Broadband over Power Lines: Challenges Ahead

Neelima Mallela and Hamid Shahnasser
SanFrancisco State University,1600 Holloway Avenue,SanFrancisco, CA 94132

Abstract — **Broadband over power lines (BPL) is an emerging technology that carries data over existing power lines at high frequencies at 2-50 MHz providing high-speed Internet access. Power lines are designed to carry low frequency electric signals. BPL deployment poses technical and economic challenges as power lines are not designed to carry data signals at 2-50MHz. Technical challenges including interference, signal attenuation, noise, lack of standards, and threat to data security are discussed. Cable modem, DSL, satellite and wireless broadband technologies are compared with BPL.This paper outlines the technical and economic areas that need to be addressed before full-scale deployment.**

I. INTRODUCTION

Data communications using frequencies less than 100KHz over the existing power lines has been there from almost a century. The idea of using existing power lines to provide high-speed Internet using broadband frequencies of at 2-50 MHz has been gaining interest over the past decade. Such communications are known as broadband over power lines (BPL) or power line communications (PLC). Today, BPL provides data rates up to 3 Mbps [1]. In the near future BPL is anticipated to provide data rates up to 200Mbps[2]. BPL injectors, repeaters, extractors and customer premises equipment (CPE) are the basic devices installed to enable power line network to provide high-speed Internet access. In this paper, the author uses the terms access BPL and indoor BPL as per U.S. Federal Communications Commission (FCC) classification [9].

From the past few years, commercial deployments of BPL took place at several locations in Europe including Germany, Spain, Korea, Chile, and Brazil [3]. More than thirty [3] BPL field trials are ongoing all over the US that might look forward for deployments. And three successful commercial deployments have been providing high- speed Internet access in US to city of Manassas, VA, Cincinnati, OH, Emmaus, PA [3]. In spite of the growth of BPL in different locations, BPL technology continues to pose technical and economic challenges in delivering broadband access over the power lines.

II. TECHNICAL CHALLENGES

A. Interference

In BPL Systems, modulated data signals are injected into power lines at differential mode. Small portion of these signals escape from the electric wires and interrupt data signals transmitting at the same frequencies by other communication facilities. These emissions cause external interference resulting in data loss. Communication facilities including amateur radios, wireless security services and military surveillance stations [6] are affected due to interference. Also, data signals from other communication facilities interfere with BPL signals passing through power lines resulting in data loss. BPL signals injected at differential mode currents flowing in opposite directions have equal magnitude and phase; the electromagnetic fields generated from the differential mode currents subtract each other. Therefore fields get cancelled out and do not radiate emissions [7]. Due to untwisted power lines, these differential mode data signals are converted into common mode current. As the fields get added for common mode currents, unwanted radiations are generated. Due to antenna behavior of unshielded wires, power lines transmitting at high frequency emit these electromagnetic radiations. This behavior causes interference to external signals transmitting at same frequencies. In the case of BPL signals, the source is purely resistive component where as the load is complex with resistive, capacitive, inductive components. Hence source impedance (Zs) is not equal to load impedance (Zl)[8]. This mismatch of impedance causes electrical imbalance resulting in asymmetry in power lines, injection points, couplers, power outlets and switches. This asymmetry also causes common mode current resulting in emission of electromagnetic radiations. This leads to data loss that is not desirable in a good communication system. Various measures to alleviate interference are available. Such measures include using low power level for BPL signal injection, frequency-notching technique, using differential mode injection devices [9], balanced line transmission for access BPL [7] and complimentary signal injection for indoor BPL [11]. Though these measures help in reducing interference, these might not completely eliminate interference.

