# Improving Power Line Communication For Cost Effective Smart Metering Application

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***Abstract*—Major hindrances to power line communication (PLC) are cable characteristics, impedance variations and noise signals from various sources. Most importantly, noisy characteristics of power line channels make it difficult to transmit data in an effective and reliable way. More often data transmitted through power line channels is corrupted by three main types of noise, the background noise, the impulse noise and the permanent frequency disturbances. Also Attenuation as a result of multipath fading effects is one of the major setbacks in power line communication over a long distance. In view of this most smart metering research works reviewed, propose wireless and/or fiber optics as transmission media at one point or the other. In this paper, we propose to improve PLC channels to make them viable alternative to other channels in smart energy metering and smart grid networks. Studies and simulations of low order modulation techniques and high order techniques have been conducted. Results show that high-order modulation scheme such as 16 QAM or higher-order QAM, when combine with Convolutional error correction coding and orthogonal frequency division multiplexing (OFDM) is a promising as modulation scheme of choice in PLC channels.**

***Keywords—Multipath fading effects, Orthogonal Frequency Division multiplexing (OFDM) , Power line communication, Smart Meter.***

## I. INTRODUCTION

Electricity utility companies distribute electricity to households and industries and with the help of energy meters, appropriate electricity bills are sent to consumers. Considering the numerous households and industries being supplied with electricity, manually reading energy meters by utility companies will require a lot of human resources which perhaps could have been invested in other sections of the company. A smart meter is usually an electrical energy meter that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility company for monitoring and billing purposes. Unlike the traditional automatic meter reading system, smart meters enable two-way communication between the meter and the central system [1].Smart meters require a means of communication between the smart meter and the utility company to enable the desired two way communication. Global System for Mobile communication ( GSM ) , zigbee , Radio and power line communication (PLC) are all possible means of communication employed by the smart metering communication network[1].

Literature on power line communications has pointed out major hindrances such as cable characteristics, impedance variations and noise signals from various sources. Most importantly, noisy characteristics of power line channels make it difficult to transmit information data in an effective and reliable way. More often data transmitted through power line channels is corrupted by three main types of noise, the background noise, the impulse noise and the permanent frequency disturbances[2][3]. Also Attenuation as a results of multipath fading effects is one of the major setbacks in power line communication over a long distance[4]. In view of this most smart metering research works reviewed[5][6][7], propose a GSM or a hybrid communication network which uses power line communication on the Low Voltage side that is from the smart meter to a data concentrator (shorter communication distance involved) and other orthodox communication methods like GSM, Fiber optics, etc from the data concentrator side to the Utility side for the simple reason being PLC is susceptible to impulsive noise (including multipath reflections introduced by impedance mismatching, time-varying due to switching of the electrical devices, and complicated noise environment) in addition to the Additive White Gaussian Noise (AWGN) most channels can be modeled with[8]. Due to the relatively long distance involved in the Medium and High voltage sides, PLC along MV/HV becomes unfavorable.

In this paper, we seek to find ways of overcoming the high bit error rates (BERs) associated with PLC channels without losing the opportunity of using multiple techniques for bandwidth improvement. The research work seeks to improve PLC channels to make them viable alternative to other channels in smart energy metering and smart grid networks. Studies of low order modulation techniques and high order techniques are conducted and a typical technique is identified to represent each of the two categories based on their popularity in literature as far as application in PLC channels are concerned. Simulations of the representatives are carried out—adding error correction techniques and orthogonal frequency division multiplexing (OFDM) as and when they are required to counter rising BERs and/or lost bandwidth due to error correction overheads. The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly modulated narrowband signals rather than one rapidly modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate intersymbol interference (ISI).

The rest of the paper is organized as follows. Section 2 gives a general overview and literature on communication channels and some error correction techniques. In section 3, bit error performance and bandwidth efficiency of both low order and high order modulation schemes are analyzed with the use of constellation diagrams. For simplicity, analysis for low order modulation was restricted to only BPSK and high order modulation to 16 QAM. Orthogonal Frequency Division Multiplexing, OFDM is analyzed in section 3. Section 4 presents MatLab simulations to compare the bit error ratios of BPSK (representing low order modulation) and 16 QAM (representing high order modulation) in a power line channel with and without error corrections. Also presented are simulations of 16 QAM with Convolutional error correction technique and OFDM. Section 5 discusses results of the simulations and Section 6 concludes the paper and presents scope of future works.

