Analysis of a Power Line Communication System Over a Non-white Additive Gaussian Noise Channel and Performance Improvement Using Diversity Reception

Munshi Mahbubur Rahman[1] & S. P. Majumder[2]

[1] Department of EECE, MIST, Dhaka, Bangladesh

[2] Department of EEE, BUET, Dhaka, Bangladesh

Correspondence: Munshi Mahbubur Rahman, Department of EECE, MIST, Dhaka, Bangladesh. Tel: 880-167-803-3111. E-mail: mmr.eece@mist.edu.bd

Received: November 14, 2011 Accepted: November 30, 2011 Online Published: June 1, 2012

doi:10.5539/nct.v1n1p26 URL: http://dx.doi.org/10.5539/nct.v1n1p26

Abstract

Performance improvement of a power line communication system is presented here considering the noise as a cyclostationary non-white Gaussian random process. Performance of a power line communication system is severely deteriorated by fading and multipath effect. The impulsive noise has been considered time variant, has short duration, random occurrence with a high power spectral density (PSD). It causes bit error in the signal. Using orthogonal frequency division multiplexing (OFDM) technique, the effect of impulsive noise and fading can be improved greatly. An analytic approach is presented to evaluate the performance of a power line communication link in the presence of the above limitations. The simulation results show that there is deterioration in system BER due to time and frequency dependence of noise and the degradation is found to be significant at higher bit rates and bandwidth. The system suffers penalty in receiver sensitivity due to non-white nature of the noise process. In this paper, an analytical approach using diversity reception is carried out to examine the performance improvement of a power line channel in fading and impulsive noise. The system bit error rate (BER) is compared numerically for both binary phase shift keying (BPSK) and OFDM system. The BER results show that there is significant improvement in OFDM. Also the performance is remarkably upgraded using diversity reception.

Keywords: cyclostationary noise, attenuation, PDF (probability density function), white noise, interference, variance

1. Introduction

The main source of Power-line noise is caused by Electric appliances connected to the line (Janse, 2008; Ma, So, & Gunawan, 2005; Ezio, 2006). Essentially, the power-lines or associated hardware improperly generate unwanted radio signals that override or compete with desired radio signals. Power-line noise can impact radio and television reception - including cable TV head-end pick-up and Internet service. Disruption of radio communications, such as amateur radio, can also occur (Massaki, 2001). Loss of critical communications, such as police, fire, military and other similar users of the radio spectrum can result in even more serious consequences. Virtually all power-line noise, originating from utility company equipment, is caused by a spark or arcing across some power-line related hardware (Janse, 2008; Tachikawa, Hokari, & Marubayashi, 1989).

During the last two decades several research works has been reported on the modeling and characterization of power line noise (Article from john nosotti.doc, 2004). Noise in a power line results due to the effect of corona, impulse voltages, electric arc between the lines, and affect the communication link severely (Voglgsang, Langguth, Koerner, Steckenbiller, & Krnorr, 2000). The nature of power line noise is found to be a non-white cyclostationary process (Masaaki, Takaya, & Hiraku, 2006). The modeling and simulation of PLC system using several types of noise are also reported (Zimmermann & Dostert, 2002; Meng, Guan, & Chen, 2005; Katayama, Itou, Yamazato, & Ogawa, 2005; Hooijen, 1997).

In a Power-line, the bit error rate (BER) performance of a communication link impaired by power line noises. These noises consist of stationary background noise and time variant impulsive noise. Impulsive noise appears as Poisson distribution. The multipath delay spread is a time dispersion characteristics of the channel. The signal is made up of the sum of many signals, each traveling over a separate path. Since these path lengths are not the same, the information carried on a PLC channel experiences a spread in delay as it travels between the transmitting station and the receiving station. Furthermore, the same multipath environment causes severe local variations in signal as these multipath signals are added constructively and destructively at the receiving antenna.

The impulsive noise and multi-path effects are the main factors considered for degrading the power line communication (PLC) performance. OFDM separate overall transmitted data in many parallel independent sub-streams. The long symbol duration time makes OFDM perform better than single carrier scheme for multi-path channel. OFDM may perform better than single carrier when the channel is interfered by impulsive noise, since it can spread the impulsive noise over multiple symbols due to inverse fast Fourier transform (IFFT).

Signal degradation in a power line communication due to multipath fading, time dispersion etc. can be overcome by diversity technique (Tanaka & Someya, 1986). The basic concept of diversity is that each of the transmitted signals is received through a number of separate channels. When several number of individual channel carrying the same information are received over multiple channels that exhibit independent fading with comparable strengths. The chances that all the independently faded signal components experience the same fading simultaneously are greatly reduced (Daisuke, Hideyuki, & Yoshiteru, 2006). In this paper, we provide an analytical approach to find the bit error rate (BER) performance of a Power Line Communication in the presence of impulsive noise and fading with diversity in reception using multiple receiving antennas.

We have presented an analytical approach to find the bit error rate (BER) performance of a communication link impaired by power line noise which is considered as non-white additive Gaussian cyclostationary process (Tachikawa & Takuma, 2010). In this paper, we have investigated the BER performance in a power line communication considering the PLC noise to be a non-white additive Gaussian cyclostationary process. We propose that in a PLC environment, firstly the BER performance can be improved by using OFDM and secondly, the performance is remarkably upgraded using diversity reception.

2. Analysis of Non-white Additive Gaussian Noise

2.1 System Model

The block diagram of the power line communication system for diversity reception used for this analysis is shown in fig.1. The digital data from the intelligent electronics device (IED) are multiplexed and transmitted from the substation to a central control station through a wireless link. The signal transmitted is accompanied with noise from the power line and is received by the receiver along with channel noise. We consider BPSK modulation and coherent demodulation at the receiver. The system model is shown in Figure 1.