About 80%[6] of MV and LV power lines in US are overhead lines. Long overhead MV cables have more potential to generate unwanted radiations than the buried LV cables [7]. Thus, interference caused from MV lines is crucial for full-scale deployment. BPL is an unlicensed service and is governed by part 15 rules by FCC [7]. Though the field trials prove that the interference levels are with in FCC part 15 limits, it is difficult to quantify the possibility of harmful interference for full-scale deployment. Negligible radiated emissions cause interference to other users of the frequency spectrum. For example, a radio amateur listener may be easily perturbed from the interference. For full-scale deployment, it is necessary to consider the level of background noise over the power lines. This helps BPL operators to maintain interference level less than the background noise level at the locations where BPL is deployed [7]. This poses a challenge. So far, FCC has specified limits on radiated emissions only for immediate vicinity of power lines. However, far field effects cannot be neglected. Some far field BPL radiations might bounce off from the ionosphere and return to earth causing interference. Such far field radiations causing long-range effects might be non-negligible but contribute to interference. Long-range effects cause interference at several thousands of kilometers from the source. For example, radiations generated due to long-range effect interfere with aircraft receiver flying above the power lines causing interference. Therefore ionosphere reflections [7], the main source of long-range effects, needs further study. In the future, regulations on interference levels may have to address long-range effects. In order to preserve other licensed services of frequency spectrum, FCC excluded certain range of frequencies [9] for BPL operation. In some cases, FCC has posed restrictions on specific geographic locations [7] posing a serious challenge. Although interference to other users of the frequency spectrum is major concern to FCC, BPL must be able to accept any kind of radiations coming from other licensed services. Therefore incoming interference needs further study before full-scale deployment. MV line discontinuities, collective effects, and optimal design are additional issues for BPL full-scale deployment. Unpredictable MV line discontinuities [7] include transformer taps, insulator jumpers and unmatched BPL repeater terminations. These generate unwanted radiations. Collective effect [6] of radiations is another issue and is intense in case of full-scale deployment. Currently, regulations and specifications on interference level are limited to one device under test. For full-scale deployment, a scenario would rise in which several power lines transmit BPL signals in parallel behaving like antenna array contributing to numerous radiations. Short wave services [6] might be easily perturbed by the collective radiations from power lines. Therefore, BPL system needs to be optimally designed [7] for successful transmission to provide high-speed Internet access to homes/offices with no harmful interference. More research is needed in areas including MV line discontinuities and collective effects of radiations before full-scale deployment.

B. Signal Attenuation

Power line network is the largest network with 95%[4] of the worldwide coverage. The signal strength gets reduced as BPL signals travel at high frequency over the long power lines. This is also due to the varied characteristics of the MV lines, LV lines and in home cables causing signal attenuation. Various factors affect signal attenuation for access BPL including types of cables used, injection point of BPL signal and injection phase used to inject BPL signal. Signal attenuation occurs more easily on the broadband (MHz) frequency than the narrowband (KHz) frequency. Distribution network simulations carried out by Tran-Anh [12] on access BPL indicate that signal attenuation increases with the increase in frequency. These simulations also indicate that signal attenuation increases with the increase in length of power lines. BPL signals over aerial cables experience less attenuation due to lack of dielectric loss [6] than the underground cables. This is also due to the different cable parameters such as total radius, etc [12]. Attenuation depends on the types of coating of power lines with insulation material, such as polyvinyl chloride (PVC) and oilpaper insulation. Results [6] indicate that attenuation is low for cables with oilpaper insulation compared to cables with PVC. Therefore the types of cables used are significant for full-scale deployment. BPL signal attenuation depends on the position of signal injected. Simulation results [12] indicate that signal attenuates more when it is injected on to MV wire compared to LV wire. Attenuation on MV lines will be same on all three phases. When the BPL signals reach LV lines, the signal attenuation varies for different phases. This variation is due to the imbalance created by different structures of MV and LV lines. This is a concern for full-scale deployment.

Several factors affect signal attenuation for Indoor BPL including power line lengths, number of branches, environment and loads connected to the power line network. Maenou, et.al, has performed measurements of signal attenuation on 2 buildings with different power line configurations. Measurement results [13] indicate that signal attenuation increases with the increase in the distance between the signal input point and the signal receiving point. Results [13] indicate that signal attenuation increases with the increase in number of branches. Results [13] also indicate that signal attenuation depends more on the number of branches than the power line lengths. This is due to the reflections generated from the terminals of branch lines. Reflections are caused due to the impedance mismatch of the loads connected to the terminals. Reflections are also caused due to the different types of cables used for major lines and branch lines. Although the power line configuration parameters, such as number of branches and the power line lengths, are same, the signal attenuation varies due to difference in environments. An environment includes the time and the electric equipment being operated in a subscriber's home/office. For example, even though the distance and number of branches are same, the measurements [13] of signal attenuation at 6th floor and 10th floors of the building are different. This difference is due to the signal attenuation is measured at different times. Signal attenuation also depends on loads connected to the electrical outlet. BPL signal attenuates more with connected loads than with no load condition. Experiments [14] are conducted for one load condition, two-load condition, three-load condition and four-load condition. Experiment results [14] indicate that signal attenuation increases with the increase in the number of loads and with the increase in distance of the loads from signal input point. Also the load level in terms of load size in power does not affect signal attenuation. For example [14], 1000W window-type air conditioner and 20-W fluorescent lamp does not have significant difference in the signal attenuation.

