BROADBAND POWER LINE COMMUNICATION: THE CHANNEL AND NOISE ANALYSIS FOR A POWER LINE NETWORK

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ABSTRACT

The scope for broadband powerline Communication is considered as a retrofit technology for wide geographical coverage wherever the human habitation exists. So during the last decade, it has drawn an enormous quantity of research work for improving communication performance and this system being standardized all over the world. The broadband power line Communication channel modelling is essential in the design of a reliable communications system. An analysis on the proposed channel model is conducted in this paper; also the paper studied the noises in Broadband powerline Communication network and its mathematical model. The channel Transfer function and Error Performance of Proposed powerline communication System noise is evaluated with various digital modulation techniques Bit error rate (BER) and signal to noise ratio (SNR) curve by using simulation software. The results indicated that the noise analysis is effective for modelling the power line communication channel. Also, we have presented the various studies on the channel performance based on Orthogonal frequency-division Multiplexing (OFDM) systems for an efficient design of a Broadband Powerline Communication (BPLC) system.

KEYWORDS

Channel model, transfer function, noise modelling, Bit error ratio, orthogonal frequency-division multiplexing.

1. INTRODUCTION

This time, broadband communication becomes the part and partial of our day to day life. Due to uneven geographical condition and demographic setup in the country, In remote distance hilly areas, desert areas broadband communication accesses are still a big issue. Where broadband communication lines are available development is faster and wherever it is not available, slower development in these area. The people of these areas feel they are isolated, lagging from the rest of the world. Broadband communication significantly impacts the social and economic growth of the country [1]. Alternatively, electrical power lines are available in most of these areas, so the deployment of a power line for broadband communication is economically feasible technology, as it stops additional expenditures on infrastructure for system channel. The communication technology through the power lines is now reflected as a worthy substitute for the realizing communication network. Broadband powerline communication permits easy fixing with relatively-low access costs because it needs no new wiring variations to allow broadband connection (it can be retrieved from at all outlet) and makes use of present power networks without adding a single new cable. Just plug the device into a socket-outlet and one is instantly linked to the Internet. However, the application of communication over the power transmission line is a quite old practice. From several years’ power utility companies have been applying these networks for data communication purposes, measurements, control, monitoring and regulation of power plant and distribution network operation. Therefore, the low voltage power-line communication turns into a very interesting field of research.

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The Power line communication technologies can be scattered into two main kinds, Broadband, and Narrowband Communication. Broadband communication over the Powerline uses a usual for high frequency and high-speed, that can have over 100 Mbps speed at the physical layer. Similarly, the Broadband powerline communications technology fall into two main categories; Access and In-house powerline network [1, 5-9]. A channel representation in several kHz to 20 MHz the frequency range was presented in [5]. Access power line technologies are used for sending data over the Low voltage system. Similarly, In-house powerline communication technology transfers data exclusively within the building and extends to all socket outlets within the house [10-12]. Figure (1) shows the structure of the broadband powerline communication network. In fact, the broadband powerline communication channel suffers from attention which is frequency dependent, and it is produced by line conductor and dielectric losses. The characteristics of internal in-house powerline channel transfer function are exciting to model due to the considerable volatility and complication of the networks. Vary significant efforts has been dedicated in the past to define the standard channel model for the broadband communication over powerline as a two wire transmission line [2, 9]. Since the indoor (home) powerline network is quite mature than the outdoor broadband access, so we focus here on the channel modelling for low voltage in the home network, between the socket outlets.

![Figure 1. Structure of Broadband Powerline communication network [16]](https://ssrn.com/abstract=3346868)

The electrical power line was designed for transmission of power at 50Hz (60Hz), having low frequency, while the broadband signal has a high frequency. The broadband Powerline Communication system has its own limits, such as it deals a challenging environment for communication. The noise, line impedance, and attenuation vary with time, frequency, and location; thus, making it challenging to model the Broadband powerline Communication channels [2].