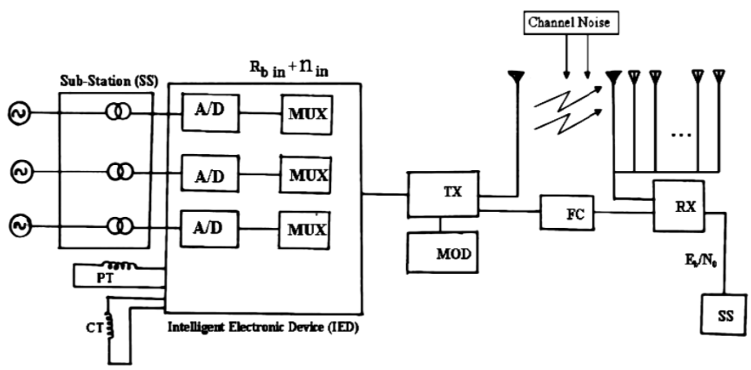

Figure1. Power line communication network

2.2 Theoretical Analysis

Noise in a power line has a periodic feature with frequency $\frac{2}{T_{ac}}$; where T_{ac} is the period of AC mains. Hence the amplitude distribution can be assumed as Gaussian. Therefore, power line noise is assumed to be cyclostationary additive Gaussian noise whose mean is zero and the variance is synchronous to the AC voltage of mains. With this assumption, the probability density function (PDF) of cyclostationary additive Gaussian noise is given by,

$$P(n(t)) = \frac{1}{\sqrt{2\pi\sigma^2 t}} \exp\left[-\frac{n^2(t)}{2\sigma^2 t}\right] \quad (1)$$

Putting $t = i\,T_s$ we can write,

$$P(n(iT_S)) = \frac{1}{\sqrt{2\pi\sigma^2 \left(iT_S\right)}} \exp\left[\frac{-n^2(iT_S)}{2\sigma^2(iT_S)}\right] \quad (2)$$

In this Equation $\sigma^2(t) = \gamma E[\rho^2(t)]$ is the instantaneous noise variance.

Since the variance $\sigma^2(t)$ is a periodic function of the frequency $\frac{2}{T_{ac}}$, the PDF is also a periodic function. Such that $P(n(iT_s)) = P(n(iT_s + j\frac{T_{ac}}{2}))$ for any integer *j*.

This is an important relation because the time dependent or non stationary features of noise are represent mathematically in the closed form of PDF.

Let the received signal is given by,

r(t) = s(t) + n(t)

s(t) = signal component

n(t) = noise component

Let us assume that the power of signal is constant for a short duration $t_0 - \delta \le t \le t_0 + \delta$, so the reference signal for this time duration can be expressed as:

$$S(t) = \sqrt{2P_S}\cos(2\pi f_C t + \varphi) \quad (3)$$

The power P_S can be calculated as,

$$P_S \approx \frac{1}{2\delta}\int_{t_0-\delta}^{t_0+\delta} S^2(t)dt \quad (4)$$

The signal is processed in a narrow band with band-pass and band-rejection filters of centre frequency f_C .

2.3 Cyclostationary Noise

A cyclostationary additive Gaussian noise whose mean is zero and variance is synchronous to the AC voltage of the mains the PDF of such noise at the instance t = iT_s can be expressed as,

$$P\left(n\left(iT_S\right)\right) = \frac{1}{\sqrt{2\pi\sigma^2(iT_S)}} \exp\left[-\frac{n^2(iT_S)}{2\sigma^2(iT_S)}\right] \quad (5)$$

Here,

$$\sigma^2(t) = \gamma E[\rho^2(t)] \quad (6)$$

equals instantaneous variance of the noise and E(.) equals ensemble average.

Based on the assumption that $\sigma^2(t)$ is a periodic function the ensemble average is replaced by the average instantaneous power of the normalized waveform taken at every $\frac{T_{ac}}{2}$. Then for $0 \le iT_S < \frac{T_{ac}}{2}$, we have instantaneous power (variance) of $\eta(t)$ as,

$$\sigma_m^2(iT_s) = \frac{1}{2m}\sum_{j=0}^{2m-1}\eta^2(iT_s + j\frac{T_{ac}}{2}) \tag{7}$$

$$\sigma_m^2(iT_s) = \frac{\gamma}{2m}\sum_{j=0}^{2m-1}\rho^2\left(iT_S + j\frac{T_{ac}}{2}\right) \tag{8}$$

In a cyclostationary noise characteristics

$$\underset{m\to\infty}{lt}\,\sigma^2{}_m(iT_S) = \sigma^2(iT_S) \tag{9}$$

Now, this function can be approximated a sample function with a small number of parameters. For this purpose the model employs the following periodic function to approximate $\sigma^2(t)$,
as such

$$\sigma^2(t) = \sum_{l=0}^{L-1} A_l \left|sin(\frac{2\pi}{T_{ac}}t + \theta_l)\right|^{nl} \tag{10}$$

Here, $l = 0, 1, 2 \ldots (L-1)$
Al, θ_l and *nl* denotes the characteristics of the noise.
By Fourier series expansion we get,

$$\sigma^2(t) = \sum_{l=0}^{L-1} A_l\cos 2\pi\frac{2l}{T_{ac}}t + B_l\sin 2\pi\frac{2l}{T_{ac}}t \tag{11}$$

where,

$$Al = \begin{cases} \frac{1}{T_{ac}}\int_0^{T_{ac}/2}\sigma^2(t)dt; & for \quad n = 0 \\ \frac{2}{T_{ac}}\int_0^{T_{ac}/2}\sigma^2(t)\cos 2\pi\frac{2l}{T_{ac}}tdt; & n \neq 0 \end{cases} \tag{12}$$

$$B_l = \frac{2}{T_{ac}}\int_0^{T_{ac}/2}\sigma^2(t)\sin 2\pi\frac{2l}{T_{ac}}tdt \tag{13}$$