## II. COMMUNICATION CHANNELS

Communication channels are the medium, comparable to a motorway, over which information istransported. They are the link between the transmitters of information and the receivers.Communication channels exist in different forms and have different physical properties thatdistinguish them from each other. Various Mathematically modeled channels like Additive White Gaussian Noise (AWGN) channel, Racian Channel and Rayleigh Multipath Fading channels can be used to represent real life physical channels[8][9].

PLC is a type of communication protocols capable to carry data on existing power line conductors also used for electric power transmission [9].Traditionally, power lines are used for conveying electrical power to devices. Power lines were not designed for delivering high frequency signals, and so the electrical and frequency response requirements of a power line are not as critical as those of data network cabling. The poor quality of a power line is not ideal for signal transmission because the channel contains noise and interference [10]. Performance of a power line communication system is severely deteriorated by multipath fading effects. High frequency signals can be injected on to the

power line by using an appropriately designed

high pass filter. Received signal power will be

maximum when the impedance of the transmitter, power line, and the receiver are matched. Dedicated communication channels like Ethernet have known impedance, thus impedance matching is not a problem. However, power line networks are usually made of a variety of conductor types and cross sections joined almost at random. Therefore, a wide variety of characteristic impedances will be encountered in the network. Further, the network terminal impedance will tend to vary both at communication signal frequencies and with time as the consumer premises load pattern varies. The impedance mismatch would result in a multipath effect resulting in deep notches at

certain frequencies). These channel imperfections make signal modulation over a power line difficult [11]. However, the advancement of signal modulation and error control coding techniques now make power line communication possible[2].In a multipath environment, it is reasonably intuitive to visualize that an impulse transmitted from transmitter will reach the receiver as a train of impulses.[12]

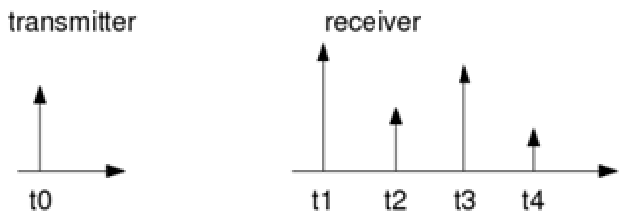


Figure 1: Impulse response of a multipath channel

Many researches [8][9][5][4] have shown that power line present three main types of noise signals namely

- Colored Background Noise: Appliances and components operating at low power, collectively generates noise with relatively low power spectral density (PSD).
- Narrow band noise, mostly amplitude modulated sinusoidal signals caused by ingress of radio broadcasting stations.
- Impulsive Noise:

1.) Periodic impulsive noise asynchronous to the main frequency, which is mostly caused by switched-mode power supplies.

2.) Periodic impulsive noise synchronous to the mains frequency, components like rectifier diodes, transistors whose cut off voltage and threshold voltage leads to switching actions in synchronous to frequency of mains power.

3.) Asynchronous impulsive noise, which is caused by switching transients in the power network.

In this paper, a modeled power line channel is simulated taking into account the harsh impulsive noise, Background noise, Narrowband interferences and multipath fading effects power line channel exhibit.

A. Modeling Power line channel

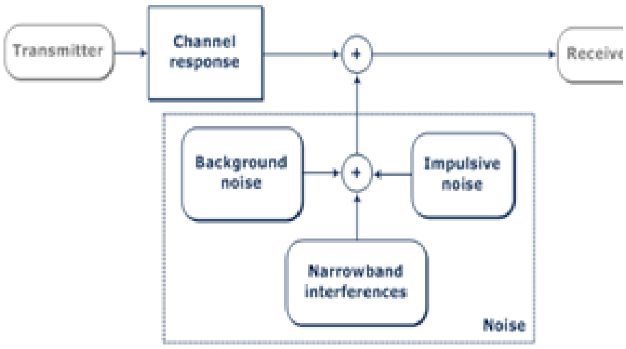


Figure 2: A modeled power line channel

In Power line transmission the propagation of data signals do not follow single path but they follow a multipath following a pattern very similar to wireless signals involved in cellular transmission. Power grid is a single central transmission line with shooting stems terminating at the end users place, as shown in Figure 3,□□ is the point of transmission (substation/service provider) and □□ is point of receiver (automated meter, customer or other appliances).

