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ŠIROKOPOJASNI PRIJENOS PODATAKA ELEKTROENERGETSKOM MREŽOM

BROADBAND OVER POWER LINES

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Pregledni članak

Sažetak: *U radu je opisan pregled širokopojasnog prijenosa podataka elektroenergetskom mrežom. Razvoj tehnologije prijenosa signala omogućio je prevladavanje problema prijenosa komunikacijskih signala putem elektroenergetske mreže. Time je omogućen širokopojasni prijenos podataka kojim se osigurava pristup Internetu koristeći postojeću infrastrukturu. Ovakva komunikacija dijeli se na: pristupnu i kućnu. Najveći ekonomski značaj ove tehnologije je mogućnost pružanja pristupa Internetu TCP/IP protokolom. Osim pristupa Internetu omogućava i implementaciju pametne elektroenergetske mreže (SCADA).*

Ključne riječi: *širokopojasni prijenos, elektroenergetska mreža, Internet, pristupni BPL, kućni BPL, pametna mreža*

Subject reviews

Abstract: *The paper presents an overview to broadband over powe lines. Over the past few years advances in signal processing technology have enabled the advent of modem chips that are able to overcome the transmission difficulties associated with sending communications signals over electrical power lines. There are two predominant types of BPL communications configurations: Access BPL and In-Home BPL. One of the largest commercial markets for BPL is the ability to provide Internet Services by means of the Transmission Control Protocol/Internet Protocol (TCP/IP) protocols. Another significant benefit of BPL is the ability to employ "intelligent" power line networks that make use of SCADA devices.*

Key words: *Broadband, power line, Internet, Access BPL, In-Home BPL, smart grid*

1. INTRODUCTION

The electric power grid is a hostile environment for high-speed data transmission, but after years of development, the technology to deliver high-speed data over the existing electric power delivery network has emerged, somewhat tentatively, in the marketplace. This technology, referred to as *Broadband over Power Lines* (BPL), uses medium- and low-voltage power lines to provide broadband Internet access to residential users and businesses and is considered by some as a third access technology offering potential competition to xDSL telecommunication lines and cable modems. Recent trends, however, indicate that the focus of BPL technology is shifting from providing broadband connectivity to smart meter usage allowing households to reduce energy costs and allow better energy management by developing a "smart grid". BPL technology is relevant to a variety of public policy issues, such as energy, communications, environmental policy, and national security policies. BPL can promote energy policy by enabling advanced metering initiatives for time-of-use pricing, load management and outage detection, but it can also enhance communications policy by providing broadband access and promoting competition for broadband services to rural and under-served areas. It is relevant for environmental policies through conservation and energy management that reduce greenhouse gases, and for national security through network redundancy and video surveillance applications that are being used for public safety and critical infrastructure protection. There are several reasons why BPL can be attractive as a third wire to the home. From the perspective of electrical utility companies the basic infrastructure is already in place (electric grid) and there is no requirement to obtain rights of way or construct ducts, nor is there a need for business or household wiring to deploy BPL. This enhances the cost effectiveness of rolling out BPL. Only the sub-station server equipment and customer conditioning service units need to be installed in order to establish a digital power line network. Another important benefit from the perspective of providers is that the power grid is virtually ubiquitous in most countries providing an already existing network infrastructure covering private customers as well as businesses. From the perspective of end users, the equipment needed to set up BPL in the home is cheaper on average than that of other broadband solutions such as DSL and cable modems. The equipment uses existing power outlets in the home making it easier to set-up and there is no need for additional wiring or installations. For end users in rural areas, who cannot receive DSL or cable modem services, BPL could have the potential to provide a broadband access which can support triple play services and automation of a smart network controlling electrical consumption. Despite the potential advantages of BPL, it faces a number of serious challenges. Technologically, BPL has floundered over the last few years because it can generate radio frequency interference with amateur and emergency radio. The slow rate of growth in BPL, with less than 30 000 subscribers in 15 OECD countries as of 2007, and the lack of international standardisation, has also meant that there have been insufficient scale economies in the manufacture of equipment. Many BPL trials and/or commercial networks are being abandoned or are being reconverted for use in smart-electrical grid monitoring [1].

2. POWER LINE AS COMMUNICATION CHANEL

PLC works no different than any electronic communication system. How PLC uses existing power grid as channel for data? Basically, power grid is intended to carry low frequency, high power AC signal. So it is not at all possible to use low frequency carrier, and it does not provide sufficient bandwidth as well. PLC signal uses carrier frequency ranging from 1.8 MHz to 90 MHz. However, with single wire transmission lines, such as electric lines, high frequencies can also be transitted over grid. A device, usually known as plug, works as a transponder for PLC network. It modulates outgoing data and demodulates incoming data. For PLC, frequency and phase modualtion is preffered. This is because PLC signal should not interfere with AC voltage or vice-versa. To achieve this goal, PLC signal should have:

- less amplitude than AC mains voltage,
- no frequency component of AC mains,
- matched wave impedance to grid.

