Survey of Power Line Communication

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ABSTRACT
In this paper a survey of power line communications has been presented. As power line distribution networks are available in almost each building that is mainly used for the supply of electrical power, it will be very interesting if such media could be used for the transmission of data. The demand of low cost telecommunication, broadband and access to internet services is increasing day by day and applied a driven force leading to further research in the field of power line communications. A number of organizations are working on power line communications and more advanced schemes are being proposed so that a new dimension could be added to the potential application of established wire line infrastructure.

Keywords
Power Line Communication, Channel Model, Multiple Access Scheme.

1. INTRODUCTION
In Power line communication technology, medium -voltage and low-voltage electrical network is used to provide communication services. Concept of communication over power line is very old; it has a history of about hundred years [1]. In early days communication was started using very low frequencies. In 1938, Englishman Edward Davy proposed a method in which measurements to be taken of battery level of sites far from the telegraph system between Landon and Liverpool. In 1897 a technique for remote measurement of electrical network meters communicating over electrical wiring was being patented by him. After so many years, in 1950 the first PLC system known as 'Ripple Control' was being developed over low- and medium-voltage electrical networks, uses the carrier frequency between 100Hz to 1 KHz. That was single directional. In 1960, the first industrial system, named as Pulsadis, developed in France, uses the power approximately hundred kilovoltamperes (kVA). Then the first CENELEC band PLC systems appeared, extending from 3 to 148.5 kHz, and allowing bidirectional communications over the LV (low voltage) electrical network, for instance, for meter readings (remote meter readings) as well as for a great number of applications relating to the home automation field (intruder alarm, fire detection, gas leak detection, and so forth). Much less power needed to be injected, since the power was reduced to levels of approximately a hundred milliwatts. It is the result of extensive research on high band width data transmission on the power line medium. Although, the first application of power lines started low frequency levels, today powerline communication is used for high frequency applications that are also known as Broadband powerline (BPL).Today, due to increasing demand of networking in home, offices, buildings, industrial organizations etc, the power lines are considered as a medium for high speed data (>2Mbps) transmission [2,3]. PLC Broadband technology is capable of transmitting data via the electrical supply network, and therefore can extend an existing local area network or share an existing Internet connection through electric plugs with the installation of specific units. Rest of the paper is organized as follows. In section II, various technologies related with PLC are presented in brief. Later in section III, the prime multiple access schemes employed in power line communication (PLC) are explained. Section IV presents various power line channel models while section V concludes the paper.

2. PLC TCHNOLOGY AND BANWIDTH
The basic principle in transmitting data through PLC (power line communication) consists in superimposing a high frequency signal that is message signal (1.6 to 30 MHz) at low energy levels over the 50 Hz electrical signal [1]. This second signal is transmitted via the power infrastructure that can be received and decoded remotely. Thus the transmitted signal is received by any PLC receiver located on the same electrical network. In order to transport the PLC signal on electrical wiring, the line frequency (for example, 110 V/60 Hz) of the electrical circuit is supplemented by a modulated signal of low amplitude around a centre frequency (carrier frequency).

Nowadays, electricity producer and distributor cannot ignore standardization of power line channel, that about to be used worldwide in the field of telecommunication. Depending on the geographical areas, standardization work may be directly associated with an international level or first be developed at a regional level. The deployment of electrical networks, their interconnections and ever increasing number of electrical appliances have resulted in the emergence of the first network standardization bodies such as IEC (International Electrotechnical commission).There are three International organizations [1] that cover all the field of knowledge regarding the system, as IEC (International Electrotechnical commission,Europe), the ISO and the ITU. The IEC (International Electrotechnical commission,Europe) and the CENELECT (Europian committee for Electrotechnical standardization) are in charge of electrical engineering and the ETSI (Europian Telecommunication Standards Institute)is in charge of telecommunications. The ISO and CEN (Europian committee for Standardization) cover all the other areas of activity [1]. These International standards are aimed to limiting the interfering emissions of the wired networks. As Powerline communication networks are simple and practical so can be quickly developed and can be sustained with the appearance of new PLC technology versions resulting in new applications and emergence of IEEE 1901 standard for PLCs in the very near future. In India power is typically generated in the power stations (very high voltage in hundreds of KV) and then transported through high voltage cables to a medium voltage sub- stations, which transforms the high voltage into lower voltages(in tens of KV) and then distributed through a number of low voltage grids.The European Committee for Electrotechnical Standardization in Brussels (CENELEC) published the standard EN 50065-1, "Signaling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz" [1]. The EN 50065-1 regulates all power-line signaling within the frequency range 3 kHz to 148.5 kHz, and it has been adopted by the German Electrotechnical Commission in DIN and VDE as DIN-EN 50065-1, classification VDE 0808, as well as by many other European national committees. Four different frequency bands are specified:

- A-band (3 kHz - 95 kHz), reserved for power companies,
- B-band (95 kHz – 125 kHz), that can be used by all applications **without** any access protocol,
- C-band (125 kHz – 140 kHz), reserved for home network systems. A mandatory access protocol (CSMA/CA = Carrier Sense Multiple Access/ Collision Avoidance) facilitates the coexistence of different incompatible systems in the same frequency band. And last but not least
- D-band (140 kHz - 148.5 kHz), that is specified for alarm- and security-systems **without** any access.
- The entire band of frequencies suitable for applications is presented in figure 1 and the same is duly explained in the concerned table1.

Table 1. Frequency Bands used in PLC

Frequency Band	**Frequency Range**	**Devoted Purpose**
	3KHz-9 KHz	To electric distribution companies
A	9 KHz-95 KHz	To electric distribution companies and Power Licenses
B	95 KHz-125 KHz	To consumers with no restrictions
C	125 KHz-140 KHz	To consumers for media access protocols only
D	140 KHz-148.5 KHz	To consumers with no restrictions

For all four frequency bands, a maximum output level is required by EN50065-1 for the signal transmission via power-line (*figure1*). For the use in home network systems, the C-band with a maximum level of 116 dB (µV) is the best choice, because a media access protocol is required. The maximum output level has to be measured by a peak level detector and a given receiver circuit during a period of one minute.

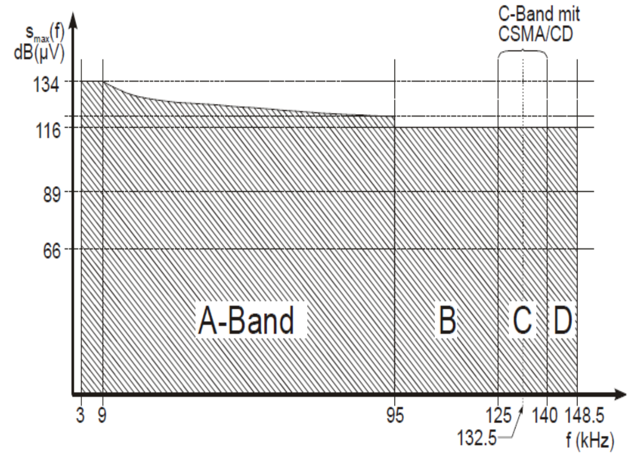

Fig 1: Maximum output level in the frequency range 3 kHz to 148.5 kHz in dB (µV) [14]

Additionally, the EN 50065-1 defines noise levels for all frequency bands, mandatory for any electrical appliance connected to the mains in Europe. Thus, the potential parasitic influence by disturbances is decreased to a minimum.

Each low-voltage grid has one substation, which transforms the voltage into about 220 V and delivers it to the connected households, via low-voltage lines. Typically several low-voltage lines are connected to the substation. Each low-voltage line consists of four wires, three phases and neutral. Coupled to the lines are cable-boxes, which are used to attach households to the grid.

The architecture of PLC networks is comparable in many aspects to that of wired networks. There are so many advantages with power line communication as it exists almost everywhere, it can be quickly deployed and uses a robust encryption method. The communication equipments can be easily connected to the electrical wired network without bearing any extra cost to consumers as demonstrated in figure 2.