Now,

$$P_n(t) = \frac{2}{T_{ac}}\int_0^{T_{ac}/2}\sum_{l=0}^{L-1}A_l\cos 2\pi\frac{2l}{T_{ac}}tdt + \frac{2}{T_{ac}}\int_0^{T_{ac}/2}\sum_{l=0}^{L-1}B_l\sin 2\pi\frac{2l}{T_{ac}}tdt \tag{14}$$

$$P_n(t) = \frac{2}{T_{ac}}\sum_{l=0}^{L-1}A_l\left[Sin2\pi\frac{2l}{T_{ac}}t\cdot\frac{Tac}{4\pi l}\right]_{t=0}^{T_{ac}/2} \tag{15}$$

$$+\frac{2}{T_{ac}}\sum_{l=0}^{L-1}B_l\left[-\cos 2\pi\frac{2l}{T_{ac}}t\cdot\frac{T_{ac}}{4\pi l}\right]_{t=0}^{T_{ac}/2} \tag{16}$$

$$= \sum_{l=0}^{L-1}\frac{A_l}{2\pi l}\sin 2\pi l - \sum_{l=0}^{L-1}\frac{B_l}{2\pi l}(\cos 2\pi l - 1) \tag{17}$$

P_n = Mean of the variance within a bit period = σ^2

2.4 Ber Calculation

We know

$$BER = 0.5erfc[\sqrt{\frac{2E_b}{N_o}}] \tag{18}$$

$$\xi = SNR = \frac{2E_b}{N_0} = \frac{E_b}{\frac{N_0}{2}} = \frac{P_s \cdot T_{ac}}{\frac{N_0}{2}} = \frac{P_s}{\frac{N_0}{2} \cdot \frac{1}{T_{ac}}} = \frac{P_s}{\frac{N_0}{2} \cdot B}$$

So,

$$\xi = \frac{P_s}{\sigma_n^{\ 2}} \tag{19}$$

$$SNR = \frac{Ps}{\sum_{l=0}^{L-1} \frac{A_l}{2\pi l} sin\, 2\pi l - \sum_{l=0}^{L-1} \frac{B_l}{2\pi l} (cos\, 2\pi l - 1)} \tag{20}$$

$$BER = 0.5erfc \left[\frac{Ps}{\sum_{l=0}^{L-1} \frac{A_l}{2\pi l} sin\, 2\pi l - \sum_{l=0}^{L-1} \frac{B_l}{2\pi l} (cos\, 2\pi l - 1)} \right]^{\frac{1}{2}} \tag{21}$$

$$BER(i) = 0.5erfc \left[SNR(i) \right]^{\frac{1}{2}} \tag{22}$$

3. Effect of Non-white Gaussian Noise

In preceding sections, a simple method of representing the performance of a power line communication link in the presence of the noise in broadband and narrow band communication channel has been demonstrated. The main purpose of this demonstration is to find out the BER in the presence of non-white additive Gaussian noise. In this work, we have proposed a model for BER for both frequency dependent and frequency independent cases, which cannot be represented by conventional models. It can be a useful tool for the performance evaluation of Power Line Communication (PLC). It can be used as a tool for the design and evaluation of power line communication system, and also as a powerful mean for the studies in interference and fading environment of the noise in power lines.

4. Diversity Reception

So far, we have analyzed the BER performance of a power line system in the presence of non-white additive Gaussian noises. So, the transmitted signal traveling in the channel is subjected to this impulsive noise, fading, time dispersion, and other degradations. To overcome all those impairments and improve signal quality, we propose diversity reception technique. In diversity technique the receiver has more than one version of the transmitted signal is received through a distinct channel. When several version of the signal, carrying the same information are received over multiple channels that exhibit independent fading with comparable strengths, the chances that all the independently faded signal components experience the same fading simultaneously can be greatly reduced.

5. Signal Combining for Diversity Reception

Diversity techniques can increase the system capacity and improve communication reliability (Tachikawa & Takuma, 2010). By transmitting and receiving multiple copies of data, a MIMO system can effectively combat the effects of fading. Due to the high hardware cost of a MIMO system, antenna diversity techniques have been applied in MIMO system design to reduce the system complexity and cost. The fact that the transmitted signal must traverse a potentially difficult environment with scattering, reflection, refraction and so on and may then be further corrupted by thermal noise in the receiver means that some of the received copies of the data will be better than others. This redundancy results in a higher chance of being able to use one or more of the received copies to correctly decoded the received signal. In fact, space–time coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible. Most work on wireless communications had focused on having an antenna array at only one end of the wireless link - usually at the receiver. Using multiple antennas improves performance of the receiver remarkably. This process of receiving diverse copies of the data is known as diversity reception and is what was largely studied (Khalifa & Zahir, 2009). Antenna arrays can provide diversity paths to combat multipath fading of the desired signal and are able of reducing the power of interfering signals at the receiver. The Combining methods considered in this paper are maximal ratio combining (MRC). Maximal ratio combining represents a theoretically optimal combiner over fading channels as a diversity type in receiver diversity in a communication system. Theoretically, multiple copies of the same information signal are combined so as to maximize the instantaneous SNR at the output (Mohammed & Widad, 2010). However system designs often assume that the fading is independent across multiple diversity channels.

Maximum Ratio Combining combines the information from all received branches for a multiple antenna system in order to increase the SNR. We employ different gains to each antenna to get better signal to noise ratio for the joint signals. We used the different proportional constant factors and gain, are approximately equal to the route mean square of the signal level. Maximum Ratio Combining can provide the diversity gain and array gain but it does not assistance in spatial multiplexing scenario. A simple diagram of branch Antenna Diversity is shown in Figure 2.

