Performance Analysis of an OFDM Broadband Power Line Communication (BPLC) System using Multipath Channel Models

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***Abstract*— Power line networks are alternate options for broadband communications although there are limitations which exists within the network due to changeable behavior of character impedances, branches etc. and causes degradation of the network performance. In this paper, analysis is presented for a orthogonal FDM (OFDM) broadband power line communication (BPLC) system to evaluate the bit error rate (BER) performance results with different channel models e.g. 15-path model and 5-path model reported earlier. The results are evaluated for different number of OFDM subcarriers and different channel parameters. It is found that there are significant improvements in BER performance with increase in the number of OFDM subcarrier for a given system bandwidth of 20 MHz. Further it is noticed that 15-path model provides better estimates of channel performance compared to 5-path model.**

Keywords- ***Broadband Power Line Communication (BPLC); Orthogonal Frequency Division Multiplexing (OFDM); Bit Error Rate (BER); Signal to Noise Ratio (SNR); Cyclic Prefix (CP);***

I. INTRODUCTION

The idea of broadband communication through power line networks is giving much interest all over the world since a long time. Because power line networks offer a convenient and cheap communication media due to its universal existence in buildings and residences, low cost of installation, the availability of outlets, and the simplicity of the power plug [1-2]. The idea of using the electric power distribution grid for communication purposes is not new at all.

However, the characteristics of power line channels are not particularly suitable for high-speed broadband communications as power lines are not specifically designed for data communication purposes. The most crucial channel properties degrading the performance of high-speed communications over power lines are noise, attenuation and multipath propagation [3-4]. In any given power line channel (medium voltage or low voltage or indoor), the number of interconnected branches in the link between sending and receiving ends, different terminal loads and branch lengths cause multipath (due to transmission and reflection of signals between the transmission line segments) characteristics that are similar to wireless channel. This multipath causes degradation of the signals propagating in the link between the sending and receiving ends [2-4].

To cope with this behavior, a very useful technique is Orthogonal Frequency Division Multiplexing (OFDM). OFDM is a special form of Multi Carrier Modulation (MCM) technique in which a high speed serial data stream is split up into a set of parallel low rate data streams. Each of the parallel data set is then modulated using a different sub-carrier. It gives significant improvement for multipath scenario as for a given delay spread the implementation complexity is significantly lower than that of a single-carrier system with an equalizer [5]. OFDM along with cyclic prefix (CP) also mitigate the effect of inter symbol interference (ISI) and inter carrier interference (ICI) introduced by the multi-path channel through which the signal is propagated. In case of the power line channel interfered by impulsive noise, OFDM can perform better than single carrier because it spreads the effect of impulsive noise over multiple symbols due to fast Fourier transform (FFT) algorithm. It also permits to separate overall transmitted data in many parallel independent subcarriers [5-7].

In this paper, we have analyzed the bit error rate (BER) performance of an OFDM broadband power line communication (BPLC) system under multipath scenario using the multipath channel model proposed in [3-4]. As in [3-4], the authors determined the channel response using different multipath channel models under variable atmosphere and different parameters and the effect of the channel models on the bit error rate performance of the PLC channel is not considered. We have used both 15-path and 5-path channel model's parameters from [3] to measure the channel response to evaluate the BER performance with OFDM in a BPLC system. Finally we have compared the results between 15-path and 5-path channel model by determining the receiver sensitivity.

II. MULTIPATH CHANNEL MODEL

The power line network varies considerably in topology, structure and physical properties from conventional media such as twisted pair, coaxial, or fiber optic cables. Because they are not particularly designed for data transmission. Noise, attenuation and multipath propagation are the main channel properties that affect the performance of data transmission over power line network. In this paper, we have used a practical multipath channel model introduced by Zimmermann and Dostert [3-4] that is suitable for describing the transmission behavior of power line channels. The model is based on practical measurements of actual power line networks and is given by the channel transfer function [3-4]:

$$\underline{H}(f) = \sum_{i=1}^{P} \underbrace{g_i}_{\substack{weighting\\factor}} \underbrace{e^{-(a_0+a_1 f^k)d_i}}_{\substack{attenuation\\portion}} \underbrace{e^{-j2\pi f(d_i/v_p)}}_{\substack{delay\\portion}} \quad (1)$$

where P is the number of multipaths, g_i is a frequency dependent weighting factor and d_i is the length of the ith path. a_0, a_1 and k are the attenuation parameters which can be derived from measured transfer functions [3]. Equation (1) represents a parametric model, describing the complex frequency response of typical powerline channels, covering all considerable effects of the transfer characteristics in the frequency range from 500 kHz to 20 MHz by a small set of parameters, which can be derived from measured frequency responses [3-4]. In the model, the first exponential presents attenuation in the PLC channel, whereas the second exponential, with the propagation speed v_p, describes the echo scenario.