To alleviate the attenuation, repeaters can be mounted on utility poles at every 1000ft to 2500ft[9]. However, high frequency signals attenuate more compared to low frequency signals. Therefore some portions of the BPL signal are highly attenuated compared to the other portions of the signal. This raises a challenge to design repeaters to serve the frequency selective ability for power lines. This enables the repeater to boost the high frequency signals more compared to the low frequency signals. However, this kind of design is a costly approach. An alternative approach would be using an amplitude equalizer before the signal is fed to repeater. Another alternative would be using reduced distances between the substation and a subscriber's home/office. In densely populated areas, most of the cables run underground. Underground cables exhibit more attenuation [6] than the overhead cables posing a challenge for BPL deployment in densely populated areas. Signal attenuation poses special economic challenges for rural deployments, discussed later.

C. Noise

Depending on the origin of noise components, the power line noise can be categorized into five [5] main categories. These include colored background noise, narrowband noise, periodic impulsive noise synchronous to the mains frequency, periodic impulsive noise asynchronous to the mains frequency and non-periodic impulsive noise. The first three noise types do not vary with time and last for seconds, minutes or even hours. These can be grouped as background noise. The other two noise types vary with time in terms of few microseconds to milliseconds. These are the most harmful noise types for data transmission over power lines. Atmospheric conditions that change occasionally causes noise in power lines. Sunspots and lightening can cause noise over the MV and LV lines. As mentioned earlier, power lines are designed to transmit 60 Hz electric current transmissions, so power lines are hostile for transmitting BPL high frequency data signals. For this reason, the electric current in the power lines is the prominent cause for the electrical noise. Electrical energy conducted from nearby power lines also causes noise [9]. Due to the antenna behavior, the power lines can receive unwanted radio frequency signals transmitted by other transmission systems. These undesired signals interrupt BPL data signals leading to power line noise [9]. Results [15] on noise levels indicate that household electrical appliances, such as fluorescent light and vacuum cleaner connected to the electrical outlet, contribute to significant noise. This is due to the sudden rush or burst of the current or voltage.

To alleviate noise, BPL signals needs to be injected at a higher power level. Because higher power level increases interference, BPL signal power level cannot be increased as much as needed. In addition to this, FCC has regulations on BPL power levels that pose a challenge for full-scale deployment. Another alternative would be using advanced transmission methods such as orthogonal frequency division multiplexing (OFDM)[16]. This is a multi carrier technology in which high frequency carrier is divided into low speed multiple sub carriers. To alleviate disruption of packets, the forward error correction technique along with OFDM technology can be used. The forward error correction [9] technique uses protective bits surrounded by the disrupted data bits to regenerate data. Thus the regenerated data is delivered to the receiver as noise-free signals. Noise might not be completely eliminated as it varies significantly with frequency, load, and time of day and geographic location. This disrupts the quality and reliability of broadband data communications. Therefore, more research on coding schemes is needed to overcome the bit errors before full-scale deployment.

D. Threat to data security

Data security is an important concern in any communication technology. Because power lines are not shielded for radio frequency signals, BPL signals generate significant electromagnetic interference [4]. Therefore, data can escape from power lines and radio receivers can hack this data with little effort. Indoor BPL behaves like a local area network. This increases the chances for a subscriber's device to receive the data not intended for it. OFDM provides built in hardware data security and data encryption [9][17]. However, threat to data security still poses a challenge for full-scale deployment.

E. Lack of Standards

Devices manufactured by different vendors are not interoperable and are vendor proprietary as BPL lacks standards [10]. Several vendors manufacture BPL equipment including Main.Net, Linksys, IOGear, Belkin, Netgear and D-Link [1]. Today, different vendors develop devices based on their own standards. Service problems arise when a vendor is no longer in the business [10] posing a serious challenge.

III. ECONOMIC CHALLENGES

BPL investors face economic challenges for full-scale deployment. It is challenging to assess if BPL can bring good returns on investments. This depends on adequate market penetration [18]. This in turn depends on the economic success of BPL vendors [10]. It is challenging to judge and to bring down the significant acquisition costs (SAC) involved in setting up the BPL in customer premises. SAC includes marketing, sales, installation and authorization [18]. Table I compares available broadband technologies with BPL.

Investors face special economic challenges for rural deployments. More repeaters are needed to improve the signal strength for rural areas. For example, one repeater is needed for every 1000 ft to 2500 ft, which means on the average 30 to 100 repeaters are used for every 20 miles [1]. Reliability of network is also a concern since failure of any one of the repeaters in network could result in interruption of service for downstream subscribers [10]. Field trials carried out up to date have been for distances of less than a mile and therefore, there are no experimental results available for networks that incorporate 30-100 repeaters in series. Sparsely populated rural areas results in assignment of one distribution transformer to possibly one subscriber leading to high investment costs on transformer bypass equipment, couplers. Preliminary studies by NREC/CRN and NRTC indicate that BPL needs over 20[10] subscribers per mile for BPL investors to overcome these financial hurdles in rural areas.

