larger bandwidths. Therefore, the bandwidth of the sub-carriers on better channels can be increased to optimize the throughput of the system.

Conclusion

BPL is still a new technology which needs further advancements to be completely practical in a wide range. The main advantage of this technology is the already existing infrastructure for BPL even in rural areas which makes its deployment economically justified and also increases the potential coverage of the technology. On the other hand, the major issue with this technology is its interference with other radio systems. This issue has limited the deployment of BPL to some extent and has increased the cost of its deployment. However some companies claim that they have overcome the problem. Soon we will see widespread deployment of BPL.

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