Noise is a significant parameter to define the nature of the powerline channel; hence it is required to study the channel noise characteristics of a broadband power line system channel. The power distribution systems are an exceptional structure for a broadband data-communication, though several noises are present due to stochastic transformation in the system load impedance. Noise in the broadband powerline communication network is categorized into three leading classes, the first one is Colored background noise, second one is the narrowband noise, and the next one is impulsive noise. Background noise and Impulsive noise are the extensive kinds of additive noise in the broadband powerline Communication systems. Impulsive noise Characteristics and its cyclic dependency on the phase synchronous to main frequency are presented in [1]. Authors in [8], proposed the Narrowband noise appears from the current form of amplitude modulation of
radio communication stations, from short, medium wave ranges. The Impulsive noises produced substantial between the existing noise categories in the broadband powerline communication networks. Some of the noise model scheme created in the available literature, whose real value normally varies vary limited, because mostly they describe the bottom-up approach, that is defining the performance of the network [1, 3, 8]. This work is an effort to discover the diverse type of noise and their analysis in a Broadband powerline communication network and also enhance the performance of the powerline channel of the system. The block diagram of the channel is offered in figure (2). The detailed Noise characteristics found in broadband powerline communication are described in section (3).

The contribution of this paper has been divided into four sections. Powerline channel model, characterization is offered in Section-2, The network channel model and Transfer function evaluation work out in this Section. Section-3 illustrated the noise analysis and error Performance of Proposed Powerline communication System. section 4 presented the OFDM modulation systems. Finally, Section-5 discusses the result and analysis as the conclusion of this paper.

2. POWER LINE CHANNEL MODEL

The structure of the powerline grid does not have independent one to one links between transmitter and receivers, whereas it seems like a line bus. It consists of numerous branches, joints in the house wiring cables and mismatched impedance that causes multiple reflections. In this type of case, multipath signal propagation effect must be taken into account. The simplified network topology proposed in this paper for broadband powerline communication network as it is shown in figure (3). When the power transmission line is utilized for high-frequency data communication, the signal data doesn’t route the direct track between the transmitter and receiver, these consequences in Multipath signal propagation. Mingling the multipath signal propagation, frequency and line length the channel Transfer function are stated as in channel analysis [5,11]. Multipath signal propagation is considered for simple illustration which can be simply evaluated as exemplified in Figure (3). The connection has four nodes A, B, C and having only one branch and with the lengths L1, L2 and L3. For the broadband powerline channel model introduced [5]. The signal transmission routes for such type grid can be inscribed as: (i.e., A → B → C, A → B → D → B → C, A → B → D → B → D → B → C, and so on) [17-20].

Figure 2. Block diagram of Powerline communication channel [11]
2.1. Algorithms for analysis

The factors define a Transmission lines are the characteristic impedance \((Z_0)\) and the Propagation constant \((\gamma)\) \([3,4]\).

The Characteristic Impedance

\[
Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}} \quad (1)
\]

and Propagation Constant

\[
\gamma = \sqrt{(R+j\omega L) \times (G+j\omega C)} = \alpha + j\beta \quad (2)
\]

The real part of \(\alpha\) is known as attenuation factor increases with frequency, can be approximated as

\[
\alpha(f) = \alpha_0 + \alpha_1 f^k \quad (3)
\]

Where \(\alpha_0\) and \(\alpha_1\) are attenuation parameters, and \(\beta\) is phase constant.

