International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 6 Issue 12|| December 2017 || PP. 35-47

Modeling of Power Line Communications for Indoor System Using MIMO coding scheme

Bhimsen Rajkumarsingh[1]*, Noorianah Lollmahamod[2]
[1]*Department of Electrical and Electronic Engineering, University of Mauritius, Reduit, Mauritius*
[2]*Orange Business Services, Mauritius*
[*] *Corresponding Author. E-mail: b.rajkumarsingh@uom.ac.mu*

Abstract:*The need to study broadband Power Line Communications (PLC) for indoor use is becoming essential with the spread of broadband technologies. This paper aims at modeling the broadband PLC channel based on indoor applications considering multipath fading andusing Multiple Input Multiple Output (MIMO) coding technique with its channel estimation to achieve better performance. In particular, the BER performance using the FIR filter model and the Rayleigh fading model for the PLC channel is evaluated and compared. The performance of orthogonal space-time block code (OSTBC) with code rates 1, ½ and ¾ with BPSK modulation in an indoor PLC channel corrupted with impulsive, narrowband and background noises is presented. The effect of increasing space-time diversity as a means to overcome the hostile nature of the PLC channel is also investigated. Moreover, the improvement in BER performance and throughput with less complex coding is shown as compared to previous works. The simulations have been carried out usingthe MATLAB environment.*

IndexTerms:*Power Line Communications, Multiple Input Multiple Output, Multipath Rayleigh Fading Channel, Channel estimation***.**

Date of Submission: 13-11-2017 Date of acceptance: 06-12-2017

I. Introduction

Power Line Communications (PLC) is an ancient idea that goes back to the early 1920's which means that data could be transferred through power lines. The Power Line Communications systems involve terminal devices that are plugged into the electrical power supply network and allow data to be transmitted through the network to other terminal devices attached to the network. It has been used for narrowband relay applications, that is, low data rates of up to 500 Kbps, such as the remote control, public lightning and domestic installations during the early years. It is only by the end of 1990's that this technology has been developed to allow higher transmission speed of data of up to 200 Mbps known as broadband PLC. In fact, this technology has brought about many advantages including the idea of its availability all around the world through the sockets in our home (Pandey & Saad, 2014). Due to its broad coverage and with no new infrastructure needed, broadband over power lines has attracted much attention to residential and commercial markets which include both indoor and outdoor applications. With regard to indoor applications, this technology is making it easier to realize users' entertainment needs such as HDTV, rough control of smart appliances, the facility to distantly manage electrical devices (Berger *et al.* 2013).

Standards have been set up in order that the spectrum coverage is respected and that the system is controlled. The frequency bands have been approved by the *International Telecommunications Union* and they are generally subdivided into narrowband (NB) and broadband (BB) PLC. Most NB-PLC devices implement IEEE 1901.2, ITU.T G.9904 and ITU.T G.9903 standards whereas BB-PLC systems use the IEEE 1901.2010, ITU-T G.hn standards and more recently, IEEE *1905.1* standard (Cortes *et al.* 2010).According to data transmission theory, it has been analyzed that when data travels through a medium, it comes upon numerous limitations such as multipath effect, fading, attenuation and other sources of interference (Moore, 2009). As a matter of fact, a true PLC channel will comprise of all these restrictions (Berger *et al.* 2013; Singh, 2012; Tan & Thompson, 2012) which need to be considered for the modeling as well as the PLC noise model which greatly affects the system (Rajkumarsingh & Poonye, 2014; Tan & Thompson, 2012) and Berger *et al*. (2013) showed that the PLC channel can be modeled by considering the reflection factors of the channel based on its multipath effect. However, they did not focus on the channel's fading effect which is one vital factor for the channel modeling. Per se, a study conducted by Choe (2012) presented that the PLC channel is affected by multipath fading or frequency-selective fading and hence can be perceived as a fading channel model. This statement was confirmed in a more recent paper whereby it declared that the fading model follow a Rayleigh distribution (Mathur, 2014). A previous work carried out by Papaioannou *et al.* (2004) illustrated the performance of the

PLC channel with STBC coding. Nonetheless, it assumed the PLC model to be frequency- flat instead of frequency-selective fading.This does not actually represent the true PLC channel since the channel consists of various reflections of signals caused by impedance mismatches (Choe, 2012). To improve the BER performance, STBC codes were employed but yet, not as efficient as orthogonal STBC codes (Hendre & Murugan, 2013).