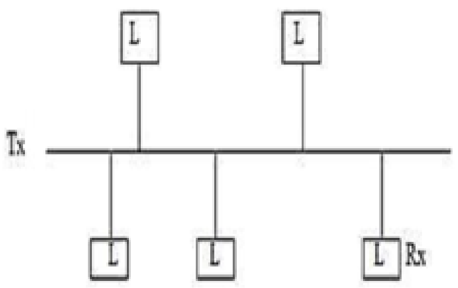


Figure 3: Topology of last mile of a power transmission line

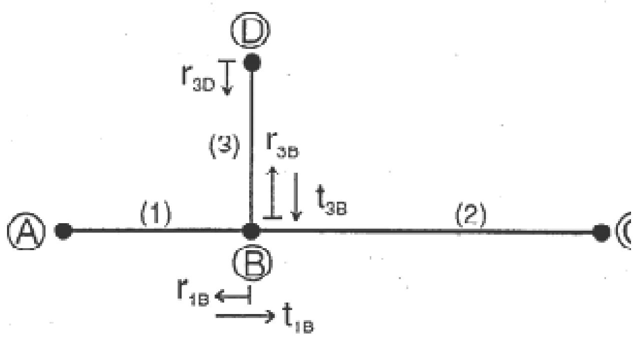


Figure 4 multipath propagation of signal from point D to C

For a simplified consideration A and C are matched which means $Z_A = Z_{L1}$ and $Z_C = Z_{L2}$. The remaining points (B) and (D) have reflection factors :$r_{1B}$ , $r_D$ , $r_{3B}$

Transmission factors :$t_{1B}, t_{3B}$

a weighting factor , $g_i$ for any particular path is given as the product of transmission factor and the reflection factor of that path

$g_i = t_i * r_i$(1)

The delay of any path is given by the equation

$\tau_i = \frac{d_i\sqrt{\varepsilon_r}}{c_0}$(2)

Where $d_i = distance\ of\ the\ path$ , $c_0 = speed\ of\ light\ in\ a\ vacuum$ , $\varepsilon_r$ = dielectric constant of the insulating material

$\frac{1}{v_p} = \frac{\sqrt{\varepsilon_r}}{c_0}$ , (3) where $v_p$ = phase velocity

Therefore (3) can be modified as

$\tau_i = \frac{d_i}{v_p}$(4)

As signals propagate along the transmission lines, this causes attenuations which can be estimated with the function A(f,$d_i$) , increasing with both frequency and distance.

Hence the transfer function of the power line channel can be estimated in the frequency domain as

$$H(f) = \sum_{i=1}^{N} g_i A(f, d_i) e^{j2\pi f \tau_i}$$

A(f,$d_i$) can be approximated by the function [4]

$A(f, d_i) = e^{-(a0 + a1.f^k)d_i}$

Where $a_1$ and $a_0$ are attenuation parameters

This modifies the H(f) to

$$H(f) = \sum_{i=1}^{N} g_i e^{-(a0 + a1.f^k)d_i} e^{j2\pi f \tau_i}$$

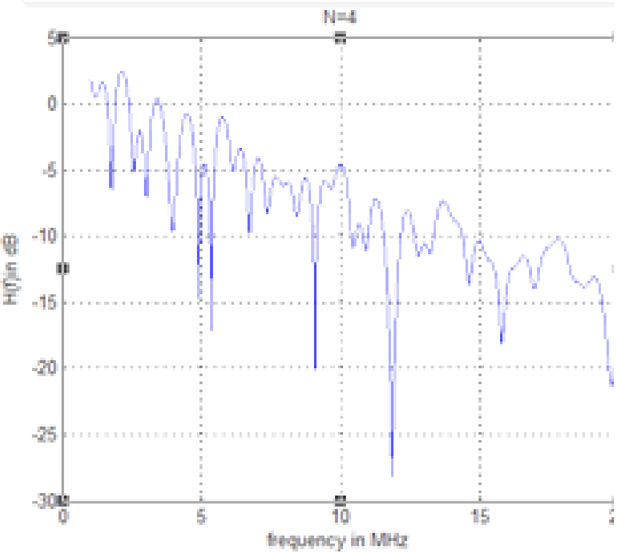


Figure 5: frequency response of simulated power line

For verification, the results of simulation are compared with measurements by [13].

