International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 5 (2017) pp. 705-710

Improving Data Transmission Efficiency over Power Line Communication (PLC) System Using OFDM

Charles U. Ndujiuba[1], Samuel N. John[1], Oladimeji Ogunseye[2]

[1]Electrical & Information Engineering, Covenant University, Ota, Nigeria.
[2]Department of Electrical & Electronics Engineering, University of Lagos, Nigeria.

Abstract

Power lines were originally designed for AC power distribution at 50 Hz and 60 Hz, and the characteristics of this channel present some technical challenges for data transmission at these frequencies. This paper presents architecture for the physical layer of a PLC transceiver based on OFDM and the impact of a PLC transmission channel. A suitable and widely accepted PLC channel model is used for simulation purpose. In achieving the aim and objectives of this research work, simulation of PLC system was implemented using OFDM as the choice of modulation scheme. The results obtained compared with the theoretical QPSK result show that OFDM reduced the degrading effect of the PLC channel leading to a good performance. Furthermore, it is observed that at a signal level of 4dB, the simulated BER matches up with the required standard which is the theoretical QPSK value. At this signal level of 4dB, the theoretical and simulated BER graphs converge. This point gives the minimum BER tolerance of 10^{-2} that is acceptable for data transmission over PLC.

Keywords: OFDM, PLC, QPSK, BER

INTRODUCTION

Power Line Communication (PLC) certainly is a cheap way to communicate, since no new wires are required, offering an existing last mile infrastructure [1]. The use of power lines which were originally designed for AC power distribution at 50 Hz and 60 Hz, present some technical challenges for data transmission at these frequencies. OFDM is now widely used as the most favorable modulation scheme for a severe communication environment such as the PLC channel [1]. The characteristics of this channel introduce the effect of noise, attenuation and multipath propagation which are the major challenges in implementing a PLC system. The application of OFDM in PLC enhances good performance through high spectral efficiency, resilience to Radio Frequency (RF) interference, and lower multi-path distortion. OFDM modulation scheme is now widely adopted, owing to its robustness to selective fading multipath and different kinds of interference [8]. Unlike single carrier modulation, OFDM is a multicarrier modulation technique, which employs several carriers, within the allocated bandwidth, to convey the information from source to destination. Each carrier may employ one of the several available digital modulation techniques (BPSK, QPSK, QAM etc..,) or sometimes a combination [4][18].

OFDM is very effective for communication over channels with frequency selective fading (different frequency components of the signal experience different fading). OFDM mitigates against the problem by converting the entire frequency selective fading channel into small flat fading channels (as seen by the individual subcarriers) [3] [13]. The process of PLC entails the conversion of communication signal into a form that will permit its transmission through electrical network. This paper examines the design of the physical layer, data layer and the channel of transmission. The system is modeled, simulated and implemented using MATLAB and the impact of OFDM is measured in terms of Bit Error Rate (BER). The organization of the paper is as follows. Firstly, the channel model and the employed OFDM system design are described in section 2. Analysis and simulation results are discussed in section 3. Finally, main conclusions are drawn in section 4.

SYSTEM DESIGN

Orthogonal Frequency Division Multiplexing (OFDM) is considered as the transmission scheme for Broadband over power lines (BPL) by most researchers. In OFDM, a high-speed serial data stream is split into a number of parallel slow data streams that are carried in multiple orthogonal subcarriers by means of Inverse Discrete Fourier Transform (IDFT). OFDM operation is carried out after the data is modulated using QPSK which is the input data stream. Subcarriers in the OFDM system are overlapping and orthogonal, which greatly improves the spectral efficiency necessary for a medium that has limited spectral capacity like the power line. In this way, OFDM can combat frequency selective attenuation and multipath propagation effect [3]. The discrete time OFDM signal can be expressed as:

$$s(n) = \frac{1}{N}\sum_{k=0}^{N-1} S_k e^{\frac{j2\pi nk}{N}} \tag{1}$$

Where N is the number of sub-carriers, S_k is a sequence of PSK or QAM symbols. In order to eliminate inter-channel interference (ICI) and inter-symbol interference (ISI), OFDM uses a cyclic prefix (CP) that is appended at the start of OFDM symbols [11]. The individual sub-streams are sent over N parallel sub-channels which are orthogonal to each other. Inverse fast Fourier transform (IFFT) on the OFDM transmitter side and Fast Fourier transform (FFT) FFT on the OFDM receiver side reduces system complexity, enabling OFDM to be easily implemented. Specifically, the OFDM Modulator System object modulates an input signal using orthogonal frequency division modulation. The output is a baseband representation of the modulated signal:

$$v(t) = \sum_{k=0}^{N-1} X_k \, e^{j2\pi k \Delta f t}, 0 \le t \le T \qquad (2)$$

where $\{X_k\}$ are data symbols, N is the number of subcarriers, and T is the OFDM symbol time.