This paper considers multipath Rayleigh fading channel for the PLC modelusing orthogonal STBC. In particular, the BER performance using the FIR filter model and the Rayleigh fading model for the PLC channel is compared. The performance of OSTBC with code rates 1, ½ and ¾ with BPSK modulation in a PLC channel corrupted with impulsive, narrowband and background noises is presented. Moreover, the effectiveness and efficiency of the proposed system is compared with previous works.

As such, Section II focuses on the theory of PLC noises. Section III describes the multipath effect in the PLC channel. The modeling of the FIR filter and the Rayleigh fading using the multipath parameters are given here. The simulation framework using the MATLAB environment is explained in Section IV. Furthermore, Section V concentrates on the simulation results which comprise of the performance comparison with the two channel models, investigatesthe effects of varying load impedances, evaluates the performance of the SISO and MIMO PLC system andexplores the effect of varying transmit and receive antennas and code rates.The implemented system is also compared to previous works in this section. The last section concludes the results obtained from the implementation of this type of PLC channel.

II. PLC noise

Liu *et al.* (2005) states that noise is one important feature which influences digital communications over power line networks apart from signal distortion due to cable losses and multipath propagation cited previously. Also, unlike other communication channels, power line noise does not follow the typical additive white Gaussian noise (AWGN) model. It originates from electrical devices linked to the power grid and exterior noise attached to the indoor network via radiation or conduction. Based upon extensive study in (Cortes *et al.* 2010),it has been categorized into the following terms:

2.1Impulsive noise: This consists of different components that can also be classified according to:

1. Periodic impulsive noise synchronous with the mains: It originates from controlled rectifiers in power supplies operating synchronously with the mains.
2. Periodic impulsive noise asynchronous with the mains: It is generated from switched power supplies and AC/DC power converters.
3. Asynchronous impulsive noise: It is caused by switching transients initiated by connection and disconnection of electrical appliances.
4. Narrowband Interference: This is usually caused by modulated and sinusoidal signals originating from broadcast stations, electrical appliances.

2.2Background Noise: This comprises of the remaining types of noise that are not counted in the previous categories. It results from the summation of several low power noise sources of indefinite origin.

Despite the short duration of impulse noise, it is considered as the main noise source over the PLC channel. The impulsive noise has been analyzed in both the frequency and time domain. Using the time domain, impulsive noise can be characterized by random variables namely the impulse with t_{wi}, the impulse amplitude A_i and the inter-arrival time $t_{arri}$for the i_{th} impulse envelope as shown in Figure 1. From experimental results carried out for indoor broadband impulsive noise (Familua, 2012), their statistical properties have been determined and are shown in Table I.

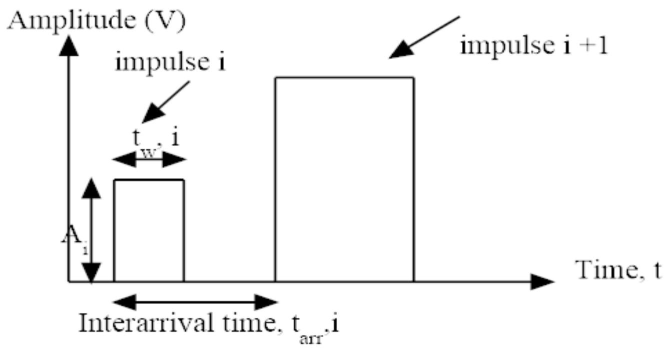

Figure1. Impulse envelopes of impulsive noise

Table I. Statistical Properties of Impulsive Noise

Parameters	Mean	Standard Deviation
Amplitude (mV)	229	121
Duration (µs)	205	157
Inter-arrival time (ms)	0.667	0.445

Narrowband interference can be modeled as the sum of sinusoidal waveforms, denoted mathematically below (Meng *et al.* 2005):

$n_{nb}(t) = \sum_{i=1}^{N} A_i(t).\sin(2\pi f_i t + \varphi_i)$(1)

Where N is the number of carriers, each having a different amplitude A_i *(t)*, different phase φ_i and different frequency f_i. The phase can be selected randomly in the interval *[0, 2π]* and does not depend on time.
Background noise is usually modelled in the frequency domain and as stated in (Zimmermann & Dostert, 1999), power spectral density of background noise in PLC channels is inversely proportional to frequency. Several studies carried out have brought about that the background noise can be considered to a sum of two Gaussian distributions or Rayleigh distributions (Bhatnagar *et al.* 2014).