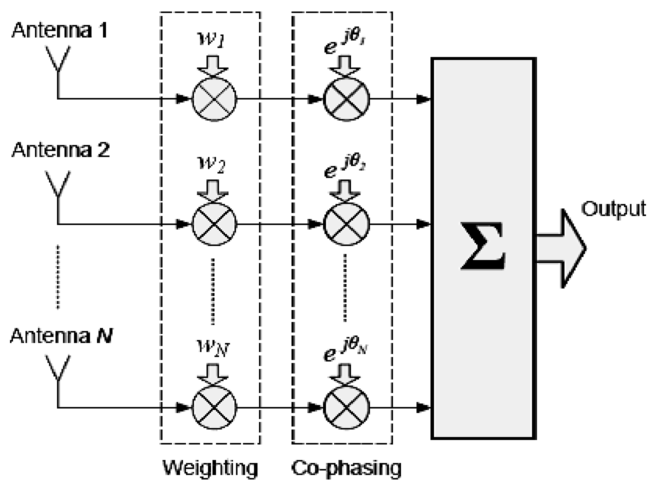

Figure 2. Signal combining (maximum ratio combining)

Maximum Ratio Combining generally works by weighting each branch with a complex factor of W_i and then adding up the N_r branches. The received signal can be written as $x(t)h_i$. The overall signal can be written as,

$$y(t) = x(t)\sum_{i=1}^{N_r} |w_i||h_i| \exp\{ j(\phi_i + \theta_i)\} \tag{23}$$

If we allow the phase $(\phi_i = -\theta_i)$ for branches, then SNR of y(t) can be writing as

$$\gamma_{MRC} = \frac{\varepsilon_x (\sum_{i=1}^{N_r} |w_i||h_i|)^2}{\sigma^2 \sum_{i=1}^{N_r} |w_i|^2} \tag{24}$$

ε_x is the transmitted energy signal. Solving the above expression by taking the derivation with respect to $|w_i|$ provides maximum combining values. In other words, each branch is multiplied with its signal-to-noise ratio. The resulting SNR can be written as

$$\gamma_{MRC} = \frac{\varepsilon_x(\sum_{i=1}^{N_r}|h_i|)^2}{\sigma^2} = \sum_{i=1}^{N_r}\gamma_i \tag{25}$$

When adding up the branches of SNR, the total SNR will be accomplished.

6. Analysis of Impulsive Noise

As mentioned earlier, PLC noise can be termed as background noise and impulsive noise. The background noise is assumed to be additive white Gaussian noise (AWGN) with zero mean and variance $\sigma^2{}_w$. The arrival of impulsive noise follows a Poisson process (Massaki, 2001) with a rate of λ units per second, so that the event of k arrivals in t seconds has the probability distribution (Tachikawa, Hokari, & Marubayashi, 1989),

$$P_k = e^{-\lambda t}(\lambda t)^k / k! \quad k = 0,1,2..... \tag{26}$$

The duration time of the impulsive noise T_{noise} and time period is T. Pi is defined as the total average occurrence of the impulsive noise duration in time T and P_0 is the average duration without impulsive noise in time T, in which duration only AWGN is present (Massaki, 2001). From (1),

$$P_i = \left[\sum_{k=0}^{\infty} e^{-\lambda T}\frac{(\lambda T)^k}{k!}(kT_{noise})\right] / T = \lambda T_{noise}\left[\sum_{k=1}^{\infty} e^{-\lambda T}\frac{(\lambda T)^{k-1}}{(k-1)!}\right] = \lambda T_{noise}\left[\sum_{k=0}^{\infty} e^{-\lambda T}\frac{(\lambda T)^k}{k!}\right]$$

At higher value of k,

$$\begin{aligned} &\sum_{k=0}^{\infty} e^{-\lambda T}\frac{(\lambda T)^k}{k!} = 1 \\ &= \lambda T_{noise} \end{aligned} \tag{27}$$

6.1 BER of Single Carrier BPSK under Impulsive Noise

If the BER under impulsive noise is P_{bi} and BER under AWGN is P_{bw}, then the BER of a single carrier BPSK is given by (Voglgsang et al., 2000),

$$P_b = P_i P_{bi} + P_0 P_{bw} \tag{28}$$

$$= \lambda T_{noise} P_{bi} + (1 \square \lambda T_{noise})P_{bw} \tag{29}$$

Now,

$$P_{bi} = Q\left(\sqrt{\frac{2E_b}{N_i + N_0}}\right) \tag{30}$$

and,

$$P_{bw} = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \tag{31}$$

Where E_b is the signal energy per bit, N_i and N_0 are the power spectral density of the impulsive noise and AWGN respectively. We get BER in BPSK under impulsive noise as

$$\begin{aligned} P_b &= \lambda T_{noise} P_{bi} + (1 - \lambda T_{noise})P_{bw} \\ &= \lambda T_{noise} 0.5erfc\sqrt{\frac{E_b/N_0}{1+\mu}} + (1 - \lambda T_{noise})0.5erfc\sqrt{\frac{E_b}{N_0}} \end{aligned} \tag{32}$$

6.2 BER of Single Carrier OFDM under Impulsive Noise

For OFDM, let the PSD of overall noise (includes impulsive noise and AWGN) be N_m where N_m is given by (Voglgsang et al., 2000),

$$N_m = N_0 + P_i N_i \tag{33}$$

If AWGN noise power is N_0 and impulsive noise power is N_i , then μ is defined as

$$\mu = \frac{N_i}{N_0} \tag{34}$$

and BER of OFDM system under AWGN and impulsive noise is

$$\begin{aligned} P_b &= Q\left(\sqrt{\tfrac{2E_b}{N_m}}\right) \\ &= Q\left(\sqrt{2\frac{E_b / N_0}{1+\mu\lambda T_{noise}}}\right) \\ &= 0.5erfc\left(\sqrt{\frac{E_b / N_0}{1+\mu\lambda T_{noise}}}\right) \end{aligned} \tag{35}$$