In [13] an experiment with a real world network was performed.

| Path No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| delay in µs | 1.0 | 1.25 | 1.76 | 2.64 |
| equivalent length in m | 150 | 188 | 264 | 397 |
| weighting factor $g_i$ | 0.4 | -0.4 | -0.8 | -1.5 |
| $k = 0{,}5$ | $a_0 = 0$ | | $a_1 = 8\ 10^{-6}$ | |

Table 1 Parameters used in real world measurement by [19]

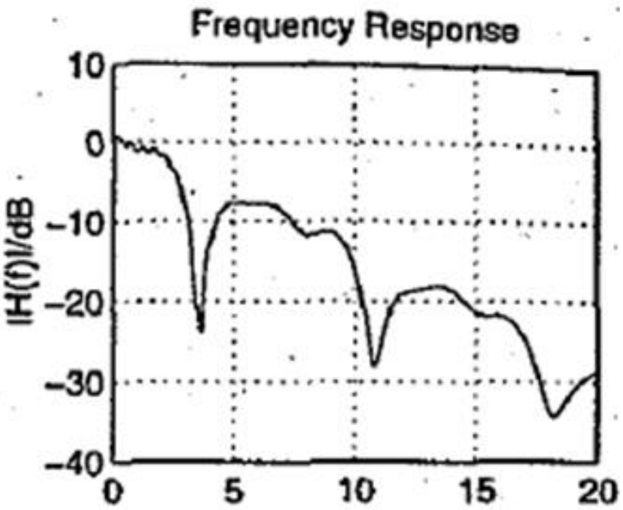


Figure 6: Frequency response of Real world power line channel

Figure 6 shows the absolute value of the measured frequency response (attenuation) of a power line link with a length of approximately 150 m. Comparing the frequency response of our modeled power line channel and the real life power line channel shows a lot of similarities. Both depict the fact that attenuation increases with frequency.

The modeled power line channel response,

$H(f) = \sum_{i=1}^{N} g_i e^{-(a0 + a1.f^k) d_i} e^{j2\pi f \tau_i}$ , is convolved with AWGN , Rayleigh multipath fading and a generated impulsive noise with very short durations to simulate the extreme harsh conditions of the modeled power line channel. AWGN accounts for the background noise whilst the, Rayleigh multipath fading channel accounts for the multipath fading effects and narrowband interferences of the power line channel.

Impulsive noise was modeled as a sum of random different time shifted sinusoids pulses with short durations.

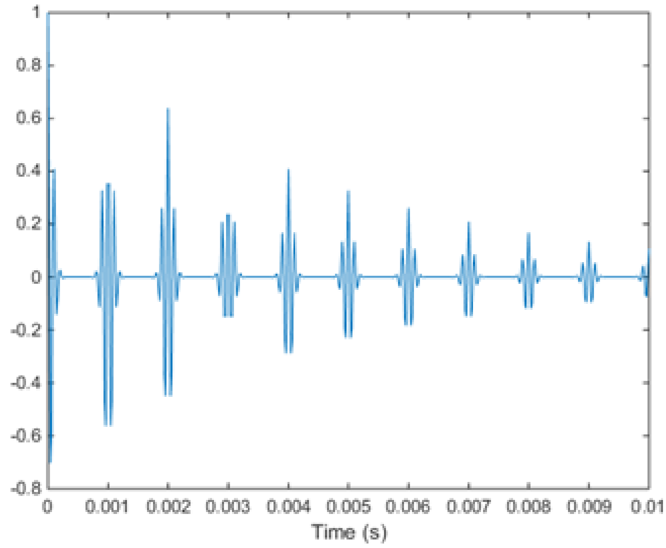


Figure 7: A modeled impulsive noise for simulated power line channel

One of the ways of improving bit error performance of a communication channel is by the use of error correction techniques[13]. A few error detection and correction techniques are reviewed in the next two subsections.

*B. Automatic repeat request (ARQ)*

In this approach, the receiver first detects the error and then sends a signal to the transmitter to retransmit the signal. This can be done in two ways:

- continuous transmission mode
- wait for acknowledgement.