The channel transfer function is specified by \([5, 12]\)

\[
H(f) = \sum_{i=1}^{N} g_i \times (e^{-[(\alpha_0 + \alpha_1 f^k) d_i]} \times e^{-2\pi f (d_i/v_p)}) \quad (4)
\]

Where \(N\) is the number of multi paths, the \(g_i\) is Weighting factor, \(d_i\) is path length of \(i^{th}\) path, \(\alpha_0\) and \(\alpha_1\) is attenuation parameters, and \(v_p\) phase velocity, \(f\)-frequency and \(k\)- exponent of attenuation factor (0.2-1.0). Part of the equation \(e^{-[(\alpha_0 + \alpha_1 f^k) d_i]}\) is an attenuation portion and the part \(e^{-2\pi f (d_i/v_p)}\) is known as delay portion. The wiring follows different-different norms in many places around the country, so measurements from all location would be necessary.
2.2. Preparation of Data and its Investigative analysis

In this analysis, the variety of cable used is common in India for house wiring; the cross section of cable is illustrated in figure (4). The powerline cables are made up of two copper conductors with inside PVC wall, which can be similar to as a proximate form of the “two-wire transmission line”.

![Diagram of typical single-phase low voltage power cable](image)

Table 1. shows the characteristics parameters estimated for different cables of network.

| Types of cable | 0   | 1   | 2   | 3   | 4   |
|----------------|-----|-----|-----|-----|-----|
| Cross section in (mm$^2$) | 1.50 | 2.50 | 4.00 | 6.00 | 10.00 |
| $\varepsilon_{eq}$ | 1.45 | 1.52 | 1.56 | 1.73 | 2.00 |
| Char. Impedance $Z_0$ in ($\Omega$) | 270 | 234 | 209 | 178 | 143 |
| Resistance $R_0$ in ($\Omega$) | 12.0 | 9.34 | 7.55 | 6.25 | 4.98 |
| Inductance $L$ in ($\mu$H/m) | 1.08 | 0.96 | 0.87 | 0.78 | 0.68 |
| Capacitance in (pF/m) | 15.0 | 17.5 | 20.0 | 25.0 | 33.0 |
| Conductance $G_0$ in (s/m) | 30.9 | 34.7 | 38.4 | 42.5 | 49.3 |

Table 2. The attenuation parameters corresponding to the length profiles [2].

| Class | $g_i$ | $a_0$ (m$^2$) | $a_1$(s/m) | $k$ |
|-------|-------|---------------|-------------|-----|
| 100m  | 1.0   | (9.40) $10^{-4}$ | (4.20) $10^{-5}$ | 0.70 |
| 150m  | 1.0   | (1.09) $10^{-4}$ | (3.36) $10^{-5}$ | 0.70 |
| 200m  | 1.0   | (9.33) $10^{-4}$ | (3.24) $10^{-5}$ | 0.70 |
| 300m  | 1.0   | (8.40) $10^{-4}$ | (3.00) $10^{-5}$ | 1.00 |
| 380m  | 1.0   | (6.20) $10^{-4}$ | (4.00) $10^{-5}$ | 1.00 |

Where $R = R_0 . 10^{-5} \sqrt{f}$ ($\Omega$ per metre) and $G = G_0 . l \times 10^{-14} 2. \pi. f$ (s/m)

2.3. Channel Transfer Function Response

In the paper, a dynamic model of powerline is considered for investigations. The cable data used in this case is a two conductor Copper conductor of diameter 8 mm, the space between the conductor is 0.15 meter, PVC insulated. It is the cable which is commonly available for house-wiring. Based on the transfer function equation (4), A software tool for obtaining the channel transfer function is developed. Also, the structure for the typical indoor broadband powerline communication network channels are shown in figure 2 is investigated; its performance is illustrated in Fig. 4. Lengths of sections $L_1$, $L_2$ and $L_3$ are 30 m, 170 m and 11.5 m respectively. The rest parameters are adopted from [2] as in table 3 and 4. Simulation is showed at the example that the number of paths $N$ is 4 and 15. In the part of equation (4), the attenuation term of the channel model, the constraint sets at $k=1$, $a_0=0$ and $a_1 = 7.8 \times 10^{-10}$ s/m. [2]. Figure (5) illustrated the channel frequency response plot for 4,15-paths, indicates that the varying trends of the transfer function in the frequency series of 1-30 MHz.
Table 3. path parameters (for N= 4) [2]

| N | 1   | 2   | 3   | 4   |
|---|-----|-----|-----|-----|
| g_i| 0.64| 0.38| -0.15| 0.05|
| d_i| 200 | 223 | 246 | 269 |

| N | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| g_i| 0.64| 0.38| -0.15| 0.05|
| d_i| 200 | 223 | 246 | 269 |