7. Performance Improvement through Diversity Reception

For OFDM, we assume that in case of diversity reception L is equal to the number of receiver, then P_b is given by (Masaaki, Takaya, & Hiraku, 2006; Zimmermann & Dostert, 2002)

$$P_b = [0.5(1-\mu)]^L \sum_{l=0}^{L-1} \left(\frac{L-1+l}{l}\right)[0.5(1+\mu)]^l \tag{36}$$

assuming 0.5(1+μ) ≈ 1 and 0.5(1- μ) ≈ 1/4Γ_c

furthermore $\sum_{l=0}^{L-1}\left(\frac{L-1+l}{l}\right) = \frac{2L-1}{L}$

so, the BER in diversity reception is given by,

$$P_b \approx \left(\frac{1}{4\Gamma_c}\right)\left(\frac{2L-1}{L}\right) \tag{37}$$

where,

$$\Gamma_c = \text{SNR in OFDM} = 2\sigma_\alpha^2 \cdot \tfrac{E_b}{N_m} = 2\sigma_\alpha^2 \cdot \frac{E_b . N_0}{1+\mu\lambda T_{noise}} \tag{38}$$

and the ratio of Impulsive noise power (N_i) to AWGN noise power (N_0) μ is given by,

$$\mu = \sqrt{\frac{\Gamma_c}{1+\Gamma_c}} \tag{39}$$

P_b is calculated taking σ_α^2 = *0.1, 0.5* and *1.0*, and *L = 2, 4, 6* and *8.*

8. Simulation Results

In order to investigate the BER performance in a power line communication system in the presence of non-white additive Gaussian noise based on the formulas derived in the previous sections, we used computer simulation with MATLAB. The expression of the signal to noise ratio is developed considering the frequency and time dependence of the cyclostationary noise. The system bit error rate (BER) is then evaluated numerically for several system parameters like system bit rate, Fourier coefficients of the non-white Gaussian noise process etc. The simulation result is shown in Figure 3, Figure 4, Figure 5 and Figure 6.

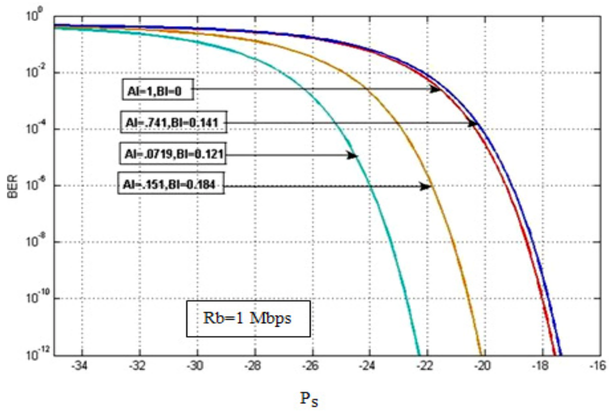

Figure 3. Plot of BER vs. PS considering BER is independent of frequency, plot is shown for Rb=1Mbps

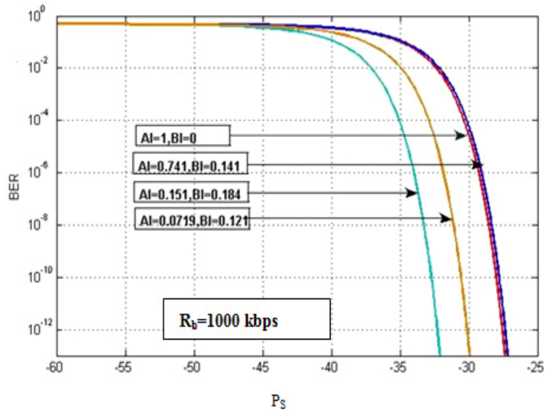

Figure 4. Plot of BER vs. PS considering BER is independent of frequency, plot is shown for Rb=1000 kbps

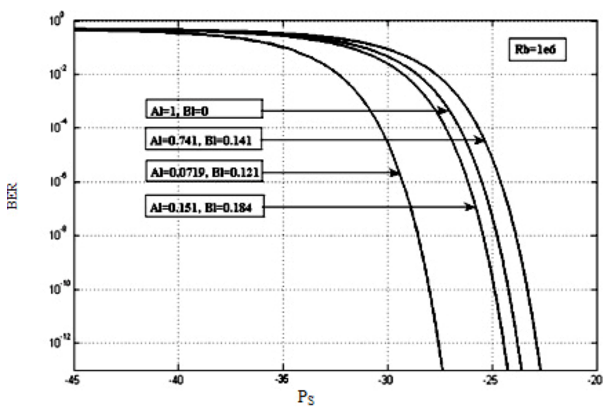

Figure 5. Plot of BER vs. PS considering BER is dependent of frequency, plot is shown for Rb = 1e6

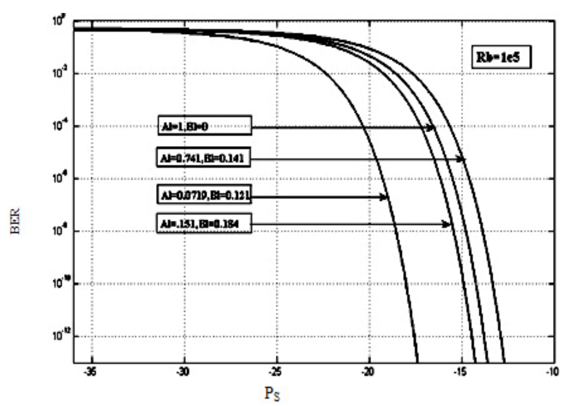

Figure 6. Plot of BER vs. P_S considering BER is dependent of frequency, plot is shown for Rb = 1e5