The data symbols, X_k, are usually complex and can be from any modulation alphabet, e.g., QPSK, 16-QAM, or 64-QAM. Figure 1 shows an OFDM modulator. It consists of a bank of N complex modulators, where each corresponds to one OFDM subcarrier.

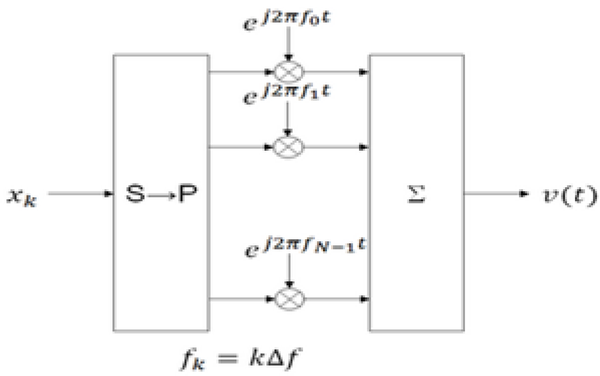

Figure 1: OFDM Modulator

There are a number of choices of parameters for OFDM system design, for consideration. They are: number of subcarriers, guard time, symbol duration, sub carrier spacing, and modulation type per sub carrier. The number of carriers in an OFDM system is not only limited by the available spectral bandwidth, but also by the IFFT size. A FFT length of 128 and cyclic prefix length of 32 is used in this design. Figure 2 shows the block diagram of the proposed OFDM based PLC system. The input signal bits undergo convolutional encoding and interleaving before being mapped into QPSK symbols. The resulting data stream undergoes OFDM Modulation procedure realized by IFFT.

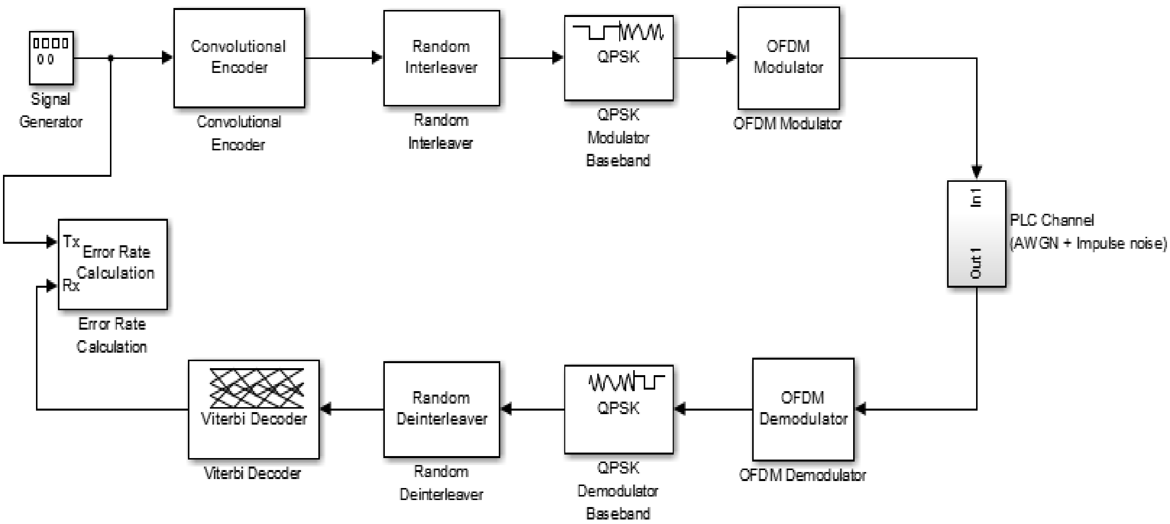

Figure 2. Block diagram of an OFDM based PLC System

Zimmermann and Dostert [2] have proposed a practical channel model 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:

$$H(f) = \sum_{i=1}^{N_p} c_i e^{-(a_0 + a_1 f^k) d_i} . e^{-j2\pi f \frac{d_i}{v_p}} \qquad (3)$$