Table 4. path parameters (for N= 15) [2]

| N | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|---|-----|-----|-----|-----|-----|-----|-----|-----|
| g_i| 0.029| 0.043| 0.103| -0.058| -0.045| -0.040| 0.038| -0.038|
| d_i| 90 | 102 | 113 | 143 | 148 | 200 | 260 | 322 |

| N | 9  | 10  | 11  | 12  | 13  | 14  | 15  |
|---|----|-----|-----|-----|-----|-----|-----|
| g_i| 0.071| -0.035| 0.065| -0.055| 0.042| -0.059| 0.049|
| d_i| 411| 490| 567| 740| 960| 1130| 1250|

In the Broadband powerline communication environment, signal distortion is expressed not only by channel transfer function \( H(f) \), but noise play an important role in it. As the noise signal is produced by interferences and inhabits part of the frequency band. The short wave communications generate noise and may affect the powerline communications.

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Figure 5. Simulated Transfer functions characteristics for N= 4,15-path

**3. POWER LINE CHANNEL NOISE ANALYSIS**

Noise in a communication system can be explained as any undesired signal which can prove an obstruction to the needed signal. In this paper, we mainly focus on the noise generated by voltage level, by the electrical devices, switching operation and network faults. The Power line networking is likewise susceptible to nosiness from devices linked to that power supply infrastructure, for example, Fluorescent tube lights, washing machine, drill, hair dryers, microwave ovens, computers, switch mode power supply etc. may generate, noise on the power line network. So there is a mass of noise sources; it can often be caused by external disturbances
and can lead to errors in a communication system [1-4]. Broadband transmission over a powerline channel is mainly affected by the ever-present noise. It means similar to the other communication channels, broadband Powerline Communication atmosphere is highly exaggerated by noise, attenuation, and line impedance of channel. In Broadband powerline communication networks the noise signal has to be measured in different positions of the network. Generally, in low/ medium voltage access Networks, measurements are made at transformation centres or substations, and in Home powerline communication it measured at the central meters or at the consumer socket outlet point. This is reflected in the most important positions of the network.

The noise features are significant constraints to define the nature of powerline communication channel interference. This noise can be considered into numerous classes reliant on its source, level amount and the time domain signature [10], as the coloured Background noise, Narrowband noise, Periodic impulsive noise (Synchronous or Asynchronous to the frequency of main supply), besides the aperiodic impulsive noise. The declining of all the noise coming from electrical powerline network is critical. Powerline noise is indicated in the block diagram of Figure (6).

![Figure 6. Types of Noise](image)

The colored background noise

\[ n_{cb}(f) = N_{in} + N_0 e^{\frac{f}{f_0}} \]  

(5)

Where \( n_{cb}(f) \) is the power spectral density of colored background noise, \( N_{in} \) is constant noise density, \( N_0 \) and \( f_0 \) are the constraints of the exponential function.

And the narrowband noise

\[ n_{nb}(f) = \sum_{i=1}^{N} A_i(t) \sin(2\pi f_i t + \varphi) \]  

(6)

where \( N \) indicates the entire number of narrowband interferers, and \( A_i(t) \), \( f_i \), and \( \varphi \) designate the amplitude, frequency level and the phase of the conventional narrowband noise correspondingly.