Table I

Comparison of BPL with available Broadband Technologies

	BPL	Cable modem	DSL	Sate-llite	Wireless
Infra-Structure ?	Existing power lines	Cable wires	Telephone local loops	Satellite dish antenna	Broadband access card
Ease of installation ?	Easy	Hard	Same as BPL	Hard	Easy
Ubiqui-tous Net-work ?	Yes	No	No	No	No
Special Feature	Service possible where there are no Cable or DSL	Highest data rates	Service possible only with in 18000 feet from telephone local office	Same as BPL	Service possible while away from home Or office
Comp-any that provides service	Cinergy At Cinci-natti ,OH	Com-Cast	AT &T	Hughes .Net	Verizon
Data rates (Mbps)	3	6-12	3	1.5	3
Rates p.m as of 10/25/06	$39.93 to[9] $49.96	$42.95 [19]	$24.99 [20]	$79.99 [21]	$79.99 [22]
Compet-itor to BPL?	-	No	Yes	No	No

IV. CONCLUSION

Broadband over power lines continues to have technical challenges including interference, signal attenuation, noise, lack of standards, and threat to data security for full-scale deployment. Rural BPL deployment continues to pose economic challenges. Although the available measures alleviate the challenges, they do not completely eliminate them. The aforementioned technical and economic areas need to be addressed before full-scale deployment of BPL is possible.

REFERENCES

[1] David Lowe, "Power Line Communications: A Business & Technology Summary",NTCA,April 26,2004.

[2] T.Masamitsu,"Technical Trends in High-Speed Power Line Communication", IEEE Trans on Commu, Vol E88-B, No 8,Aug 2005.

[3] Dr.David S.Yaney, "Presentation to Washington Area CTO Roundtable, 21 Jan 2005", Current Technologies

[4] Baid,A,"OpeningUpPowerfulLinesOfcommunication", IEEE potentials Dec 2005,Vol 24,issue 5,pp.41-45.

[5] M.Zimmermann,K.Dostert,"AnAnalysisOfTheBroadband Noise Scenario in Power line Networks", ISPLC 2000.

[6] M.Gebhardt,et.al, "Physical and Regulatoryconstraints for communication over the power supply grid",IEEE Commu. Magn vol 41 no 5,May 2003,pp. 84-90

[7] Paul S.Henry,"Inteference Characteristics of Broad band over power lines systems using Aerial Medium Voltage wires",IEEE Commu. Magn April 2005 pp. 92-98

[8] F.Issa, M.Goldberg, E.Marthe ,F.Rachidi,"In Situ Characterization of Impedance Mismatch in a Medium Voltage Network", 9th ISPLC, April 2005,pp.414-416

[9] Gilbert Held,"Understanding Broadband over Power Line",ISBN 0-8493-9846-0 .

[10] S.E.Collier,"Delivering Broadband Internet Over Power Lines:What you should know",Rural Electric power conferenc,May 23-25,2004

[11] M.Rubinstein,J.L.Bermudez,"Discussion on the assessment and mitigation of radiation from BPL networks",9th ISPLC, April 6-8 2005

[12] T.Tran,et.al,"DistributionNetworkModelingforPowerline CommunicationApplications",ISPLC2005,pp361-365

[13] T.Maenou,"Study of Signal Attenuation Characteristics in Broadband over power lines",IEEE ISPLC ,March 2006, pp217-221

[14] C.J.Kim, M.F.Chouikha, "Attenuation Characteristics of High Rate Home-Networking BPL Signals",IEEE Trans. Power Delivery,vol 17,No 4,Oct 2002 pp.945-950

[15] H.Meng,et.al ,"Modeling and Analysis of Noise Effects on Broadband power-line communications",IEEE Trans. Power Delivery, vol 20,No.2,April 2005,pp.630-637

[16] M.Obradovic,,"Power Line Communications Based On OFDM"

[17] G.Jee,et.al.,,"Demonstration of technical viability of BPL SystemsOnMedium-andLow-Voltage Lines in the United States", IEEE Commun.Mag,May 2003,pp. 108-112

[18] P.A.Brown,"Identifying Some Techno-Economic Criteria in BPL/BPL Applications and Commercialization",April 2005 ISPLC,pp.234-239

[19]http://www.comcast.com/shop/buyflow/default.ashx?SourcePage=Internet ~Online

[20]https://swot.sbc.com/swot/dslMassMarketCatalog.do?do=view&serviceType=DYNAMICIP ~ Online

[21]http://www.nationwidesatellite.com/HughesNet/service_plans/HughesNet_plans.asp ~ Online

[22] http://solutions.vzwshop.com/bba/default.htm ~Online.