In continuous transmission mode, the data is being sent by the transmitter continuously. Whenever receiver finds any error it sends a request for retransmission. However, the retransmission can either be selective repeat or go back N step type. As the name suggests, in selective repeat those data units containing error are only retransmitted. While in go back N type, retransmission of last N data unit occurs. Next, in wait for acknowledgement mode, acknowledgement is sent by the receiver after it correctly receives each message. Hence, when not sent, the retransmission is initiated by the transmitter. [14][15]

*C. Forward error Correction (FEC)*

In this approach, error is both detected and corrected at the receiver end. To enable the receiver to detect and correct the data, some redundant information is sent together with the actual information by the transmitter. As Forward Error Correction involves additional information during transmission along with the actual data, It also reduces the effective data rate which is independent of rate of error. Hence, if error occurs less frequently then Automatic request approach is followed keeping in mind that retransmission is feasible. But for A power line channel, a Forward error Correction is recommended [8]. Bit Error rate performance of Reed Solomon (RS) and Convolutional error correction techniques were compared in [14] using MATLAB for simulation. Results are shown in Figure 8. From Figure 8, Convolutional error coding performs better that Reed Solomon coding.

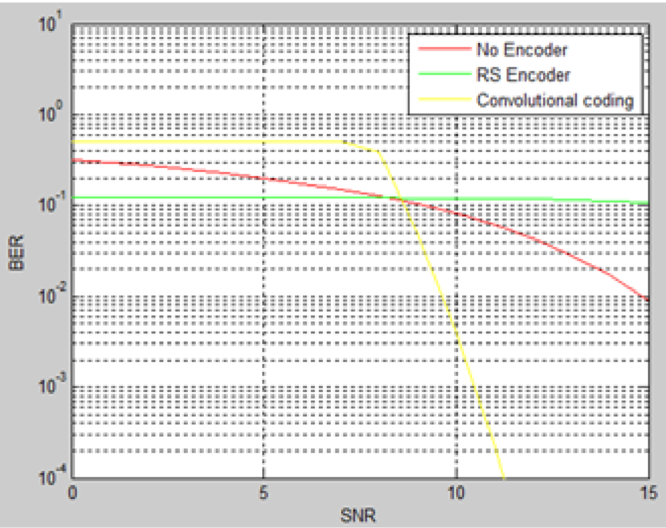


Figure 8: BER vs. SNR of Reed Solomon and Convolutional coding[14]

III. MODULATION

*A. Basic Modulation Schemes*

Performance of Power Line communication can be improved by properly selecting a suitable modulation scheme [2]. BPSK, M-PSK and M-QAM are all possible modulation schemes which can be used with PLC. Constellation diagrams for these as shown in figure 4 and 5, shows that BPSK performs better in terms of bit error ratio since there is a relative large distance between symbols and decision line but also very bandwidth inefficient since it can take only two symbols[18].

However Other higher order modulations like QPSK, 8 PSK, , 16 PSK, 16 QAM, 64 QAM, etc. are relatively bandwidth efficient since they make use of more symbols but have poorer bit error ratio since distance between decision line and symbols are relatively small.

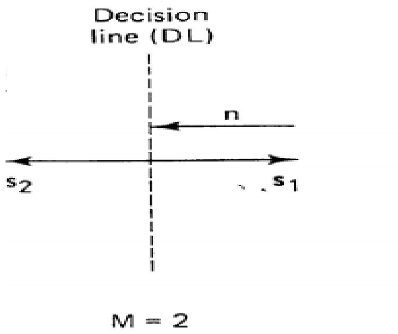


Figure 9:Constellation diagram for BPSK

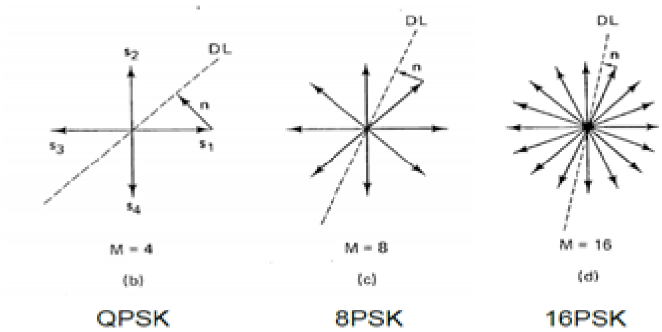


Figure 10: Constellation diagrams for higher order Phase Shift Keying Modulations.