III. Multipath Effect in PLC

3.1Multipath effect in PLC

PLC channels are affected by multipath phenomenon like wireless communication channels. This would mean that signal propagation does not only take place through only a 'line of sight' path between transmitter and receiver but additional echoes are also considered. This is due to several reflections initiated by junctions in house service cables, house connection boxes, etc. with diverse characteristic impedances (Zimmermann & Dostert, 1999).

Tan & Thompson (2012) approved that an indoor PLC network frequently shows a T type topology. When a signal passes through the tree from source to destination, the signal energy will be divided by the branches at the joints, and echoed at the branch ends due to impedance mismatches, thus resulting into a grouping of the signal circulating through the direct path from the transmitter and a number of reflections from network branches. As seen in Figure 2, there are 3 segments with lengths l_1, $l_2$and $l_3$with their respective characteristic impedances Z_{l1}, Z_{l2} and Z_{l3}.Theoretically, it can be said that there are infinite number of reflection paths and the outcome is a multipath channel with frequency selective fading. For a basic consideration as assumed in (Mlynek *et al.* 2012), T_A and $T_C$are matched which means that $Z_{l1} = Z_A$ and $Z_{12} = Z_C$, thus reflection will occur only along the segment BD and $Z_{l3} \neq Z_D$.

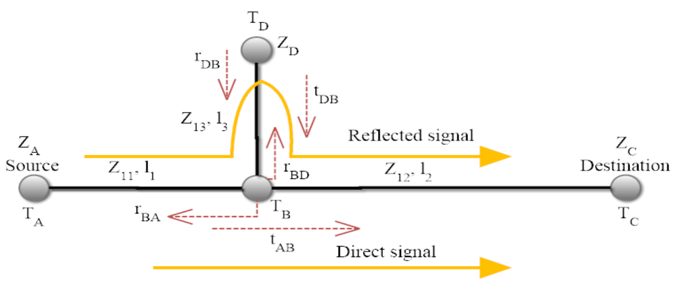

Figure2. Multipath T-type topology

T_A, T_B, $T_C$and T_D represent the points forming the T-topology.

Path 1: $T_A \Longrightarrow T_B \Longrightarrow T_C$

Path 2: $T_A \Longrightarrow T_B \Longrightarrow T_D \Longrightarrow T_B \Longrightarrow T_C$

Path 3: $T_A \Longrightarrow T_B \Longrightarrow T_D \Longrightarrow T_B \Longrightarrow T_D \Longrightarrow T_B \Longrightarrow T_C$

...

Path N: $T_A \Longrightarrow T_B \Longrightarrow T_D \Longrightarrow \ldots T_B \Longrightarrow T_C$

Each transmitted signal reaches the receiver through *N* different paths. Each path *i* is well-defined by a certain delay τ_i and a certain attenuation factor C_i. As such, the PLC channel can be termed by means of a discrete-time impulse response *h (t).* The impulse response of the channel *h (t)* can be inscribed as an addition of the delayed and attenuated Dirac pulses (Duche & Gogate, 2014).
The transfer function leads to the equation as follows:

$$H(f) = \sum_{i=1}^{N} g_i . A(f, d_i) . e^{-j2\pi f \tau_i} \quad (2)$$

If the transfer function is to be expressed in terms of its phase, it becomes:

$$H(f) = \sum_{i=1}^{N} g_i . e^{-\alpha(f) d_i} . e^{-j\beta(f) d_i} \quad (3)$$

N is the number of fading paths, each path *i* has a weighting factor $g_i$which represents the product of the transmission and reflection coefficients along the path and it is usually less than 1. $A(f, d_i)$ is the attenuation factor caused by PLC transmission cable losses in the form of heat or signal leakage and *f* is the frequency of operation. The delay τ_i of a path *i* can be obtained from the length d_i, and the speed of light in vacuum c_0 and the relative permittivity ε_r as below:

$$\tau_i = \frac{d_i \sqrt{\varepsilon_r}}{C_0} \quad (4)$$

Where, $\sqrt{\varepsilon_r}$is the dielectric constant of the insulating material.
Based upon extensive study (Singh, 2012), $A(f, d_i)$ can be estimated by the mathematical formula for attenuation factor α. As such, $\alpha(f)$ can be obtained from the sum of attenuation parameters. This will lead to:

$$A(f, d_i) = e^{-\alpha(f) d_i} \quad (5)$$

Where, $\alpha(f)$ is the attenuation constant and is evaluated as follows:

$$\alpha = \frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}} = \frac{R}{2}\frac{1}{Z_c} + \frac{G}{2} Z_c \quad (6)$$