III. OFDM BPLC SYSTEM MODEL

The block diagram of the OFDM transmission system considered for analysis is shown in Fig. 1 [5].

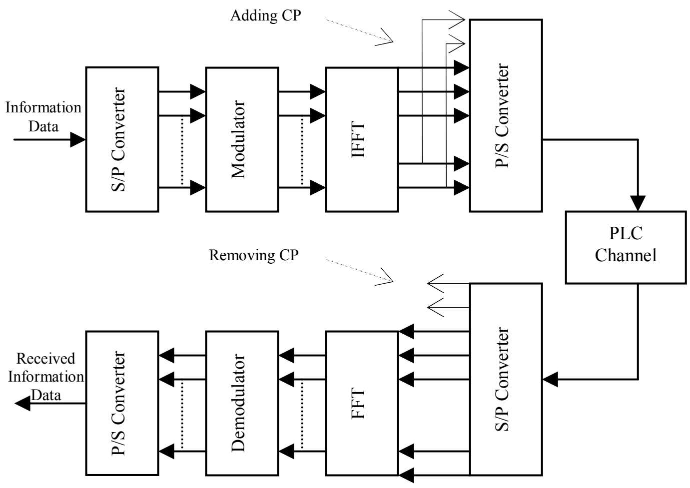

Fig. 1: Block diagram of a BPLC system with OFDM

At the transmitter side before modulation, the high rate data stream is first converted to low rate data stream by serial to parallel conversion. After modulation, each parallel sub-channel data is fed into IFFT circuit to generate OFDM signals. Cyclic Prefix is then added with the OFDM signals to mitigate the ISI and ICI effects and again converted into high speed serial data and fed into the PLC channel. After the PLC channel, the received signal is processed to remove the CP and FFT is carried out to convert the time domain signal to frequency domain. Coherent demodulation for each subcarrier is then carried out to extract the data bit and finally parallel to serial conversion is done to get the high speed data stream.

IV. ANALYSIS OF OFDM BPLC SYSTEM

The complex envelope of OFDM is given by,

$$v(t) = \sqrt{\frac{2E_b}{T_s}} \sum_{k=0}^{\infty} \sum_{n=0}^{N-1} a_{k,n} \tilde{\varphi}_n(t-kT)$$

$$= \sum_{n=0}^{N-1} v_n(t) \quad (2)$$

where E_b is the energy over a OFDM symbol, T_s is the symbol period, $a_{k,n}$ carries the information to be sent over the k-th symbol interval $t \in [kT, kT+T]$ and the n-th subband (n=0,1,2,…,N-1), N being the number of OFDM subcarrier, $v_n(t)$ is the complex envelope of the signal transmitted in the n-th subband and is given by

$$v_n(t) = \sqrt{\frac{2E_b}{T_s}} \sum_{k=0}^{\infty} a_{k,n} \tilde{\varphi}_n(t-kT) \quad (3)$$

where $\{\tilde{\varphi}_n(t)\}_{n=0}^{N-1}$ is a set of complex orthogonal waveform and is given by

$$\tilde{\varphi}_n(t) = \begin{cases} \exp\left[j2\pi \left(n - \frac{N-1}{2} \right) t/T \right], & t \in [0,T] \\ 0 & t \notin [0,T] \end{cases} \quad (4)$$

Each waveform in the set $\{v_n(t)\}_{n=0}^{N-1}$ corresponds to a distinct (nth) subcarrier with frequency $f_c + \frac{2n-(N-1)}{2T}$.

In general, the received signal is the sum of a linear convolution with the discrete power line channel impulse response $h(t)$ and additive white Gaussian noise $n(t)$. For this, we assume that the channel fading is slow enough to consider it constant during one OFDM symbol. In addition, we assume that the transmitter and receiver are perfectly synchronized. Based on the fact that the cyclic prefix is sufficiently long to accommodate the power line channel impulse response, or $h(t)=0$ for $t<0$ and $t>N-1$, we can then write,

$$r_k(t) = \sum_{\tau=0}^{N-1} h(\tau) v(t-\tau) + n(t) \quad (5)$$

The block of the received signal corresponding to k=0 has the following N received samples

$$\vec{r}_0 = (r_{0,0}, r_{0,1}, \ldots, r_{0,N-1}) \quad (6)$$

Demodulation is performed after computing the fast Fourier transform (FFT) on the block $\vec{r}_0$ to yield N decision variables

$$Z_{0,n} = \frac{1}{N}\sum_{\ell=0}^{N-1} r_{0,\ell} \exp\left(-j\frac{2\pi n\ell}{N}\right), \quad n = 0,1,\ldots,N-1. \qquad (7)$$

In the OFDM receiver, the decision device estimates the transmitted information $\hat{\vec{a}}_k = (\hat{a}_{k,0}, \hat{a}_{k,1}, \ldots, \hat{a}_{k,N-1})$, based on the N decision variables $Z_{k,n}$, n=0, 1, …, N-1.