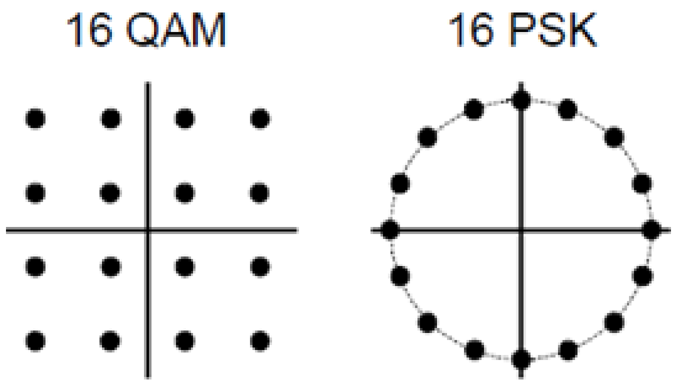


Figure 11: Constellation diagram for 16 QAM and 16 PSK.

From Figure 11, 16 QAM and 16 PSK are similar in terms of bandwidth effectiveness since they are have equal number of symbols but 16 QAM has a better BER performs.

*B. OFDM*

Orthogonal frequency division multiplexing, OFDM is a method of digital modulation in which a signal is split into several narrowband channels at different frequencies. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate. OFDM combines the better bit error performance of a low order modulation scheme and the bandwidth efficiency of higher modulation others. Due to the bandwidth efficiency of OFDM, it is recommended for coded modulations where redundant bits are added to the transmitted data[19].

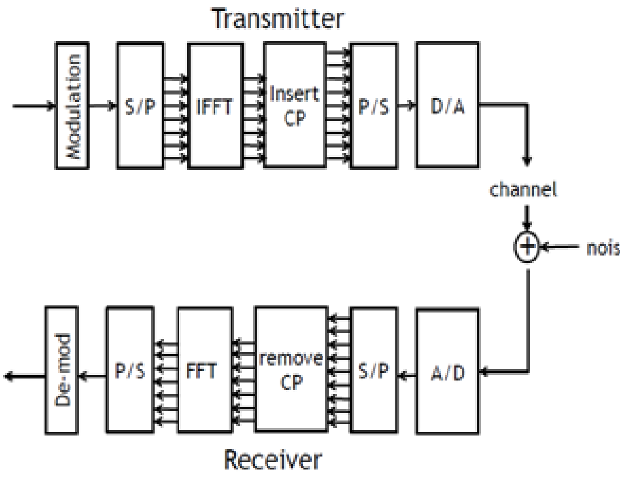


Figure 12: OFDM diagram

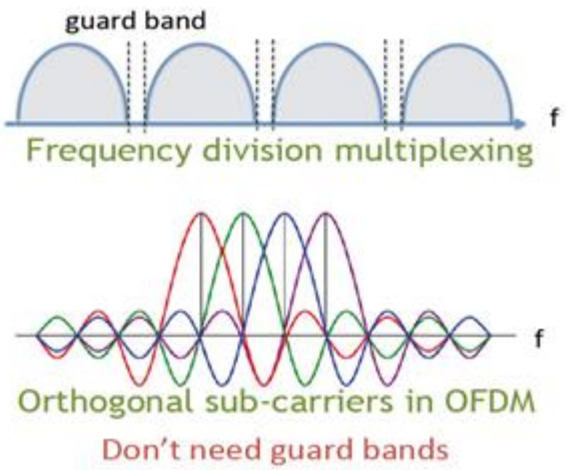


Figure 13: Comparing Orthogonal Frequency Division multiplexing with Frequency Division Multiplexing

The bandwidth effectiveness of OFDM is depicted in Figure 13 which compares OFDM to FDM. In OFDM, guard bands are not required as a result of the orthogonal nature of the signals.

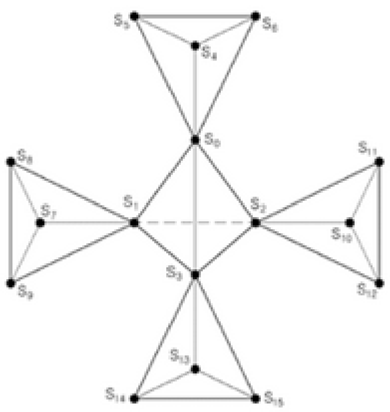

Figure 14: Constellation diagram for 16 QAM using OFDM

IV. SIMULATION AND RESULTS

A number of simulations were run with the modeled power line channel using MATLAB/SIMULINK software.

Various simulations using BPSK and QAM as the modulation scheme were performed on themodeled power line channel. Simulations of 16 QAM with and without convolutional error correction technique are performed. And finally a simulation of 16 QAM with convolutional error correction technique and OFDM is performed.