Where N_p is the number of multipath, c_i and d_i are the weighting factor and length of the i^{th} path respectively. Frequency-dependant attenuation is modeled by the parameters a_0, a_1 and k. In the model, the first exponential represents attenuation in the PLC channel, whereas the second exponential, with the propagation speed v_p, describes the echo scenario. The attenuation parameters for 15-path model were obtained using physical measurements [2]. c_i represents the weighting factor, $e^{-(a_0+a_1 f^k)d_i}$ the attenuation portion and $e^{-j2\pi f \frac{d_i}{v_p}}$ the delay portion. The used parameters are given in table 1.

Table 1. Parameters for 15-path PLC Channel Model

Attenuation parameters			
k=1	a_0= 0	a_1= 7.8*10^{-10}	v=3*10^8
Path parameters			
i	C	d/m	
1	0.029	90	
2	0.043	120	
3	0.103	113	
4	-0.058	143	
5	-0.045	148	
6	-0.04	200	
7	0.038	260	
8	-0.038	322	
9	0.071	411	
10	-0.035	490	
11	0.065	567	
12	-0.055	740	
13	0.042	960	
14	-0.059	1130	
15	0.0491	1250	

The proposed channel model has two parts: background noise (I_{AWGN}) modeled as AWGN with mean zero and varianceσ_w^2, and the impulsive noise $I_{impulse}$ is given by:

$$I_{impulse} = b_k g_k \quad (4)$$

Where b_k is the Poisson Process which is the arrival of impulsive noise, and $g_k$is white Gaussian process with mean zero and variance σ_i^2 .

The combined PLC channel function is modeled as given:

$$I_C = I_{impulse} + I_{AWGN} \quad (5)$$

$$I_C \equiv H(f) \quad (6)$$

Therefore, the received signal after transmission is expressed as:

$$Y(n) = I_C \otimes S(n) \quad (7)$$

ANALYSIS AND SIMULATION RESULTS

In order to evaluate the performance of the designed system illustrated by Figure 2, the model is simulated using MATLAB R2015a. Emphasis is placed on the channel characteristic, OFDM performance and BER graph. The input signal is a stream of binary data, and Quaternary Phase Shift Keying (QPSK) is the preferred method of digital modulation. The BER plot shown in Figure 6 gives the overall performance of the simulated system.

Effect of the PLC and AWGN channel

The input data is shown below in Figure 3. It is a stream of data consisting of 96 binary digits. This represents the source into the system. It is encoded using convolutional encoder to aid against channel error, passed through an interleaver, QPSK and finally OFDM block.