Operating frequency for PLC is chosen such that it won't come in attenuation band for a grid line. Effective impedance Z for particular operating frequency can be calculated as follows:

$$Z = R + j(2\pi FL + \frac{1}{2\pi fC}) \quad (1)$$

When impedance is properly matched, maximum PLC signal power is transmitted, helping to improve signal to noise ratio (SNR). PLC signal is also affected by noise in grid. Fluctuation in AC mains, sudden load changes and short circuits cause spikes. Spikes have random frequency and amplitude which is unpredictable. Lightning can also cause hazardous spikes in grid. By chance, if frequency of spike matches with carrier of PLC, it could interfere in signal. Certain electrical appliances also cause disturbance to PLC devices. Those include reactive appliances such as motors, Zener diodes, dimmers, and cathode ray tubes. These devices create their own noise signal which could flow back in AC mains and surroundings.

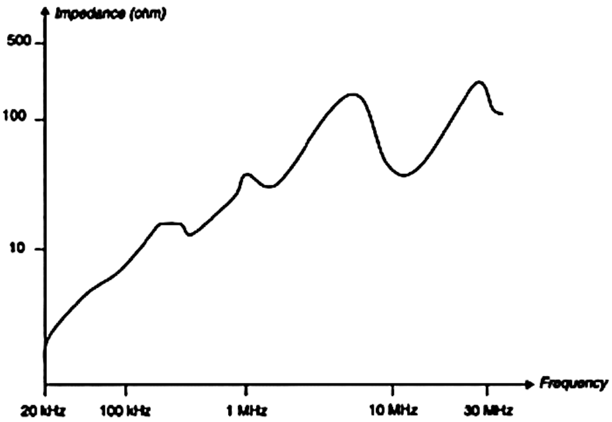

Figure 1 Impedance for various frequencies [2]

Filters are used to attenuate these noises. Each PLC device is equipped with notch filter to reject mains frequency. Devices used in transmission grid, such as meter, have theri own attenuation of PLC signal. So if the PLC signal passes through series of such devices, it will be attenuated considerably; causing SNR to fall. Attenuation and frequency response of grid have put a limit on PLC technology. It has been said that to investigate power line network performance in detail so as to optimize its transmission system a reasonably accurate channel model must be available [3]. Hensen [4] proposed a simple power line model where attenuation was increasing with frequency that did not take into consideration the multipath phenomenon. The second model was proposed by Philipps *et al.* [5], whose transfer function is given by (3). In (3) out of N number of possible signal flow paths, each path delayed by time τ_i is multiplied by a complex factor ρ_i (product of transmission and reflection factors).

$$H(f) = \sum_{i=1}^{N} \rho_i e^{-j2\pi f \tau_i} \quad (2)$$

The method in [5] was extended by Zimmermann *et al.* [6] to account for the attenuation of the signal flow and is given by (2). In (2) each path is characterized by weighting factor $\mathbf{g_i}$ (product of transmission and reflections factors) and path length $\mathbf{d_i}$. The attenuation factor is modeled by the parameters a_0 , $\mathbf{a_1}$ and $\mathbf{k}$, which are obtained from measurements. Banwell *et al.* [7] proposed a model which accounts for a multi-conductor configuration. The model that power line researchers commonly use is that of Zimmermann *et al.* [6] since its modeling results conforms with that of measurements and is easy to apply.

$$H(f) = \sum_{i=1}^{N} g_i e^{-(a_0 + a_1 f^k) d_i} e^{-j2\pi f \frac{d_i}{v_p}} \quad (3)$$

To generalize the model used to suit any power line configuration, a power line network with distributed branches shown in Figure 2 was considered. The transfer function is given by (4a). In (4a), N_T is the total number of branches connected say at node „“ and terminated in any arbitrary load. Let n, m, M, H_{mnd} (f) and T_{Lmd}, represent any branch number, any referenced (terminated) load, number of reflections (with total L number of reflections), transfer function between line n to a referenced load m at the referred node d, transmission factor at the referenced load m at referred node d respectively. With these the signal contribution factor α_{mnd} is given by (4b), where ρ_{nmd} is the reflection factor at node“d“ between line **n** to the referenced load m, γ_{nd} is the propagation constant of line **n** that has line length l_n . All terminal reflection factors P_{Lnd} in general are given by (4c), except at source where $\rho_{L11}=\rho_s$ is the source reflection factor [8]. Also Z_s is the source impedance, Z_n is the characteristic impedance of any terminal with source whileV_s and Z_{LdNT} are source voltage and load impedance respectively based on Figure 2. The output referenced voltage V_{mMT} (f) in frequency domain is given by (5). The time domain response is obtained by inverse Fourier transform of (5).