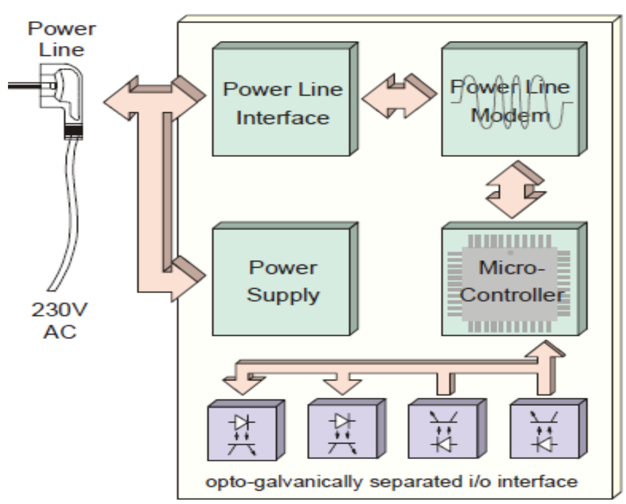

Fig 2: Block Diagram of Power Communication System with Electrical Wiring

3. MULTIPLE ACCESS SCHEMES WITH PLC

Today with the advent of technology , use of high speed applications like internet, voice and data has been increased that's why many researches has been done in last few years to expose the properties of power line channel at the frequencies up to 20 or 30 MHz for fixing power line channel as a communication system.

Orthogonal frequency division multiplexing and Spread spectrum Modulation are the two modulation schemes that are mainly used with broadband power line communication. Various broadband power line communication (PLC) solutions based on OFDM technology are currently exists [4].

CDMA (Code Division Multiple Access) modulation is a type of spread spectrum modulation used in some PLC solutions as it is very successful candidate in various communication areas and suggests that it is a good candidate in broadband power line communications as well.

There have some researches been done for evaluating the performance of OFDM and CDMA systems in power lines. In [4] the comparison of OFDM and CDMA for broadband power line communication has been made by simulation. performance analysis model of OFDM under the effect of impulsive noise and multipath effects has been developed by close formulas and verified by simulation [7].

The first direct sequence multiple access (DS-CDMA) [6] is being used with low frequencies of power line channel. In high frequency bands (1-40MHz) minimum output energy receivers (such as RAKE receiver) and multiuser detection techniques have been used. The receiver in the CDMA system is based on coherent receiver structure. In coherent receivers the multipath effect could not be balanced. Multipath effect, signal follow the shortest path, is serious problem of power line communication.

To counter the multipath effect CDMA systems with RAKE receiver has been designed. RAKE receiver uses several "subreceivers", each delay slightly in order to tune into the individual multipath components. In [4] a CDMA system with and without RAKE receiver has been introduced. On the other hand multicarrier code division multiplexing (MC-CDMA) [7] has been widely researched with power line channel. It shows all the advantages of OFDM, since OFDM has very good performance in both wireless and power line communications.

The multicarrier CDMA scheme is similar that of normal OFDM scheme the main difference is that in MC-CDMA the same symbol in parallel through many subcarriers is being transmitted, whereas in OFDM one transmits different symbols. In [8] a comparison between two asynchronous multi- access direct sequence code division multiple access (DS-CDMA) and multicarrier code division multiple access (MC-CDMA) with binary and polyphase long sequence has been made.

The PLC signal is modulated in amplitude, frequency, or phase around a carrier frequency [1]. The duly modulated signal is sent through power line carrier channel fro transmitter side and is retrieved by reverse process at receiver side. The basic diagram of power line communication system is shown in figure 3.