The signal to noise ratio (SNR) at the output of k-th subcarrier demodulator is given by [5]

$$\xi_k = |H_k|^2 \alpha_g \cdot \frac{E_b}{N_0} \qquad (8)$$

where H_k is the coefficient of the power line transfer function at the k-th subcarrier frequency as shown in eqn. (1), N_0 being the noise power, α_g is the guard interval ratio that relates with T_N and T_{guard} as given in eqn. (9).

$$\alpha_g = \frac{T_N}{T_N + T_{guard}} \qquad (9)$$

The parameters T_N and T_{guard} are information time and guard time of the OFDM symbol [5].

Therefore, the bit error rate (BER) for the k-th subchannel is given by

$$P_{bk} = Q\left(\sqrt{2\xi_k}\right)$$

$$= Q\left(\sqrt{\frac{2|H_k|^2 \alpha_g E_b}{N_0}}\right) \qquad (10)$$

Then the average BER can be expressed as:

$$P_b = \frac{1}{N}\sum_{k=0}^{N-1} Q\left(\sqrt{\frac{2|H_k|^2 \alpha_g E_b}{N_0}}\right) \qquad (11)$$

V. Results and Discussion

Following the theoretical analysis, the bit error rate (BER) performance results of a BPLC system with OFDM are evaluated for two different power line channel models. The parameters corresponding to the 15-path model and 5-path model are shown in Table I and Table II [3]. For the following calculations and discussions, we have also used T_{guard} = 1.28 µs and T_N = 10.24 µs [5] to determine the value of α_g from (9).

For 5-path model, the attenuation parameters a_0, a_1 and k are considered as variable whether they are constant in case of 15-path model.

TABLE I

PARAMETERS OF THE 15 PATH MODEL [3]

Attenuation parameters					
k=1		a_0=0		a_1=7.8×10^{-10} s/m	
Path parameters					
i	g_i	d_i/m	***i***	g_i	d_i/m
1	0.029	90	9	0.071	411
2	0.043	102	10	-0.035	490
3	0.103	113	11	0.065	567
4	-0.058	143	12	-0.055	740
5	-0.045	148	13	0.042	960
6	-0.040	200	14	-0.059	1130
7	0.038	260	15	0.049	1250
8	-0.038	322			

TABLE II

ATTENUATION PARAMETERS FOR A 5-PATH MODEL [3]

Class	d_i	a_0 [m^{-1}]	a_1 [s/m]	k
100 m	1	9.40×10^{-3}	4.20×10^{-7}	0.7
150 m	1	1.09×10^{-3}	3.36×10^{-7}	0.7
200 m	1	9.33×10^{-3}	3.24×10^{-7}	0.7
300 m	1	8.40×10^{-3}	3.00×10^{-9}	1
380 m	1	6.20×10^{-3}	4.00×10^{-9}	1

The results are evaluated for different number of OFDM subcarriers N and are depicted in Fig. 2 for 15-path power line channel model. The results are depicted as a function of bit error rate (BER) versus SNR (E_b/N_0) for different values of N i.e. N = 8, 16, 32, 64, 128, 256 etc. It is evident from the results that there are improvements in BER performance with increase in the number of OFDM subcarrier.

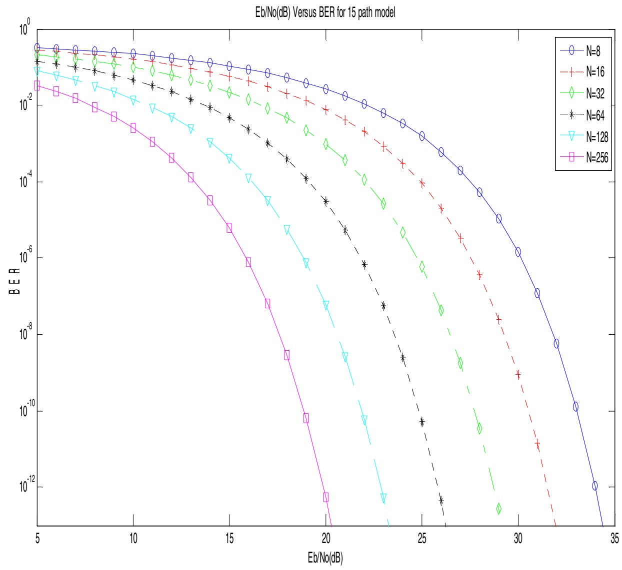

Fig. 2: Plots of bit error rate (BER) versus SNR (E_b/N_0) in dB for an OFDM BPLC system with number of OFDM subcarrier N=8, 16, 32, 64, 128, and 256 based on 15-path channel model.

