

Performance Analysis of Broadband Power Line Communications with OFDM Transmission

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Abstract— Power line noise is significantly affects on the bit error rate performance of broadband power line communications. The channel model is affected by stochastic attenuation and deep notches which can lead to the limitation of the channel capacity and achievable data rate. In this paper, we analyze the bit error rate (BER) of orthogonal frequency division multiplex (OFDM) using binary phase shift keying (BPSK) modulation technique. The channel characteristic is assumed to be generalized broadband power line channel model and the noise behavior is modeled according to Middleton class A, which is contrast to the other wireless channel and power line communications (PLC). Using central limit theorem, the noises on each sub-carriers are behave as Gaussian noise. Bit error rate of BPSK and MPSK are analyzes under different schemes. We notice that the loss factor, frequency and distance are significantly improving BER performance.

Keywords— Middleton Class A Noise, Multi-Carrier Modulation, Power Line Communication, Low voltage, OFDM

I. INTRODUCTION

The increasing interest in modern multimedia applications, such as broadband internet, hi definition TV (HDTV), etc. requires new access techniques for connecting private premises to a communication backbone. One promising technology, broadband over power lines (BPL), intends to use the existing power-line network as a high speed digital data channel to connect the private users to one another and to a very high data rate backbone. Each home is equipped with electricity by means of low voltage (LV) power-line grid. LV lines are distributed to each power plug in every room in a house. Thus, LV power lines can be an appropriate candidate for providing broadband access to all the users in a building and home networking. However, like other technologies BPL also faces its own set of obstacles and technical challenges [1].

The characteristics of LV power lines are very well known and there are a variety of research activities in this area to explore different features of the LV grid. Since the power line network is not designed for communications purposes, the channel exhibits an unfavorable frequency selective transfer function. Furthermore, this channel is distorted by impulsive

noise and by severe narrowband interference. Unlike many other communication channels, power line channel does not represent an additive white Gaussian noise (AWGN) environment. Noise in LV power line is characterized within two categories: background and impulsive noise [2], [3] and [4].

Many electric appliances frequently cause man-made electromagnetic noise on power line channels. Such man-made noise produces an impulsive distortion on channel causing a burst of noise. A large impulse often causes the entire transmitted symbol to be corrupted and it can be devastating to the overall system performance. One of the major burdens of BPL is the electromagnetic compatibility (EMC) of this technology to other wireless systems [3].

Since electric wires might radiate electromagnetic waves at high frequencies, precautions need to be employed in order to avoid any interference to other wireless devices. For this reason, the transmitted power over BPL is limited and it is desirable to decrease this power by as much as possible. Therefore, the available signal-to-noise ratio (SNR) at the receiver is often restricted to a relatively low number. Consequently, this system operates at very low SNR values and communications schemes that improve the performance at low SNR values are crucial for the system deployment [4].

However, like all other technologies, PLC also faces its own set of obstacles and technical challenges. The communication medium of this technology, the power lines, has been designed for transmitting electrical power without any thought on communications. It generally appears as a harsh environment for the low-power high-frequency communication signals. The three important channel parameters, namely noise, impedance, and attenuation, are highly variable with time, frequency, and location. In order to overcome these difficulties, many efforts have gone into the characterizing and modeling of the PLC channel [5].

Multicarrier modulation has long been known as an efficient modulation scheme for the band-limited channels [6]. OFDM is considered as one of the most promising modulation methods for powerline communications [7]. Besides its high

spectral efficiency, OFDM has some desirable properties, which can be utilized properly in order to mitigate the harsh characteristics of powerline channels.

In this paper, we analyze BER performance of multi carrier modulation scheme. The modulation technique is assumed to be binary phase shift keying (BPSK). Since the noise modeling on power communication is different from the wireless channel, which assumed to be white Gaussian noise. In our paper, noise is model according to Middleton class A and the performance analysis is done for low voltage power line channel model.

The rest of this paper is organized as follow, section II provides the system model including noise characteristics and low voltage power line channel model. We also provide the Middleton Class A noise model. In section II shows the mathematical model and performance Analysis of OFDM with BPSK modulation on each sub-channels under Middleton class A noise behavior. The Simulation and discussion is represented in section IV. Finally the conclusion of our research contribution is shown in section V.