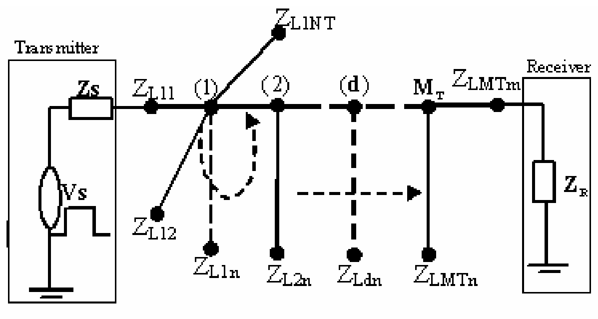

Figure 2 Power line network with distributed

$$H_{mM_T}(f)=\prod_{d=1}^{M_T}\sum_{M=1}^{L}\sum_{n=1}^{N_T}T_{Lmd}\alpha_{mnd}H_{mnd}(f) \qquad n\neq m$$

(4a)

$$\alpha_{mnd}=P_{L_{nd}}^{M-1}\rho_{mnd}^{M-1}e^{-\gamma_{nd}(2(M-1)l_{nd})}$$

(4b)

$$P_{Lnd}=\begin{cases}\rho_s, d=n=1(source)\\ \rho_{Lnd}, otherwise\end{cases}$$

(4c)

$$V_{mMt}(f)=H_{mMt}(f)*\left(\frac{Z_{Ldn}}{Z_{Ldn}+Z_s}\right)V_s \qquad (5)$$

Any communication system comprises a transmitter, a receiver, the medium, and a signal. In a generic PLC system, the transmitter modulates and injects the signal into the power line (Figure 3). The receiver at the opposite end of the link demodulates the signal and retrieves the data. The impedance of the power line attenuates the signal as it travels from the transmitter to the receiver. Any noise in the medium also corrupts the signal as it moves through the power line. The factors that affect the performance and reliability of a PLC system include the transmit-signal strength, the noise on the power line, the impedance of the power-line network, the protocol in use, and the receiver's sensitivity. Stronger signals are less prone to the corrupting effects of noise on the power line and can travel farther.

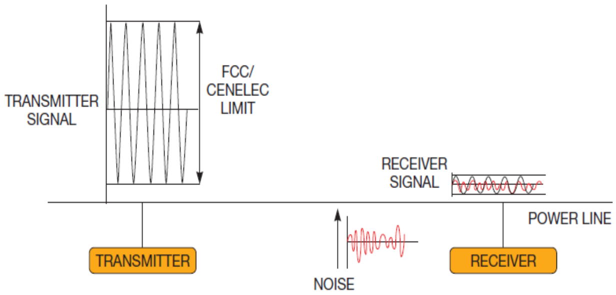

Figure 3 The impedance of the power line, along with noise on the line, can significantly

Transmit signal strength also affects the PLC node's power consumption because the node consumes more power as more signal energy enters the line. In the best-case scenario, developers would increase the signal strength of the transmitter until they achieved the best performance and power consumption over the power line. However, organizations such as CENELEC in Europe tightly control transmit-signal strength. CENELEC also regulates the harmonics that the main transmitter signal can inject into the power line. These regulations prevent signals on different frequency bands from corrupting one another. When selecting a PLC device, check that it meets the transmit-signalstrength requirements for your target market. It should also comply with the standards that CENELEC sets. Ideally, the transmitting gain should be configurable so that you can tune signal strength based on the rest of the system. Additionally, confirm how much energy the PLC node consumes to achieve the best transmit-signal strength that CENELEC require.

2.1 Impedance

The impedance that a signal sees on a power line affects the signal power that the transmitter can transfer into the power line. This impedance depends on the impedance of the power line and that of the nodes—that is, the appliances—that connect to it. Power line impedance changes whenever you plug an appliance or a node into a power socket. Maximum signal power transfers when the impedance that the signal sees in the power line matches that of the transmitter circuit. The greater the difference between these two impedances, the less the transferred signal power; as a result, PLC performance degrades. The dynamic change in impedance over time is one of the toughest issues to address in power- line applications. PLC transmitters and receivers must anticipate these impedance changes in the power line if they are to achieve robust signal performance. Continually matching the impedance of the transmitter to that of the power line allows maximum signal transfer, and high receiver impedance ensures minimal signal loss on the receiver side.