Further, the plots of bit error rate (BER) versus SNR (E_b/N_0) for 5-path channel model are shown in Fig. 3 with number of subcarrier as a parameter. It is noticed that there is improvement in BER performance with increase in the number of subcarriers.

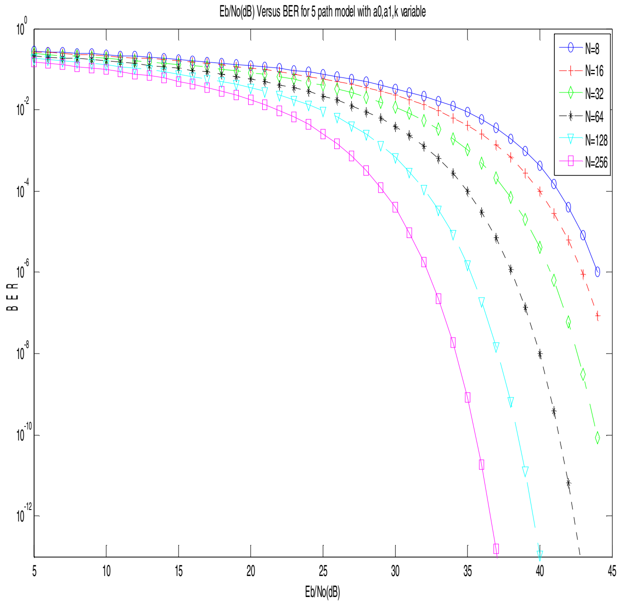

Fig. 3: Plots of Bit Error Rate (BER) versus SNR (E_b/N_0) in dB for an OFDM BPLC system with number of OFDM subcarrier N=8, 16, 32, 64, 128, and 256 based on 5-path channel model.

The receiver sensitivity to achieve a given BER of 10^{-6} is shown in Table III and Table IV for 15-path and 5-path models respectively.

TABLE III

VALUES OF E_b/N_0 AND N WITH BER=10^{-6} FOR 15 PATH MODEL

N	E_b/N_0 (dB)
8	30.22
16	27.5
32	24.85
64	21.91
128	18.97
256	15.88

TABLE IV

VALUES OF E_b/N_0 AND N WITH BER=10^{-6} FOR 5 PATH MODEL

N	E_b/N_0 (dB)
8	43.91
16	43.13
32	41.09
64	38.44
128	35.31
256	32.19

The plots of receiver sensitivity versus SNR (E_b/N_0) are depicted in Fig. 4 for both the channel models. It is noticed that there are significant variation in the values of receiver sensitivity between the two models. For example, the required receiver sensitivity for N=64 for 15-path model is 21.91 dB where it is 38.44 dB for 5-path model. So the improvement for N=64 is almost 16.53 dB in case of 15-path model.

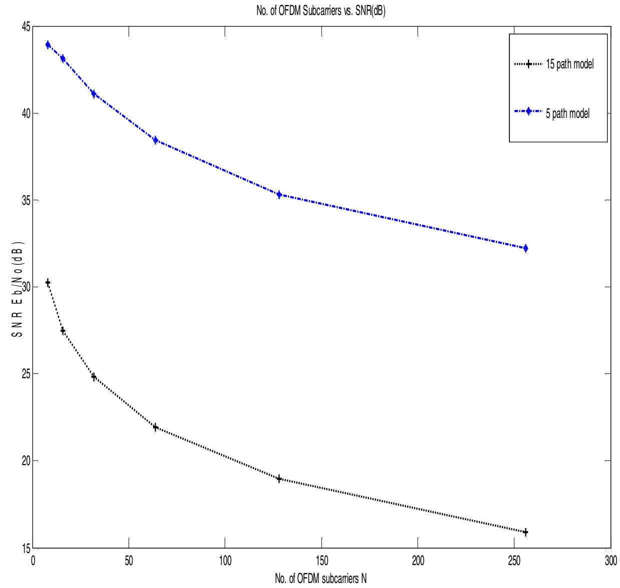

Fig. 4: Plots of receiver sensitivity versus SNR (E_b/N_0) in dB for BER=10^{-6} with number of OFDM subcarrier N as a parameter

Thus it is clear that 15-path model estimates the PLC system performance more accurately than 5-path model.

VI. CONCLUSIONS

Analytical approach is represented to evaluate the bit error rate of a broadband power line communication system using two different channel models e.g. 15-path model and 5-path model with OFDM modulation. The results show that there are significant improvement in BER performance with increase in OFDM subcarrier and the 15-path model better estimates the BER. The results will find application in design of broadband power line communication (BPLC) systems.

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