II. SYSTEM MODEL

A. Generalized Multipath Signal Propagation Model of the Transfer Function

Combining multipath propagation described by [5] and frequency and length-depending attenuation given by

$$H(f) = \sum_{n=1}^N |g_n(f)| e^{g_n(f)} e^{-a_0 + a_1 f^k} l_n e^{-j2\pi f \frac{l_n}{v_p}}. \quad (1)$$

Equation (1) describes the signal propagation along a path by the delay portion and the low-pass characteristic, i.e., the attenuation increasing with length and frequency, by the attenuation portion. The weighting factor summarizes the reflection and transmission factors along a propagation path. Due to the fact that reflection points may exhibit complex and frequency-dependent values, is shown in a general complex and frequency-dependent. The signal components of paths always add together at the receiving point.

B. Simplified Model

Extended measurement campaigns revealed that it is possible to further simplify the specification of the weighting factors to being complex, but not frequency dependent. In many cases of practical interest, g_n can even be assumed as real-valued. In heterogeneous networks, often several paths with almost equal delays exist, so that it is not rewarding to trace the factors g_n back to their physical origins. From a multipath point of view g_n simply describes the weight of path n . The simplified version of the frequency response is given by [5]

$$H(f) = \sum_{n=1}^N g_n \exp(-(a_0 + a_1 f^k)) l_n \exp\left(-j2\pi f \frac{l_n}{v_p}\right) \quad (2)$$

Equation (2) represents a parametric model, describing the complex frequency response of typical power line channels, covering all substantial effects of the transfer characteristics in the frequency range from 500 kHz to 20 MHz by a small set of parameters. Moreover, the number of paths, allows a control of the precision of the model, which is especially important for defining reference channels for PLC system performance analysis.

TABLE 1: Parameters of the Model of the Transfer Function

n	Number of the path, where the path with the shortest delay has the index $n = 1$
a_0, a_1	Attenuation parameters
k	Exponent of attenuation factor (typical values are between 0.5 and 1)
g_n	Weighting factor for path n in general complex, can be considered as combination of the involved reflection and transmission factors
d_n	Length of path n
τ_n	Delay of path n

C. Middleton Class A Noise

The statistical modeling of impulsive noise has been of interest to researchers for a long time. Middleton in [8] and [9] categorizes impulsive noise in two classes of A and B. The noise in BPL can be considered as class A Middleton noise. Based on this model, the noise, impulsive plus background noise, is a sequence of i.i.d complex random variables with the probability distribution function (pdf) of

$$p(z) = \sum_{m=0}^{\infty} \frac{\alpha_m}{2\pi\sigma_m^2} \exp\left(-\frac{z^2}{2\sigma_m^2}\right), \quad (3)$$

$$\text{with } \alpha_m = \exp(-A) \frac{A^m}{m!}. \quad (4)$$

The variance is defined as

$$\sigma_m^2 = \left(\sigma_{bg}^2 + \sigma_{im}^2\right) \frac{\left(\frac{m}{A}\right) + \Gamma}{1 + \Gamma}, \quad (5)$$

$$\text{and } \Gamma = \frac{\sigma_{bg}^2}{\sigma_{im}^2}, \quad (6)$$

where σ_{bg}^2 and σ_{im}^2 are the power of background noise and impulsive noise, respectively. The parameter A is called the

impulsive index, which is the product of the average rate of impulsive noise and the mean duration of a typical impulse. With our notation, the impulsive index A is equal to $A = n_b \times t_{r2}$. For a small A , we get a highly structured impulsive noise whereas for large values of A , the noise probability density function (pdf) becomes Gaussian [10]. The parameter Γ is called the background-to-impulsive noise ratio. By combining (5) and (6), the variance can be expressed as

$$\sigma_m^2 = \sigma_{bg}^2 \frac{\left(\frac{m}{A}\right) + \Gamma}{\Gamma} . \quad (7)$$

Equation (7) shows that the pdf of noise is a weighted sum of Gaussian pdfs with a mean equal to zero

III. MATHEMATICAL ANALYSIS

The basic idea of OFDM is to split a high rate data stream into a number of lower rate streams and transmit these streams simultaneously, and in parallel over a number of orthogonal subcarriers. The orthogonality of subcarriers guarantees that the streams do not interfere with one another. It is possible that subcarriers lose their orthogonality due to multipath or the channel non-stationary behavior. In this case, subcarriers interfere with one another and cause inter-carrier interference (ICI). The system model of multi-carrier modulation is represented in Figure 1.