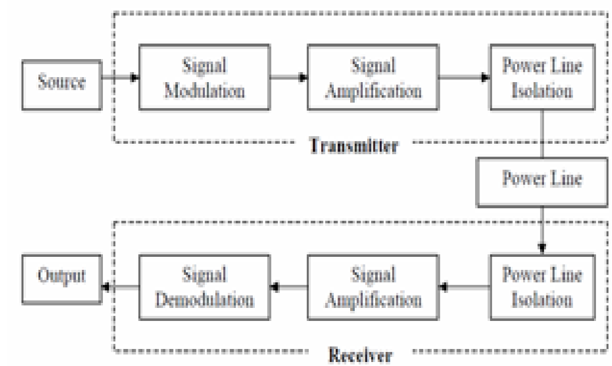

Fig 3: Power Line Communication System

The power line channel suffers from multipath fading and frequency selectivity along with manmade impulsive bursty noise. This limits the performance of the channel for very high data rates. Performance enhancement technique such as coding can help a multicarrier system to tackle with impulsive noise burst. Further researches should be carried out in the field of efficient coding, modulation and transmission methodologies, in order to ensure reliable communication over power lines. Space-time coding is a new coding modulation technique for multiple antenna wireless systems [9].space-time coding combine temporal and spatial diversity in order to provide less attenuated replicas of the transmitted signals to the receivers and thus mitigate the destructive effects of attenuation. By implementing the space-time codes in the power line communication environment one can take the advantage of spatial diversity in the use of three phase power line. In [10] the space-time block coding is applied to power line communication (PLC) in comparison to wireless communication.

Two types of modulation BPSK, PAM implemented with PLC [10].Block codes, cyclic codes convolutional codes etc, are easily being used with power line communication. These different multiplexing techniques OFDM, CDMA, DS-CDMA, and MC-CDMA have been described by simulation in [11]. These techniques are proved to be applicable for power line communication, while transfer characteristics of power line is just as frequency selective and has deep fadings as the radio channel does. The main difference is the big impulsive noises which are present in the power line medium only and which seem to be overcome by these techniques. When describing the various existing solutions it can be seen that the solutions which use spread spectrum modulation tend to be narrow bandwidth applications, whereas only those solutions using OFDM to date have been seen to increase in bandwidth and multicarrier techniques are being promising multiple access scheme for power line communication.

4. POWER LINE CHANNEL MODEL

Using power line in broadband communication is an interesting task as electric wiring is basically designed for supplying electric power not for data transmission. The electronic appliances used in different power line networks in domestic, professional and industrial environment, produces some electromagnetic emissions which interfere in with the nearest devices, that's why a special frequency band has been allotted for the power line communication. In figure 4, the applications internet applications with wireless applications along with power stations have been duly demonstrated. The communication equipments are well connected with the network though routers and various substations and power plant.

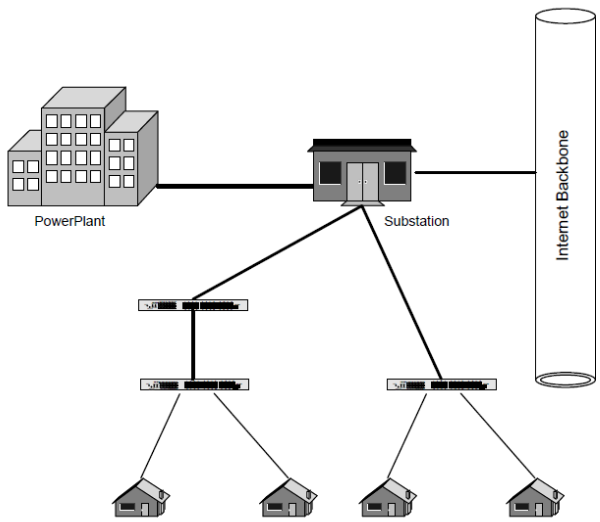

Fig 4: Connecting PLC Networks to the Internet

National or international standards organizations have set down rules that should be followed for the utilization of each frequency band, from zero to tens of gigahertz. Two frequency bands are allocated to PLC; for low bit rate power line communication 3 to 148 kHz and for high bit rate 2 to 20 MHz [20]. Modelling the power line channel [17] is a tough task since its nature is unpredictable nature with frequency, time of day, geographic location and rural environment. The main parameters, taken into account are the impedance, attenuation and noise. Absolute impedance of the power distribution system up to 30 MHz has been carefully studied in several countries, showing similar results between European countries and the US. The main problem lies in the enormous fluctuation in the frequency range of interest though this fluctuation is relatively reduced in the range from 1MHz to 30 MHz [18].

Indoor and outdoor power line channel attenuation has been examined before. These reports show that an attenuation level of 40-100 dB/Km of distance can be expected but it is highly depend on frequency that's why leading frequency-selective channel behaviour. In power lines total of five types noises present. Three of them are considered as background noise fourth is impulsive noise which has random nature and very high power spectral density. Multipath effect is serious problem of power-line communication. That's why researchers have attempted to come up with appropriate channel models. The earlier channel models were channel dependent, for example indoor applications models by Benwell and Galli [12] and the low and medium voltage applications models by Zimmermann and Dostert [13], Hesen and Schulz [14], Phillips [15] etc. some of the low and medium voltage channel models were extended to the indoor applications also. Generally the modelling of power line channel is categories either in time domain or in frequency-domain models [16].the performance of a channel can be accessed more accurately by its transfer functions.