Figures 15 and 16 present simulation results showing BER of BPSK and 16 QAM, respectively, in the modeled power line channel. Simulation results show that BPSK, which is a lower order modulation performs better, in terms BER, compared to 16 QAM. These simulations were run to compare the Bit Error performance of a power line channel with respect to the order of modulation. Comparing Figures 15 and 16,it is clear that bit error performance decreased with the order of modulation. Constellation diagrams from Figures 10 and 11 explain why there is the need for a higher order modulation despite the established fact that higher order modulation schemes have relatively poor performance in terms of bit error rates. Bandwidth efficiency of the high-order modulation schemes as compared to that of BPSK is the main reason why one would want to consider using a high-order modulation scheme for smart metering application over a power line channel. However, to be able to do this something must be done about the poor bit-error performance.

One way to counter the poor bit-error performance of high-order modulation technique such as 16 QAM over a PLC channel is to apply an error correction procedure. In [14], simulations were run to compare the performance of Reed Solomon and convolutional error correction coding techniques. As shown in Figure 8, Convolutional error coding technique out performs Reed Solomon coding. In view of this, convolutional error correction technique is considered in this paper. Figure 17,shows simulation result when convolutional error coding technique was combined with QAM 16 over the simulated power line channel. This showed a great performance enhancement in terms of bit error rate compared to the results from Figure 16.

Though results from Figure 17 shows a great improvement in terms of bit error performance bandwidth efficiency would have to be compromised. From [7] [14] and [15] , redundant bits are introduced during the error correction technique. But since one of the main objectives of this paper is to propose a modulation scheme which would have a high bit-error performance and also be bandwidth efficient, OFDM is proposed. Constellation diagram for OFDM shown in Figure 14 explains the improvement on bandwidth efficiency when OFDM is used. This is due to the fact that orthogonality introduced amongst the symbols. Other advantages of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly modulated narrowband signals rather than one rapidly modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate intersymbol interference (ISI). The final Simulation was done with QAM 16 with OFDM and Convolutional error correction coding method. Result of this simulation is shown in Figure 19. This shows a better BER performance compared to all the previous results. Also there is the intrinsic effect of bandwidth efficiency of OFDM to offset the effect of loss of bandwidth due to the redundant bits introduced by the error correction code applied.