We consider the uncoded BER of power line communication system and assume that no intersymbol interference between bits and carrier frequencies. So the received signal is given by

$$r(n) = h(n) * \sum_{n=1}^N b(n) e^{\frac{j2\pi nk}{N}} + z(n) , \quad (8)$$

where $k=1,2,\dots,N$, $*$ denotes the convolution operation, $h(n)$ denotes the channel impulse response, $b(n)$ is the transmitted data bit, N is the total number of modulated carrier frequency and z_k is the Middleton class A noise, where the probability density function (pdf) is given in (3). Take the inverse discrete Fourier transform (IDFT) of (8), the result is shown in (9)

$$\begin{aligned} R_k &= \frac{1}{\sqrt{N}} \sum_{n=1}^N r(n) \exp\left(\frac{-j2\pi nk}{N}\right); k=1,\dots,N \\ &= H_k b_k + Z_k ; k=1,\dots,N \end{aligned} \quad (9)$$

where $Z_k = \sqrt{N} \frac{1}{N} \sum_{n=1}^N z'_n$ and $z'_n = z(n) \exp\left(\frac{-j2\pi nk}{N}\right)$.

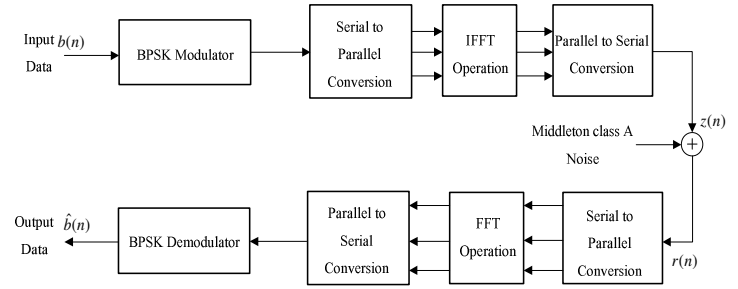


Figure 1: Generalized block diagram realization of an OFDM system.

From Central Limit theorem, Z_k is known to be the Gaussian random variable with zero mean and the standard deviation is

given by $\sigma_g = \sqrt{N} \frac{\sigma_z}{\sqrt{N}} = \sigma_z$ where the variance of σ_z is represented by

$$\sigma_z^2 = \frac{e^{-A} \sigma_{bg}^2}{\Gamma} \sum_{m=0}^{\infty} \frac{A^m}{m!} \left(\frac{m}{A} + \Gamma \right), \quad (10)$$

and $\Gamma = \frac{\sigma_{bg}^2}{\sigma_{im}^2}$. Since the discrete Fourier transform of the

Middleton class A over the carrier frequency yields the noise have a Gaussian distribution. Using binary phase shift keying, the BER is given by

$$P_b = \mathcal{Q} \left(\sqrt{\frac{2H_k^2 E_b}{N_0}} \right), \quad (11)$$

where H_k is the frequency response of the channel model and $\frac{E_b}{N_0}$ denotes the signal energy per noise power per bit, while

$\mathcal{Q}(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-\frac{y^2}{2}} dy$ denotes Q-function. If we extend our model for MPSK modulation, the bit error rate (BER) is given by

$$P_b = 2\mathcal{Q} \left(\sqrt{\frac{2(\log_2 M) H_k^2 E_b}{N_0}} \sin \frac{\pi}{M} \right), \quad (12)$$

and the BER over all subcarrier is presented by (13), where N denotes the number of sub-channel.

$$P_{bOFDM} = \frac{\sum_{k=1}^N \left(2\mathcal{Q} \left(\sqrt{\frac{2 \log_2 M H_k^2 E_b}{N_0}} \sin \frac{\pi}{M} \right) \right)}{N}. \quad (13)$$

IV. CONCLUSIONS

In this section, the simulation result for BPL is presented. The loss parameters are $k=0.7$, $g_1=1$, $a_0=9.33 \times 10^{-3} m^{-1}$, $a_1=3.24 \times 10^{-7} s/m$, and carrier frequency is 950 kHz. In figure 2, the modulation scheme is BPSK and the connection distances are 200, 250 and 300 m, respectively. We compare with the ideal case (without fading). We observe that the higher distance, the higher bit error rate. For our simulation, the distance of connection at 200 m yields the best BER performance.