The model of the colored noise is similar to the Additive White Gaussian noise (AWGN). The power spectral density of background noise \( n_{bg}(f) \) is the sum of colored background noise \( n_{cb}(f) \) and narrowband noise \( n_{nb}(f) \) can be expressed from (5) and (6) as

\[ n_{bg}(f) = n_{cb}(f) + n_{nb}(f) \]  

(7)

Signal to noise ratio is a measure to quantify how much a signal has been corrupted by noise and calculated as

\[ \text{Signal to Noise ratio (SNR)in dB} = 10 \log_{10} \left( \frac{P_{signal}}{P_{noise}} \right) \]  

(13)

The signal to noise ratio higher than 0 db, designates higher signal power than the noise power.
3.1. Error Performance of Proposed Communication System

This structural design has been extensively researched with broadband power line communications by scientists and engineers in the research world. The Broadband powerline communication system is a complicated one and using model for functional blocks such as different kinds of modulator-demodulator, encoder and decoder, and all kinds of signal source, channel model, noises, filters, amplifiers etc. The channel model shown in figure (7) shows only a subset of the functional blocks in broadband powerline communication.

In this segment, we present numerical simulation results that show the system error performance of the proposed powerline communication networks. The theoretical and calculated signal to noise ratio (SNR) and bit error rate (BER) of the proposed powerline channel under BPSK and QPSK, the curve is drawn using ‘bertool’ in MATLAB for AWGN environment. In both the scheme, an improvement in BER has been observed. QPSK scheme is always preferred to BPSK in multipath fading channels. Figure (8) below presents BER and SNR performance curve in the AWGN channel.
4. OFDM SYSTEM

Orthogonal frequency division Multiplexing (OFDM), is the succeeding technology for high speed communication system. In the previous section, we analyzed Error Performance of Proposed Communication System. OFDM system model has been adopted for BPLC communications as it gives better performance at high frequencies used in BPLC [13-17]. OFDM is a special form of the frequency-division multiplexing (FDM) multicarrier modulation technique. In multicarrier systems, the information to be transmitted is split into multiple smaller chunks and transmitted independently. Each of these subcarriers contains numbers of parallel data streams or channels and is modulated conventionally at a low symbol rate; these are groups of bits of data related to (but not the same as) gross bitrate, which is expressed in bits/second. The single carrier, multi-carrier, and OFDM frequency spectral curve is shown in figure (9) below [14].

![OFDM spectrum curve](image)

Figure 9. OFDM spectrum curve[14]

The OFDM modulation techniques are found to provide better error handling, efficient use of bandwidth and reduction in inter-symbol and inter-channel interference [13]. Now here we have discussed the various studies on the channel performance based on orthogonal frequency-division Multiplexing (OFDM) systems as in BPLC system, OFDM modulation is used. The use of orthogonal frequency division Multiplexing (OFDM) is also considered a critical feature allowing broadband powerline communication (BPLC) to avoid certain frequencies. Orthogonal frequency division Multiplexing (OFDM) uses numerous orthogonal subcarriers to transmit the data, it also provides improved robustness beside frequency selective fading and Narrowband interference, and is efficient in distributing with multi-path delay spread [17-18]. In figure (10) shows the block diagram of broadband powerline communication with OFDM transmission.

![BPLC communication model with OFDM transmission](image)

Figure 10. BPLC communication model with OFDM transmission [16]
5. RESULT AND CONCLUSIONS

The broadband powerline communication technology is an exciting alternative for High-speed data communication, the work carried out for the channel analysis for the proposed channel model. The analysis of both the channel and the noise is obtained from limited data and the transfer function and Error Performance of Proposed channel model are simulated by using MATLAB software. The simulation results show the increase of power line length is produced deep notches which signify attenuation on the broadband power line communication Channel. Further, this paper is evaluated noise error performance with various digital modulation techniques. The results indicate that the channel Transfer function and Noise analysis is effective for modelling the of power-line Communication channel. OFDM is an attractive modulation scheme for the high data rate BPLC applications.

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