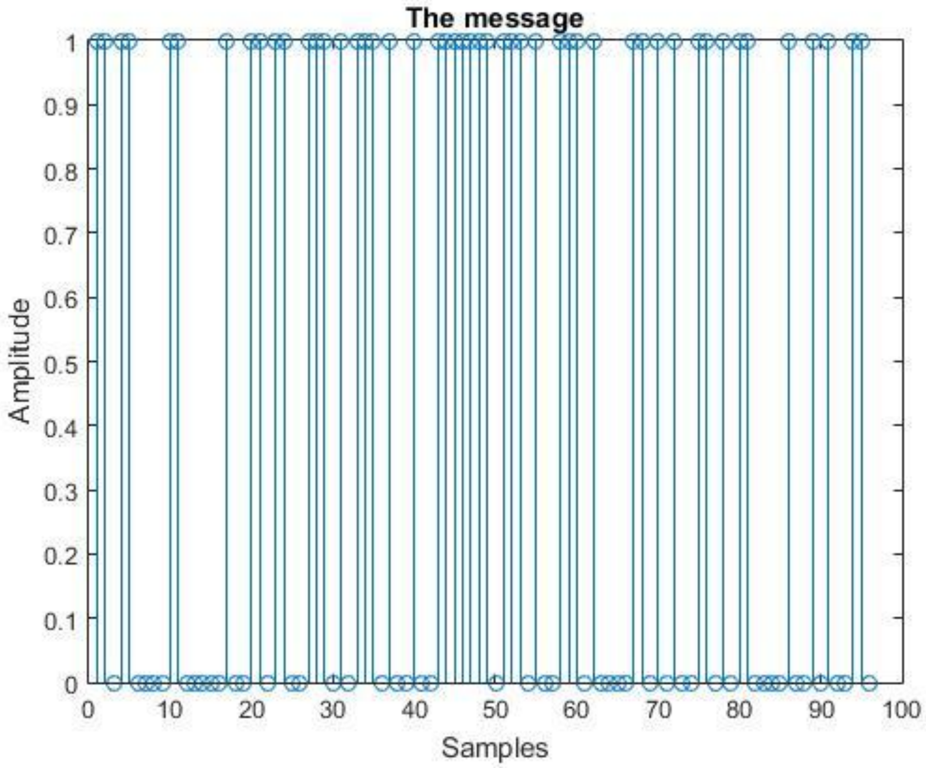

Figure 3. Input signal data

The channel factor is a combined effect of PLC impulse noise and the AWGN The channel introduced distortion to the encoded and modulated transmitted data. The plot of the modulated signal that is passed through the channel and recovered at the channel output shows the level of distortion introduced by the PLC channel. The channel output is a noise like signal. Therefore, it is not difficult to determine the effect the noise has on the transmitted signal.

The recovery responses of the system i.e. channel encoding and modulations, are measured against the ability to recover the original data from the distorted noisy signal introduced by the system. The diagram in Figure 4 shows the scatter plot of the noisy signal generated by passing the modulated data through the channel.

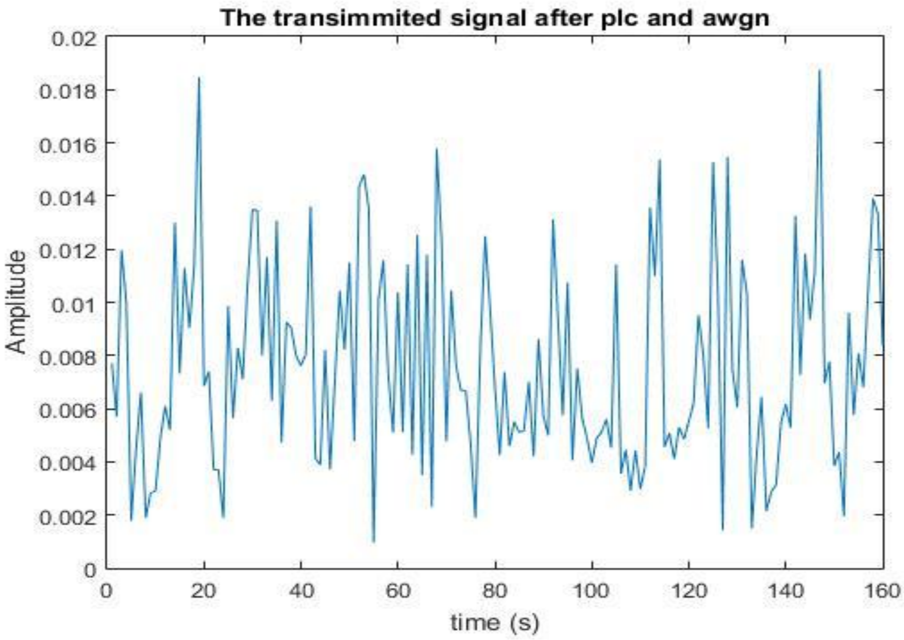

Figure 4. Transmitted data through PLC channel and AWGN

The recovered signal output is given in Figure 5. It is the result gotten after the distorted signal is recovered using Fast Fourier Transform (FFT), QPSK demodulation, interleaver and Viterbi decoder respectively.

.