9. Discussion on Results

Following the theoretical approach presented in section II, we evaluate the bit error rate (BER) performance of a power line communication system with white and non-white power spectral density of noise. The results are presented in Figure 3 through Figure 6 for various system parameters. Figure 3 shows the plot of BER versus P_S for different values of Fourier coefficients of the noise variance. It is noticed that there is significant improvement in BER performance depending on the values of Fourier coefficients A_l and B_l. Optimum performance corresponds to a set of values of A_l and B_l. Similar results are depicted in Figure 4 for data rate 1000 kbps. Comparison of Figure 3 and Figure 4 shows that there is deterioration in system BER due to higher data rate.

Results for frequency dependent noise PSD are depicted in Figure 5 and Figure 6 considering the Fourier coefficients as above. It is noticed that system performance is improved in the case of frequency dependent noise which is considered as a narrowband noise.

9.1 OFDM System with Diversity Reception

The BER performance is analyzed and compared for both BPSK and OFDM channel in single carrier receiver. The results show that the performance is significantly improved in OFDM. Results for diversity reception system are discussed in the following sections.

9.2 BER Performance in Impulsive Noise

Three noise scenarios is considered, namely ‘Heavily disturbed’, ‘Moderately disturbed’ and ‘Lightly disturbed’ (Ma, So, & Gunawan, 2005; Meng, Guan, & Chen, 2005). For plotting Equation (36), the parameters are taken from (Ma, So, & Gunawan, 2005) where IAT is the inter arrival time of the impulsive noise, which is the reciprocal of the arrival rate λ. The parameters as listed in Table 1. The BER performance in impulsive noise is shown in Figure 7, Figure 8 and Figure 9.

Table 1. Parameters of the impulsive noise scenario

	Impulsive noise scenario	IAT (1/λ)	T_{noise}
I	Heavily disturbed	0.0196s	0.0641ms
II	Moderately disturbed	0.9600s	0.0607ms
III	Lightly disturbed	8.1967s	0.1107ms