3. BPL ARCHITECTURE OVERVIEW

From the system engineering perspective, BPL provides effective data communication through a combination of the electric network within the home or office, the power distribution grid, and the backbone network which transfers the data signal from the Internet Service Provider (ISP) to the power lines. BPL systems take advantage of one of the largest and the most pervasive networks, the power distribution grid. The power distribution grid is made up of a number of components aimed at delivering electricity to customers, and includes overhead and underground Medium Voltage (MV) and Low Voltage (LV) power lines and associated transformers. First, power is generated at power stations and distributed around a medium to large geographical area via High Voltage (HV) lines. Second, in areas where power needs to be distributed to consumers, transformers will be used to convert this high voltage into a lower voltage to transport over MV power lines. These transformers are generally located at electrical sub-stations operated by the utility or power supplier. Such MV power lines will be used to transport electricity around smaller geographical areas such as small towns. Finally, for the purposes of using electricity in the home or business a transformer is used to reduce the voltage down to safer and more manageable voltages at the customer's house or business premises. This power is usually transported over LV power lines. These LV power lines include the lines that traverse a customer's home or business. Over the existing power distribution grid, recent technological advancements have led to the development of new systems that make it possible to deliver broadband services. These systems are comprised of **access BPL**, **in-house BPL**, or a combination of both technologies. **Access BPL** uses electrical transmission lines to deliver broadband to the home, and uses injectors, repeaters, and extractors to deliver high-speed broadband services to the customer. Injectors/or concentrator are devices that aggregate the end user Customer Premises Equipment (CPE) data onto the MV grid. *Injectors* are tied to the Internet backbone via fibre lines and interface to the MV power lines feeding the BPL service area. A repeater is a physical-layer hardware device used on a network to extend the length, topology, or interconnectivity of the physical medium beyond that imposed by a single segment. *Extractors* provide the interface between the MV power lines carrying the signals to the customers in the service area. BPL extractors are usually located at LV distribution transformers that service groups of households. Since the BPL signal loses strength as it passes through the LV transformer, extractors are required to retransmit the signal. In other cases, couplers on the MV and LV lines are used to bypass the LV transformers and deliver the signal to the customer. There's a third type of extractor transmitting a wireless signal directly from the MV power line to the customer**. In-house BPL** is broadband access within a building or structure using the electric lines of the structure to provide the network infrastructure. In-house BPL will network machines within a building. Unlike access BPL, in-house BPL utilises the electric wiring in a privately owned building and not the electric power lines owned, operated or controlled by an electricity service provider. Broadband devices are connected to the in-building wiring and use electrical sockets as access points. In-house BPL technologies are largely designed to provide short-distance communication solutions which compete with other in-home interconnection technologies. Product applications include networking and sharing common resources such as printers. Multiple choices in possible architectures offer electric utilities and their partners flexibility in selection of BPL business model and deployment plans by market type. Figure 4 shows the simplified medium voltage (MV) network. The BPL signal in this network is transmitted over the MV system from a head-end in the local network, and for the purpose of final distribution of BPL service to the end user, either a local repeater to counter the signal-blocking effect of the local transformer, or alternatively a WiFi wireless LAN access point can be used. Today's BPL market has three architecture options as illustrated in Figure 4:

- Option 1: wireless: transformer avoided, OFDM used for distributing data, WiFI exchange point at user-end ant the MV line transmitter using IEEE 802.11 standard,
- Option 2: wired: transformer avoided, OFDM employed, BPL extractor routes data from MV to LV and user,
- Option 3: wired: bypass transformer with LV/MV coupler and repeater.

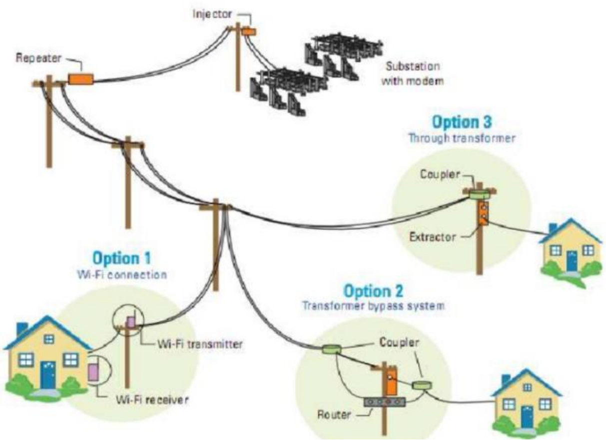

Figure 4 Different BPL architectures

In Europe the system head-end is the local step-down transformer, and the LV wire is used for the broadband data distribution. The local stepdown transformer is usually located further from the final customer, and can distribute power to typically tens of hundreds of customers.

3.1 How it works

At a high-level, a BPL network consists of three key segments, the backbone, the middle mile, and the last mile as shown below in Figure 5. The BPL vendors are primarily seeking to address the "last mile" segment all the way into "the home" market. From the end user's perspective, BPL technology works by sending high-speed data along medium or low voltage power lines into the customer's home.