Since the signal is received through multipaths hence the power line channel can be regarded as a multipath environment. Each transmitted signal reaches the receiver not only through direct path but also delayed and attenuated. The multipath channel model based on Zimmermann and Dostert is represented by the equation (1), which describes the signal propagation along a path by the delay portion and the low pass characteristic, that is, the attenuation increasing with length and frequency, by the attenuation portion.

$$H(x) = \sum_{i=1}^{N} |g_i(f)|\, e^{\varphi g_i(f)} e^{-(a_0+a_1 f^x) d_i} e^{-j2\pi f \tau_i} \quad ..(1)$$

The weighting factor g_i summarizes the reflection and transmission factors along the propagation path. It is complex and frequency dependent parameter. N is the total number of paths. In the equation (1) three factors has been combined, $|g_i(f)| e^{\varphi g_i(f)}$ is the weighting factor, $e^{\varphi g_i(f)} e^{-(a_0+a_1 f^x) d_i}$ is attenuation portion and $e^{-j2\pi f \tau_i}$ is the delay portion. This model has been widely proved in practice.

Phillips has proposed two ways for modelling the power line channel model [15][18]; one is Echo model and another one is series resonant circuit model[15]. The Echo model is based on channel measurements from in house network to portray the channel transfer function.

The propagation model that is impulse response can be represented as the sum of n Dirac pulses which are multiplied ρ_i with and delayed by τ_i.

$$h(t) = \sum_{i=1}^{N} \rho_i \, e^{j\varphi_i} \delta(t - \tau_i) \quad ..(2)$$

In equation (2) the complex attenuation is ρ_i. And φ_i is the phase attenuation of the attenuated factor. This model is deployed by many researchers.

The series resonant circuit model [15] is based on impedance measurement of electrical lines. Loads can be described by one or few series resonant circuits that consist of Resistance R, Inductance L and Capacitance C. the impedance of the series resonant circuit can be calculated easily, that is given as;

$$Z_s(s) = R + j2\pi f L + \frac{1}{j2\pi f C} \quad .... (3)$$

The transfer function is;

$$H_s(f) = \frac{1}{1 + \frac{Z}{Z_s(f)}} \quad .... (4)$$

A notch in amplitude characteristics can be seen at resonant frequency. the depth of notch is depend on Impedance Z and Resistance R. the transfer function of the power line can be modelled as a cascade of K decoupled series resonant circuits.

The overall transfer function is;

$$H(f) = \sum_{i=1}^{K} H_s(f) \quad \text{.....…. (5)}$$

The parameters are taken constant throughout the modelling. Both the models proposed by Phillips perform quite well in the multipath environment.

Another channel model based on transmission and reflection factors in conjunction with propagation constants was proposed by *Anatory et al*. for a PLC network with two conductor transmission line system. The resent model is generalized transmission line (TL) approach for determining channel responses. Simple noise model has also been described in [15]. In [19] a component based model of PLC has been discussed to simulate the power line channel.in [19] the channel model has been automatically generated from the integration of component models that are along the topology of distribution network and the location of transmitter and receiver. Although a lot of work has been done on channel modelling using methods pointed above, there is no agreed method to be adopted for channel modelling by the power line communication community. [17] Compares the different modelling methods and generalized transmission line approach.

5. CONCLUSIONS

Power line channel surely is a cheap way to communicate, since it doesn't require any additional wiring. It can support the social needs for access to digital services from anywhere at any time. But it is a difficult task. Despite these difficulties several communication techniques have been selected for applied on power line channel and there is a wide list of references in relevant conferences and journals. Finally, the overall conclusion coming from this paper is that power line communication could definitely become an easily adopted alternate for communication system. The market of PLC devices will continue to grow in the near future with the integration of PLC interfaces like Wi-Fi, Eathernet, cable T.V. and so on, to fulfil the aim of both network engineers and telecommunication engineers.

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