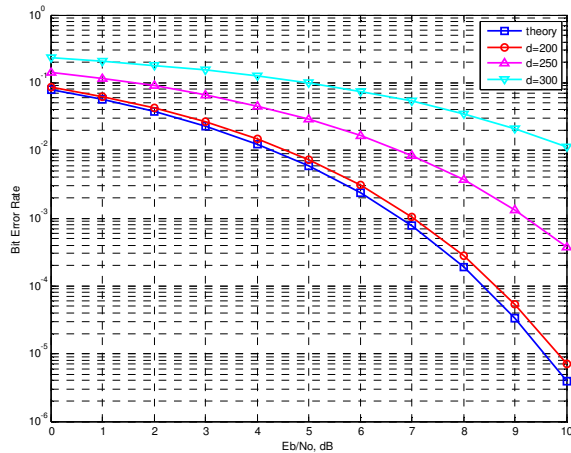


Figure 2: Bit error rate for the different values of connection distance.

In figure 3, we show the BER at 950 kHz, 1 MHz and 2 MHz. The loss parameters are as same as in Figure 2, but the connection distance is defined as 200 m. We notice that frequency is significantly affected on the BER. The loss parameter, k , is also affected on the BER performance. We can see that at k equal to 0.7 improve the system performance.

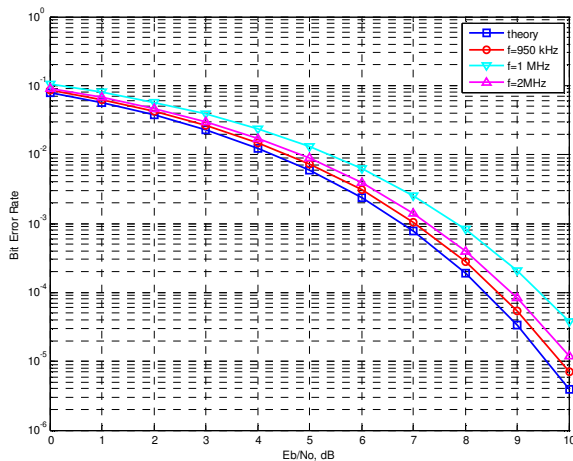


Figure 3: Bit error rate for the different values of carrier frequency.

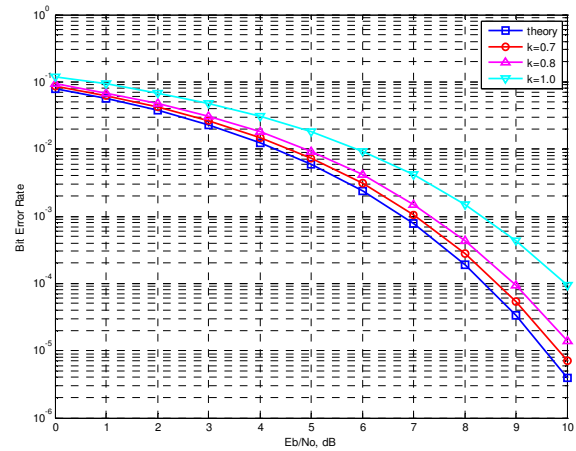


Figure 4: Bit error rate for the different values of loss K factor.

The comparison of modulation scheme for BPL is present in Figure 5. BER is done for BPSK, 8-PSK and 16-PSK modulation. We notice that BPSK modulation provides the best BER performance. In order to improve the BER, quadrature amplitude modulation (QAM) should be applied over subcarrier.

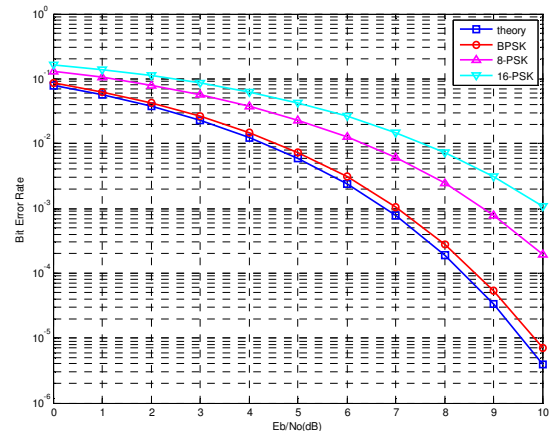


Figure 5: Bit error rate for the BPSK, 8-PSK, 16-PSK.

V. CONCLUSIONS

In this paper, we present the BER performance of multi carrier modulation. We assumed that the channel model is defined according to echo model, where the frequency response is denoted by Zimmermann. In contrast to the previous work, our noise is assumed to be Middleton class A noise, which is different from other wireless channel and other work in power line communications that assumed to be additive white Gaussian model. From the simulation results; we observe that the loss parameter (a_0 , a_1 and k), frequency, and distance are significantly affects on the BER.

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