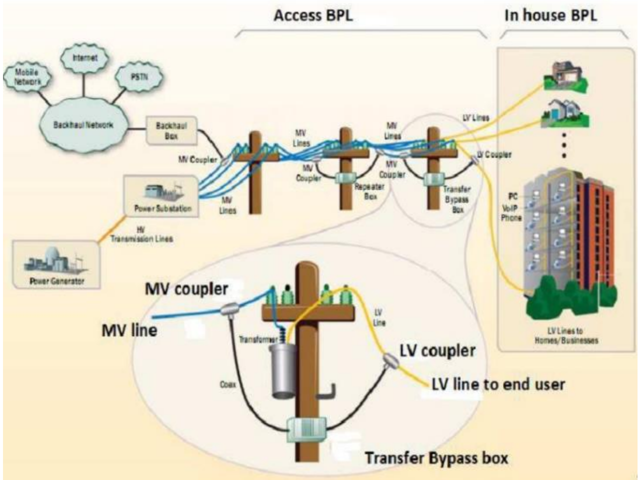

Figure 5 Power grid modified for BPL's purpose

The signal traverses the network over medium and low voltage lines either through the transformers or by-passes the transformer using bridges or couplers. The technology transports data, voice and video at broadband speeds to the end-user's connection. The user only needs to plug an electrical cord from the "BPL modem" into any electrical outlet then plug an Ethernet or USB cable into the Ethernet card or USB interface on their PC. Any Internet Service Provider (ISP) can interface with the BPL network and provide high speed Internet access. The data signal can also interconnect with wireless, fiber or other media for backhaul and last mile completion. The actual hardware used for the deployment varies by manufacturer but typically feature some common characteristics. By combining the technological principles of radio, wireless networking, and modems, developers have created a way to send data over power lines and into homes at speeds equivalent to those of DSL and cable. By modifying the current power grids with specia lized equipment, the BPL developers could partner with power companies and ISP's to bring broadband to everyone with access to electricity. The Internet is a huge network of networks that are connected through cables, computers, and wired and wireless devices worldwide. Typically, large ISPs lease fiber-optic lines from the phone company to carry the data around the Internet and eventually to another medium (phone, DSL or cable line) and into the homes. Trillions of bytes of data a day are transferred on fiberoptic lines because they are a stable way to transmit data without interfering with other types of transmissions. The idea of using AC power to transfer data is not new. By bundling radiofrequency (RF) energy on the same line with an electric current, data can be transmitted without the need for a separate data line. Because the electric current and RF vibrate at different frequencies, the two don't interfere with each other. Electric companies have used this technology for years to monitor the performance of power grids. There are even networking solutions available today that transfer data using the electrical wiring in a home or business. But this data is fairly simple and the transmission speed is relatively slow. There are several different approaches to overcoming the urdles presented when transmitting data through power lines. The power lines are just one component of electric companies' power grids. In addition to lines, power grids use generators, substations, transformers and other distributors that carry electricity from the power plant all the way to a plug in the wall. When power leaves the power plant, it hits a transmission substation and is then distributed to high voltage transmission lines. When transmitting broadband, these high-voltage lines represent the first hurdle. HV power is unsuitable for data transmission. It's too "noisy." Both electricity and the RF used to transmit data vibrate at certain frequencies. In order for data to transmit cleanly from point to point, it must have a dedicated band of the radio spectrum at which to vibrate without interference from other sources. Hundreds of thousands of volts of electricity don't vibrate at a consistent frequency. That amount of power jumps all over the spectrum. As it spikes and hums along, it creates all kinds of interference. If it spikes at a frequency that is the same as the RF used to transmit data, then it will cancel out that signal and the data transmission will be dropped or damaged en route. BPL bypasses this problem by avoiding high-voltage power lines all together. The system drops the data off of traditional fiber-optic lines downstream, onto the much more manageable 10 kV of medium-voltage power lines. Once dropped onto the medium-voltage lines, the data can only travel so far before it degrades. To counter this, special devices are installed on the lines to act as repeaters. The repeaters take in the data and repeat it in a new transmission, amplifying it for the next leg of the journey. In one model of BPL, two other devices ride power poles to distribute Internet traffic. The coupler allows the data on the line to bypass transformers, and the bridge , a device that facilitates carrying the signal into the homes. The transformer's job is to reduce the 10 kV volts down to the 220-volt standard that makes up normal household electrical service. There is no way for low-power data signals to pass through a transformer, so you need a coupler to provide a data path around the transformer. With the coupler, data can move easily from the 10 kV line to the 220V line and into the house without any degradation. The last mile is the final step that carries Internet into the subscriber's home or office. In the various approaches to last-mile solutions for BPL, some companies carry the signal in with the electricity on the power line, while others put wireless links on the poles and send the data wirelessly into homes. The *bridge* facilitates both. The signal is received by a powerline modem that plugs into the wall. The modem sends the signal to your computer.

4. IMPLEMENTATION CHALLENGES

The most obvious challenges to implementing BPL arise from the fact that power line grids were originally developed to transmit electrical power(high voltage AC at low frequencies of 50 or 60 Hz) from a small number of sources (the generators) to a large number of sinks (the end customers). Power grids were neither designed nor devised for communications purposes. Even though the interest in using power lines for communications is not new, their early use for data transmission was mainly for simple, low-data-rate (a few kilobits per second) remote monitoring and meter reading applications at a low frequency (typically only up to a few hundred kilohertz). The main challenges to BPL arising from the nature of the power grid have been the extremely harsh, unpredictable, time and location variable characteristics of the power line channel, and potential interference concerns (in both directions) . Because power lines are not twisted and have no shielding, they can produce electromagnetic radiation that is easily detected by radio receivers. For the same reasons, power lines can also easily pick up nearby radio frequency signals. A related challenge facing BPL centers around data sensitivity. To prevent interception of sensitive data by unintended and unauthorized receivers, data encryption is a must. The fact that the power line grid is a shared medium and BPL is a contention-based system creates additional challenges. Because all users share the available channel capacity or bandwidth, as the number of users goes up, per-user throughput goes down. An average available throughput of 50 Mbps implies roughly an average of 1 Mbps per user, a speed on par with the current average speeds delivered by DSL or cable modem. However, BPL is thought to be distance limited, similar to DSL. Thus, the distance between the customer‘s home and the supplying substation is a factor in the bit rate available to the user.