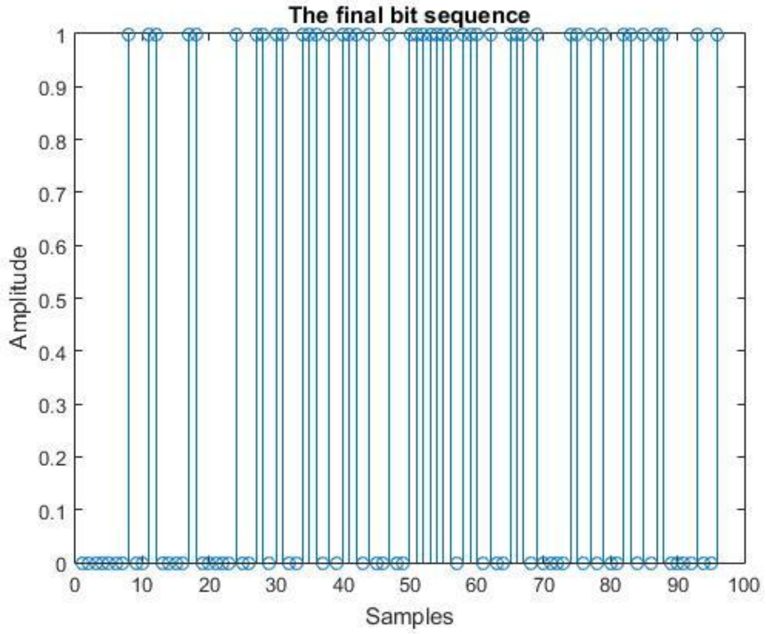

Figure 5. Recovered binary data

PERFORMANCE RESULT USING BIT ERROR RATE (BER) GRAPH

A visual comparison of the input and final output which are displayed above can be done but a more suitable approach is using the Bit Error Rate (BER). The measurement of the performance of the system is illustrated with the bit-error rate (BER). The ***biterr*** function in MATLAB is used to compare two sets of data and computes the number of bit errors and the bit error rate. The plot in Figure 6 clearly shows the comparison between the simulated BER result for the channel and the theoretical QPSK BER curve. It can be observed that as the value of SNR increases, the BER of the simulated PLC system decrease and approaches that of the theoretical QPSK BER. At a SNR of 4dB, the theoretical and simulated BER graphs converge. This point gives the minimum BER tolerance of 10^{-2} that is acceptable for data transmission over PLC. At a signal level of 4dB, the rate of convergence approaches zero. The rate of BER convergence of the simulated data is estimated below in table 2.

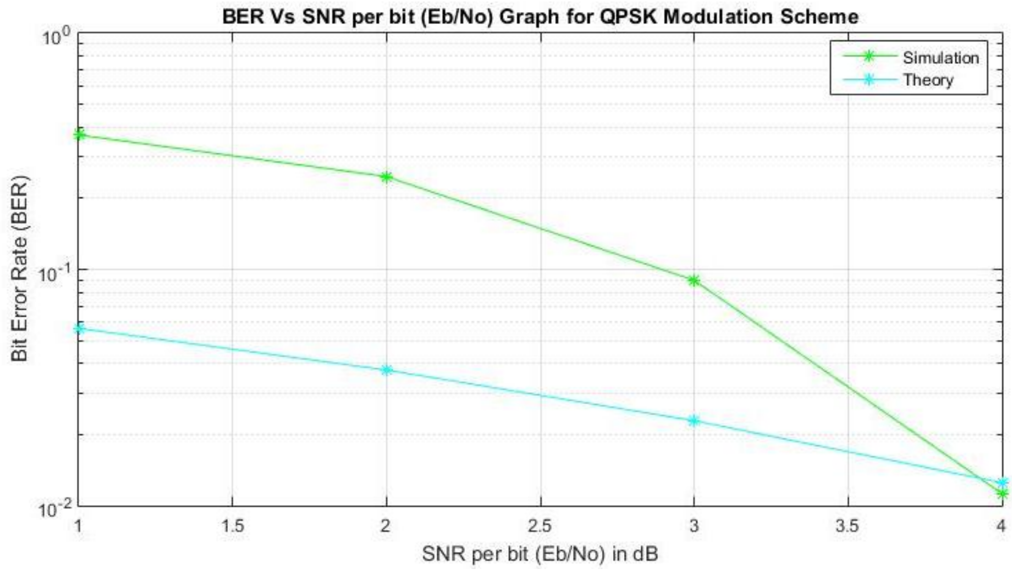

Figure 6. BER graph comparing theoretical and simulated data

The BER values of the simulated graph, represented by *r1* in the code, and also the BER values of the theoretical data represented by *thr* obtained from the graphs are given below in table 2.