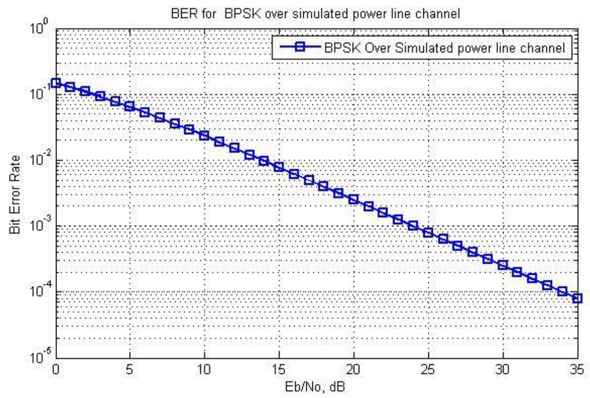


Figure 15: BER vs. SNR of BPSK in simulated Power Line Channel

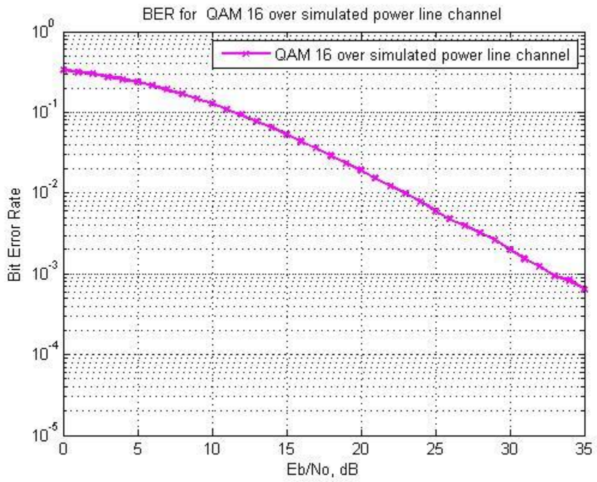


Figure 16: Simulation results of 16 QAM over the power line channel

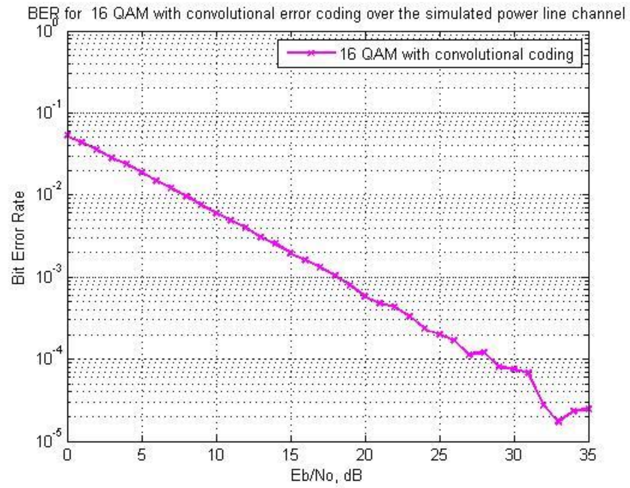


Figure 17: BER for QAM 16 over the modeled power line channel with Convolutional coding

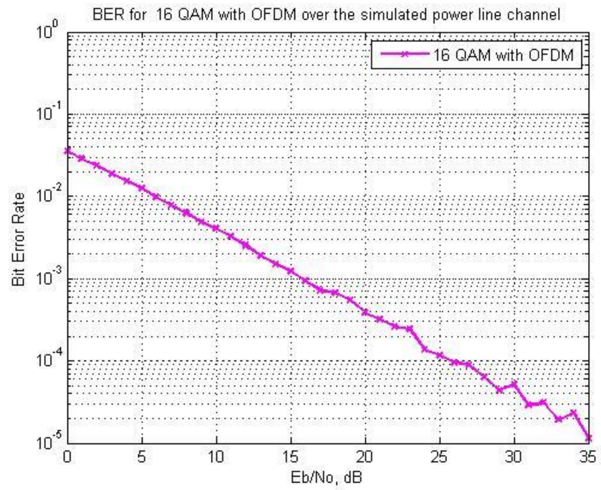


Figure 18: BER 16 QAM with OFDM over simulated power line channel

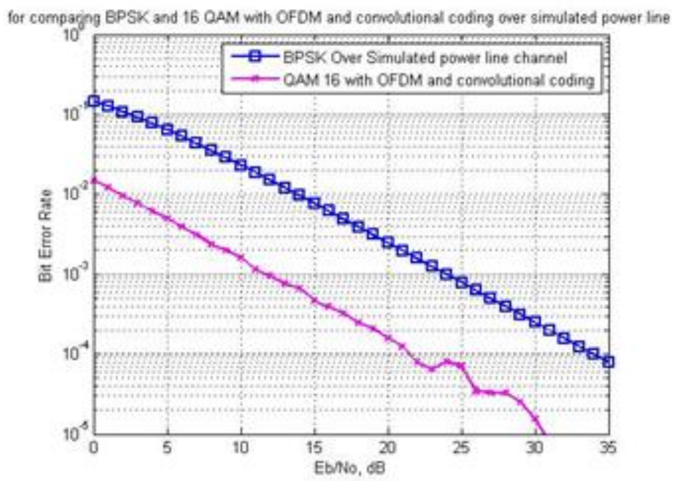


Figure 19: OFDM with 16 QAM over simulated power line channel with Convolutional coding simulation.

VI . CONCLUSION AND FUTURE WORK

In this paper, we have sought to find ways of overcoming the high bit error rates (BERs) associated with PLC channels without losing the opportunity of using multiple techniques for bandwidth improvements. The research work particularly sought to improve PLC channels to make PLC a viable alternative to other transmission media in smart energy metering and smart grid networks. Studies of low order modulation techniques and high order techniques were conducted and a BPSK was chosen to represent the former category of modulation techniques whilst 16 QAM was chosen to represent the latter category. Simulations of the representatives were carried out with 16 QAM being finally simulated with convolutional error correction code and OFDM to counter poor bit-error rates and loss of bandwidth due to error correction overhead.

Based on the simulation result, we propose a modulation scheme which combines OFDM and Convolutional error correction coding with a high-order modulation scheme such as QAM as the scheme of choice for PLC channels. This, when investigated further and adopted, is likely to give a boost to the implementation of smart metering application and smart grids in general.

Very high modulation schemes like 64 QAM, 128 QAM, etc were not simulated. Also Peak to Average Power Ratio, PAPR which is a major drawback in OFDM systems was also not considered. These are some points to consider for investigation in future works.

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