4.1 Electromagnetic compatibility

Electromagnetic compatibility (EMC) is the ability of a device or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances in the form of interferences to any other system in that environment, even to itself. Broadband data can be transmitted at different frequencies, over the same wires, however, in order to enable high-speed and long-distance transmission of data on power lines several technological obstacles have to be overcome. These include data interference or electrical signal interference, the distance over which data can travel while still providing good quality, and the lack of international standards and specifications. The technological issues of BPL in this section deal with how BPL should be implemented to minimise interference with other services such as amateur radio frequencies and international standardisation efforts for BPL technology to increase reliability, interoperability, and security of broadband transmission over power lines. Potentially harmful radio frequency interference (RFI) has been one of the most serious potential technological obstacles to BPL. BPL works by sending radio frequency signals along the power lines using frequencies anywhere from 1.7 to 80 MHz. Some of the BPL signals can cause interference in licensed frequency bands over 1.7-8 MHz, generally known as HF or shortwave bands. Also, various structures in or near power lines may become radiators or antennas at the high frequencies at which BPL data are transmitted. This can also result in interference with a variety of existing licensed radio services, including ham/or amateur radio operators, public safety, emergency response frequencies, military, aviation, maritime, and shortwave broadcasts. BPL signals may propagate down the wires by conduction, but due to the fact that the wires are not solidly shielded or adequately balanced with close conductor spacing, the BPL signal will tend to radiate, which can result in interference. Furthermore, both the high level of injection of radio frequency energy and attenuation of conducted signals on power lines will have a direct influence on interference. Low-voltage networks were designed only for energy distribution to households and a wide range of devices and appliances are either switched on or off at any location and at any time. This variation in the network charge leads to strong fluctuation of the medium impedance. These impedance fluctuations and discontinuity lead to multipath behavior of the PLC channel, making its utilization for the information transmission more delicate. Beside these channel impairments, the noise present in the PLC environment makes the reception of error-free communication signal more difficult. EMC is the first requirement to be met by any device, before it enters the market and even before it enters the wide production phase. However, this remains the main challenge that the PLC community is facing. Several services use one or multiple parts of the spectrum 0–30MHz that is targeted by the PLC system. This makes the set of possible EM victims of PLC devices larger.

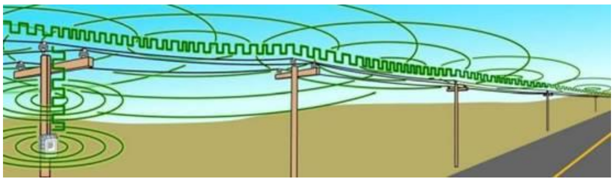

Figure 6 BPL act as aerial [9]

In spite of it, standardization activities aregoing on and trying to reach international flexible standards for the electrical field strength limits. Since powerlines were never intended to be used for piggybacking data, a number of problems arose when trying to do so. 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. This particular band of frequencies are known as HF (which is actually 1– 30 MHz). This part of the radio spectrum has very special properties not found elsewhere. With this band, one can communicate around the world with very minute power levels. This is due to the fact that radio waves in this band can bounce off the ionosphere multiple times to get to the destination. A carrier current system transmits radio frequency energy to a receiver by conduction over the electric power line. It's essential to regulate carrier current systems and powerline carrier systems, and each is subject to different emission limits. It's also important to limit 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 c 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. Another issue is high attenuation (Figure 7) at high frequencies and noise (internal and external). This leads to the necessity for a lot of error correction/prevention in any protocols using power lines as a physical layer. One thing that cannot be resolved, however is a failing in the electrical properties of the powerlines themselves. They act as aerials (Figure 6) because they are not shielded. This means that they can pick up noise and transmit it on as well as emit interference. BPL operates at the same frequencies as short wave radio and low-band VHF. This can render various radio systems including those of governments unusable. Amateur radio enthusiasts the world over seem to be united in their distaste for what BPL does to the airwaves. Additionally, compared to Ethernet cabling, which has consistent characteristics, power line is not controlled or constant over time. The constant plugging and unplugging, turning on and off, of these appliances throughout the day and evening causes the powerline characteristics to constantly change.