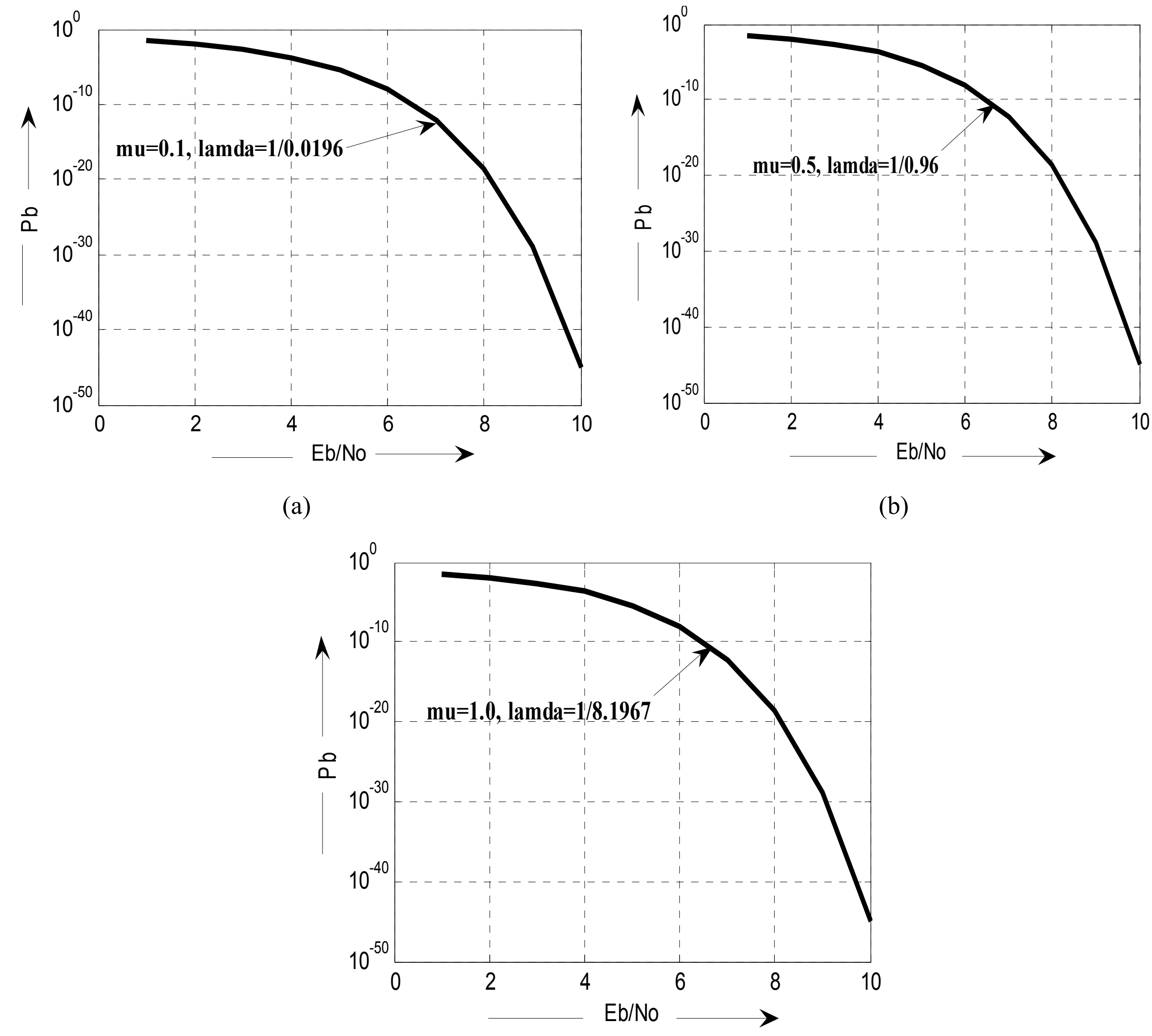

Figure 7. (a)Plot of BER vs. SNR in OFDM system for μ=0.1 and λ=1/0.0196; (b) Plot of BER vs. SNR in OFDM system for μ=0.5 and λ=1/0.96; (c) Plot of BER vs. SNR in OFDM system for μ=1.0 and λ=1/8.1967

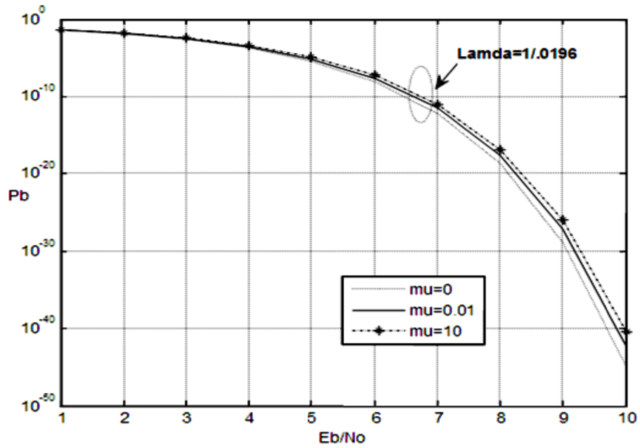

Figure 8. Plot of BER vs. SNR in different values of μ, taking λ=1/0.0196

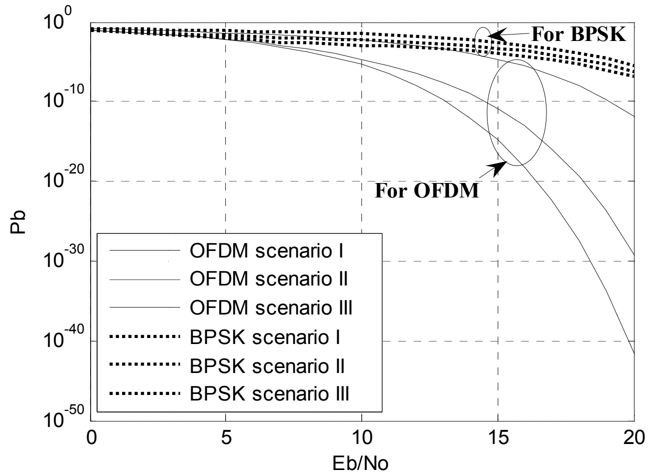

Figure 9. BER in BPSK and OFDM under impulsive noise in different scenario given in Table 1

9.3 Performance Improvement in Diversity Reception

From the above analytical results it is clear that the BER performance of power line communication can be improved using OFDM. Moreover it can be further improved significantly using diversity reception. Using Equation (36), the results show that the performance is improved to a significant level. Again the improvement in increasing number of receiver is shown in Figure 10, Figure 11 and Figure 12.

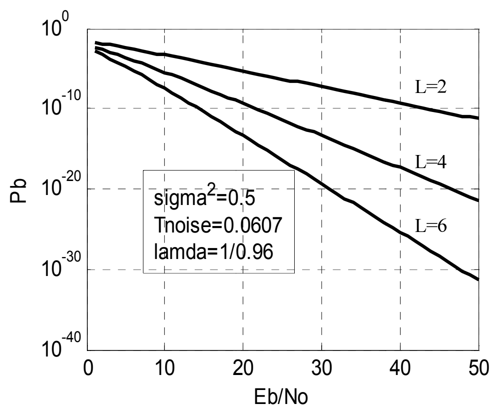

Figure 10. BER performance in diversity reception (L=2, 4, 6)

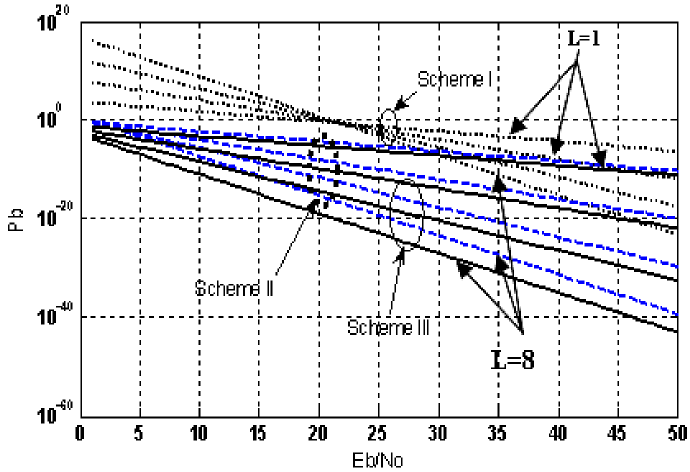

Figure 11. BER performance in diversity reception (Diversity reception for L=1, 2, 4, 6 and 8)

Note: For Figure 11, Scheme I: Sigma^2 = 0.1, Tnoise = 0.0641, lamda = 1/0.0196; Scheme II: Sigma^2 = 0.5, Tnoise = 0.0607, lamda = 1/0.96; Scheme III: Sigma^2 = 1.0, Tnoise = 0.1107, lamda = 1/8.1967.