Table 2. Bit error rate data for simulated and theoretical

	Bit Error Rate (BER)		Rate of convergence
SNR (dB)	simulated (r1)	theoretical (thr)	(r1 - thr)
1	0.3708	0.0563	0.3145
2	0.2472	0.0375	0.2097
3	0.0899	0.0229	0.067
4	0.0112	0.0125	-0.013

CONCLUSION

We have ascertained that OFDM has proven to be effective in multipath environments; a system that has an impulsive channel characteristics mixed with AWGN. The the input signal has been recovered with an allowable tolerable error rate acceptable for data transmission as compared with a theoretical QPSK value. It was observed that BER effectively reduce as the Eb/No gains increases. The simulation results verified the correct operation and performance of OFDM system with the reduction of error rate as the signal power increases.

REFERENCES

[1] P. L. Katsisz, G. D. Papadopoulos and F.-N. Pavlidou (2011). Comparison of coded orthogonal frequency division multiplexing and multicarrier code division multiple access systems for power line communications

[2] Zimmermann and K. Dostert, "A multipath model for the powerline channel," IEEE Trans. Communications, vol. 50, No. 4, pp. 553-559, April. 2002.

[3] Frenger, Pal, Pal Orten, and Tony Ottosson, "Convolutional Codes with Optimum Distance Spectrum," IEEE Communications Letters, Vol. 3, #11, Nov. 1999, pp. 317-319

[4] Simon, M. K., and Alouini, M. S., Digital Communication over Fading Channels – A Unified Approach to Performance Analysis, 1st Ed., Wiley, 2000.

[5] Simon, M. K, "On the bit-error probability of differentially encoded QPSK and offset QPSK in the presence of carrier synchronization", IEEE Trans. Commun., vol. 54, May 2006, pp. 806-812.

[6] Andrews, J. G., A. Ghosh, and R. Muhamed. *Fundamentals of WiMAX*. Upper Saddle River, NJ: Prentice Hall, 2007.

[7] Dahlman, E., S. Parkvall, and J. Skold. *4G LTE/LTE-Advanced for Mobile Broadband*. London: Elsevier Ltd., 2011.

[8] Agilent Technologies, Inc., "OFDM Raised Cosine Windowing". http://wireless.agilent.com/rfcomms/n4010a/n4010aWLAN/onlineguide/ofdm_raised_cosine_windowing.htm.

[9] Clark, G. C. Jr. and J. Bibb Cain, *Error-Correction Coding for Digital Communications*, New York, Plenum Press, 1981.

[10] Gitlin, Richard D., Jeremiah F. Hayes, and Stephen B. Weinstein, *Data Communications Principles*, New York, Plenum, 1992.

[11] G. Begin, et.al., "Further results on high-rate punctured convolutional codes for Viterbi and sequential decoding," *IEEE Transactions on Communications*, vol. 38, No. 11, pp 1922–1928, Nov. 1990.

[12] Power Line Communication Frequencies, www.eiwellspring.org/plc/PLCfrequencies.html

[13] EMC: The Impact of Power Line Communications, Part 1, Diethard Hansen, Compliance Engineering, 2003, www.ce-mag.com

[14] PLC interference: Report about measurements concerning power line Communications systems (PLC) and harmful interference caused by PLC in the HF bands 2000–30,000 kHz, Federal Ministry for Transport, Innovation and technology (Austria), February 2006.

[15] http://www.bmvit.gv.at/telekommunikation/funk/plt/download/etsijwg16td09.pdf

[16] V. Tarokh, N. Seshadri, and A. R. Calderbank, "SpaceTime Codes for High Data Rate Wireless Communication: Performance Criterion and Code Construction," *IEEE Trans. Info. Theory*, vol. 44, no. 2, Mar. 1998, pp. 744–65.

[17] Routin J, Brown. Power line signaling electricity meters. U.K. Patent Office, British Patent No. 24833, 1987.

[18] Charles U. Ndujiuba, Augustus E. Ibhaze, "Dynamic Differential Modulation of Sub-Carriers in OFDM", Journal of Wireless Networking and Communications 2016, 6(1):21-28. DOI: 10.5923/j.jwnc.20160601.03.