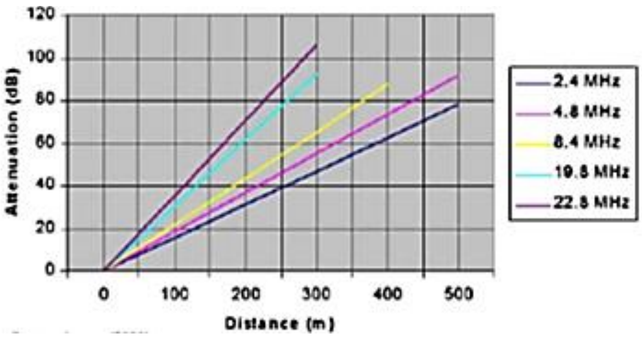

Figure 7 Average measured attenuation (dB) versus distance for outdoor powerlines as a function of frequency (in Europe) [10]

Trying to send data over this inconsistent medium is what has stumped powerline technology companies for years. Power lines, copper twisted pair, and coaxial cable all act like natural low pass filters, meaning higher frequencies are attenuated more than lower frequencies when attempting to transmit them through the medium. The exact slope of the graph of attenuation depends on the specific construction of the material, but in general, twisted pair is suitable up to 100 MHz and coaxial cable can go up to about 3 GHz. Again, these are very general figures and determining the suitability for any application depends on other factors. Power lines would be suitable for up to perhaps 20 KHz, maybe 350 kHz at a stretch, with caveats, but note that this is kilohertz, not megahertz or gigahertz. These are essentially audio frequencies, and equate to a data rate in the neighborhood of ISDN. Again, unlike all other broadband mediums, power lines are excellent radiators of the frequencies PLC uses. Copper twisted pair, coaxial cable, and fiber are all inherently non-radiating mediums. It should be noted that twisted pair and coaxial cable do actually radiate to some extent, but in proportion to the amplitude of the signal they are carrying, it is minuscule. According to radio amateurs and some broadcasters, PLC is said to be a polluter of the radio spectrum, causing a large rise in the noise floor' in urban areas akin to "radio smog".

4.2 Noise on the power line

The noise in PLC networks is diverse and is described as the superposition of five additive noise types, that are categorized into two main classes – on the one hand is the background noise, which remains stationary over long time intervals, and on the other is the impulsive noise, which consists of the principle obstacle for a free data transmission, because of its relative high intensity. This impulsive noise results in error bursts, whose duration can exceed the limit to be detected and corrected usually by used error correcting codes. Therefore, the impulsive noise in PLC networks has to be represented in appropriate disturbance models. Once the transmit signal has been injected into the power line, its integrity depends on the amount of noise on the line; stronger noise does greater damage to the signal. Noise can come from multiple sources. Simplistically speaking, noise on the line subdivides into impulse and continuous noise. Impulse noise is unpredictable and occurs in bursty sequences (Figure 8).

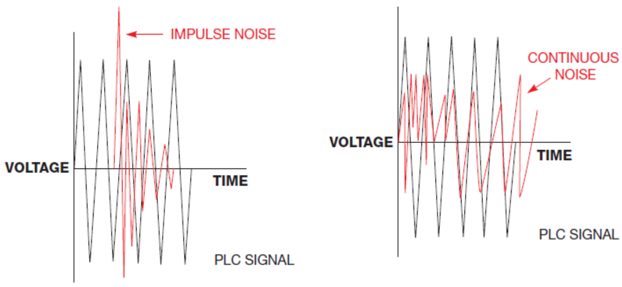

Figure 8 Impulse and continuous noise on the power line [11]

This type of noise can come, for example, from a switched on blender in the kitchen. It can be difficult to design a system that can tolerate the unpredictability and magnitude of impulse noise without compromising its data rate. This type of noise often obliterates any data packets on the line. Continuous noise is more predictable than impulse noise (Figure 8). Continuous noise is usually a function of the quality of the region's power-line installation. The developers of the power- line infrastructure designed it to efficiently carry power, not data, so they paid little attention to noise levels during power-line installation. Power lines' noise level depends on what part of the world a system operates in. To enable robust communication over the power line, the SNR (signalto- noise ratio) must remain above a certain threshold. If high-amplitude, continuous noise exists within the frequency range of the PLC system, you should isolate the noise by moving it away from PLC receivers or by adding a blocking inductor to the power supply of the noise-generating equipment, thereby attenuating the noise frequency below the receiver's SNR. Developers can also use several other techniques to overcome the effects of noise. These techniques include the use of bidirectional communication, retries, error detection, and AGC (automatic gain control). If a PLC system communicates in only one direction, the transmitter cannot know whether communication succeeds. This shortcoming was one of the biggest of the original unidirectional *X10 PLC technology* [12]. Bidirectional communication allows the receiver to send an acknowledgment after successful reception of data. In case the receiver does not receive an acknowledgment, the transmitter can take corrective action. In a bidirectional system, communication confirmation can occur through an acknowledgment mechanism. If an intelligent transmitter does not receive a reply from the receiver, then it can resend data packets. A PLC's implementation of built-in retries can be a powerful means of achieving reliable PLC. Even after a receiver successfully receives a data packet, it still must check it for any noise-caused damage. CRCs (cyclic redundancy checks) enable the receiver to detect any data-packet errors. When the receiver detects an erroneous data packet, it can either request the transmitter to resend it or not acknowledge the data, triggering the transmitter to automatically retry transmitting a data packet. To overcome the effects of continuous noise, some PLC devices implement AGC. Using AGC, the receiver dynamically adjusts its sensitivity above the noise floor so that it can better differentiate between noise and data. Clearly, the more ways a system can accommodate or overcome noise, the more reliable the system. Hence, it is beneficial to implement acknowledgment- based bidirectional communication with retries and CRC.