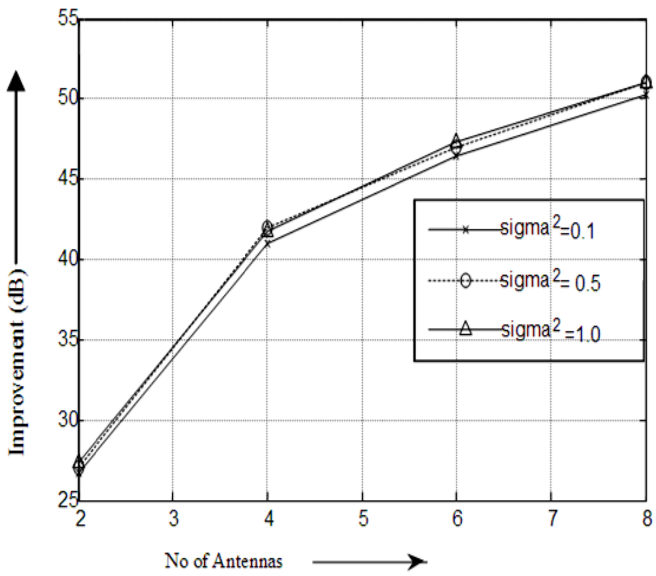

Figure 12. Plot of performance improvement (dB) in diversity reception vs number of antenna

10. Conclusion

In this paper, firstly we evaluate the bit error rate (BER) performance of a power line communication system with white and non-white power spectral density of noise. Secondly, a simple method of improving the performance of a power line communication link in the presence of the impulsive noise, fading and multipath effect in broadband and narrow band communication channel has been demonstrated. The main purpose of this demonstration is to find out the BER in the presence of above mentioned impairments. In this work, we have proposed a model to mitigate the losses for impulsive noise, fading and multipath effect by OFDM technique and reception diversity. It can be a useful tool for performance upgrading of Power Line Communication (PLC) (Daisuke, Hideyuki, & Yoshiteru, 2006). However, the importance of this proposed model is not only the introduction of a tool for the design and evaluation of power line communication system, however, in diversity reception, the optimization of the antennas has not been studied, remains for future works.

References

Anindya, M., & James, C. J. (2004). *Power line communication – An overview*. IEEE Xplore

Article from john nosotti.doc. (2004). *Power-line Communications (PLC) or Broadband-over-Power- line (BPL).* Crc powerline proposal.

Daisuke, U., Hideyuki, N., & Yoshiteru, M. (2006). *Performance Evaluation of CMFB Transmultiplexer for Broadband Power Line Communications under Narrowband Interference Power Line Communications and Its Applications*. 2006 IEEE International Symposium. pp. 50–55.

Ezio, B., Stefeno, G., Lee, Y. H., Vincent, H. P., Vinck, A. J. H., & Tranter, W. H. (2006). Power Line Communication. *IEEE jounnal on selcted areas in Communications, 24*(7).

Hooijen, O. C. (1997). A channel model for the low-voltage power line channel: measurement and simulation results. *Internatonal Symposium on Power line Communications and its Applications*, 51-56.

Janse, V. R. (2008). *Effective coupling for power line communications.* University of Johannesburg.

Katayama, M., Itou, S., Yamazato, T., & Ogawa, A. (2005). *Modeling of cyclostationary and frequency dependent power-line channels for communications.* In Proc. 4th Int. Symp. Power Line Commun. Appl., 123-130.

Khalifa, S. A. M., & Zahir, M. H. (2009). *Performance of Bit- Interleaved Coded OFDM in Power Line Communications with Impulsive Noise.* The 2009 International Conference on Advanced Technologies for Communications.

Ma, Y. H., So, P. L., & Gunawan, E. (2005). Performance Analysis of OFDM Systems for Broadband Power Line Communications Under Impulsive Noise and Multipath Effects. *IEEE Transaction on Power Delivery, 20*(2).

Masaaki, K., Takaya, Y., & Hiraku, O. (2006). A Mathematical Model of Noise in Narrowband Power Line Communication Systems. *IEEE Journal on Selected Areas in Communications, 24*(7), 1267-1276. http://dx.doi.org/10.1109/JSAC.2006.874408

Massaki, K. (2001). Introduction to Robust, Reliable and High-Speed Power-Line Communication Systems. *IEICE Transactions on Fundamentals E84-A, 12*(1), 2958-2965.

Meng, H., Guan, Y. L., & Chen, S. (2005). Modeling and analysis of noise effects on broadband power line communications. *IEEE Transactions on Power Delivery, 20*(2), 630-637. http://dx.doi.org/10.1109/TPWRD.2005.844349

Mohammed, A. K., & Widad, I. (2010). Performance Transmit and Receive Diversity Techniques for Different Modulation Signal. *Journal of Telecommunications, 4*(2).

Tachikawa, S., & Takuma, M. (2010). Performances of FH/MFSK Lump Likelihood Ratio Decision Methods and their Applications for Power Line Communications. *Journal of Telecommunications, 3*(1).

Tachikawa, S., Hokari, H., & Marubayashi, G. (1989). *Power line data transmission.* IEICE Technical report, SSTA89-7.

Tanaka, M., & Someya, R. (1986). The noise characteristics and transmission characteristics on data transmission using power line. *IEICE trans, 69*(10), 1147-1149.

Voglgsang, A., Langguth, T., Koerner, G., Steckenbiller, H., & Krnorr, R. (2000). *Measurement characterization and simulation of noise on powerline channels.* In Proc. 4th Int. Symp. Power Line Commun. Appl, 139-146.

Zimmermann, M., & Dostert, K. (2002). Analysis and modeling of impulsive noise in broad-band powerline communications. *IEEE Transactions on Electromagnetic Compatibility, 44*(1), 249-258. http://dx.doi.org/10.1109/15.990732