5. BPL IN ACTION - POWER LINE NETWORKING

Two powerful market forces are converging to drive the implementation of effective home networking; high bandwidth consumer applications and the urgent need to develop the smart grid. Both require an effective home network with high QoS for consumer applications (HDTV, IPTV, gaming) and high reliability for smart grid applications. While local area networks in commercial buildings and campuses are ubiquitous with mature standards in place (IEEE 802.3X and IEEE 802.11X), home networking has been characterized as a mix of competing interests and standards that have held back the widespread implementation of a robust home networking topology. That picture is now getting much clearer. Powerline networking is emerging as the backbone for home networks allowing any device to be connected wherever there is a power outlet in the home. Today, BPL devices are becoming popular at every place. Users prefer those for expanding network because wiring a network cable is not practicable all the times. The most popular use of BPL is to expand Local Area Network (LAN) and telephone lines. With increasing popularity and competiton cost of BPL in-house devices is being reduced every day. Most of the devices used are based on HomePlug specifications [13]. Market forces are now demanding a compatible, interoperable powerline network that offers a comprehensive solution with a future migration path and backward compatibility. Adapter plugs into a standard electrical socket and draws power for the device. At the same time, it sends data signals down via the mains wiring. A second adapter (Figure 9) can then be placed on any electrical outlet in the home/office to receive the signal. Now any Ethernet device (Internet, cable/ADSL broadband modem or another computer) can connect to the Ethernet port and create a home/office network. Range on can be expected to be 100 m or more. As there are many similarities between BPL and Wi-Fi technologies with the exception of the communication medium concerning the proposed throughputs, functionalities, or even device cost. Therefore, it was rather logical to notice that these two technologies get closer to allowing use of the electrical network as the Ethernet backbone and the Wi-Fi interfaces to connect the customers of the local area network.

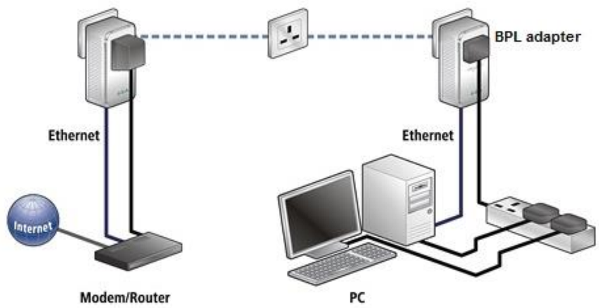

Figure 9 Typical LAN configuration using BPL adapters

An increasing number of manufacturers propose devices combining both technologies. The development of the latest standards will soon bring devices combining HomePlug AV and IEEE 802.11 Super G dynamic to market in order to provide better throughputs and the broadcasting of HD video streams.

6. CONCLUSION

Even though the importance and direct socioeconomic impact of access to broadband services are well understood, currently only 4 percent of the Earth's population has access to some type of broadband services, typically via DSL or cable modem. BPL offers a new, potentially powerful alternative means of providing high-speed Internet services, VoIP, and other broadband services to homes and businesses by using existing MV and LV power lines. Because roughly 60 percent of Earth's inhabitants have access to power lines, BPL could play a significant role in bridging the existing digital divide. The main advantage of this kind of communication system is the existing infrastructure, which simplifies the implementation. But the success of BPL, like that of any new technology in its infancy, depends on more than strong theoretical results or successful field testing. It also depends greatly on the appropriate business models and deployment plans. As the regulatory uncertainties and interference issues surrounding BPL dissipate, and with the success of many field trials and early commercial deployments, the release of various standards, and the growing availability of reasonably priced standardized and reliable equipment, the road to BPL is becoming increasingly well paved and broadband over power lines seems to be well energized. By 2020, all Europeans should have access to Internet of above 30 Megabits per second (Mbps) and 50% or more of European households have subscriptions above 100 Mbps. This target is from the Digital Agenda for Europe, a flagship initiative of the Europe 2020 strategy for a smart, sustainable and inclusive economy. The European BPL market is currently declinening. BPL was under test for a while in Europe to deliver online content over utility distribution lines. Practically, all of these test projects yielded undesired results such as interference with the radio waves forcing the utilities to abandon most of these projects. The disastrous results of the BPL pilot projects undertaken have cast a dark shadow over the viability of BPL as competing internet technologies such as DSL, WiFi, and WiMAX. With all these disadvantages, the report predicts a steady demise for BPL technology that provides Internet connectivity over power lines. Promising market field for tecnology is home/office networking. In addition to savings, increased efficiency and reliability of the network, the satisfaction of the consumers is also achieved. Overall, BPL has a future albeit a limited one.

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