IV. Power Line Channel Models

The multipath effect of the PLC is commonly used to model the PLC channel, basically known as the echo-based model (Rajkumarsingh & Poonye, 2014). The echo-based model can be realized by using a direct form FIR digital filter structure as illustrated in Figure 3, assuming that the main signal is synchronized. An FIR filter is usually characterized by an order of N with N+1 numerator coefficients. Thus, taking into consideration the direct path of the signal, the total number of paths is N+1. The numerator coefficients denote the weighting factors.

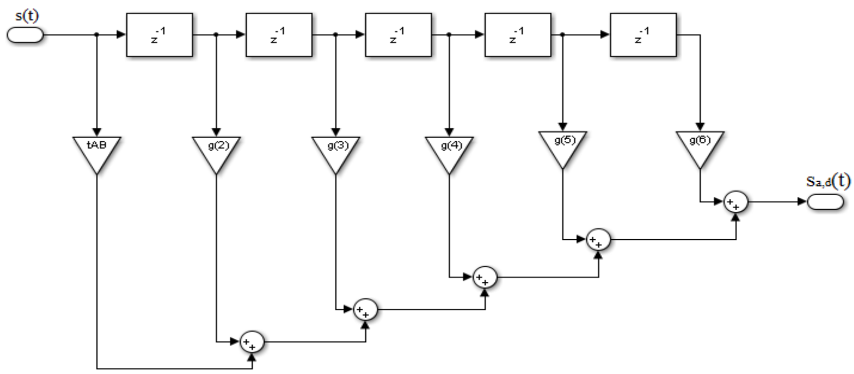

Figure 3. Echo-based model in the form of an FIR filter

In a more recent study (Mathur, 2014), it has been detailed that the Rayleigh fading model is extensively used for modeling the PLC channel. It was experimentally proven that parameters of the measured transfer functions follow the Rayleigh distribution. As a matter of fact, this paper will consider the Rayleigh fading effects to be valid for the PLC channel using the parameters written above.
A channel is said to be Rayleigh-distributed if the real and imaginary parts of the response are i.i.d., that is, independently and identically distributed Gaussian with equal variance and zero mean. Frequently, the gain and phase components of the channel's distortion are suitably characterized as a complex number. Its probability density function is given by:

$$f(x; \sigma) = \frac{x}{\sigma^2} e^{-x^2/(2\sigma^2)} \quad , x \geq 0 \quad (7)$$

Where,
σ is the scale factor of the distribution.

The PLC channel can be said to be frequency-selective. This would mean that its channel spectral response contains fades due to the numerous reflections causing elimination of certain frequencies at the receiver or deep nulls due to destructive interference (Zimmermann & Dostert, 2000).
Another important factor of Rayleigh fading channel is the Doppler shift which is caused by motion of objects. However, in the case of a PLC channel which is a wired medium, there will no Doppler effect since there is no movement of any object. Therefore, there will no Rayleigh fading due to Doppler Effect but only due to multipath propagation.

4.1 Assessment of the Multipath parameters

Typically, for indoor power line distribution, two-wire transmission lines are used and as such, NAYY35 and NAYY150 cables are employed for outlet-outlet and inter-junction connections respectively (Zimmermann & Dostert, 2000).
Figure 4 illustrates a PLC modem connected to the mains (A) with a NAYY150 cable and this is linked to two sockets whereby two appliances (TV set, Microwave) (C, D) are connected by NAYY35 cables. B represents the mismatch point whereby reflection will occur. The load impedances of the PLC modem (mains) and the TV set are assumed to be constant, i.e. $Z_A = Z_{11}$, $Z_C = Z_{12}$ whereas the load impedance of the microwave $Z_D$is to be varied to create impedance mismatching. Since the two appliances are linked to the same type of cables, $Z_{13} =Z_{12}$.

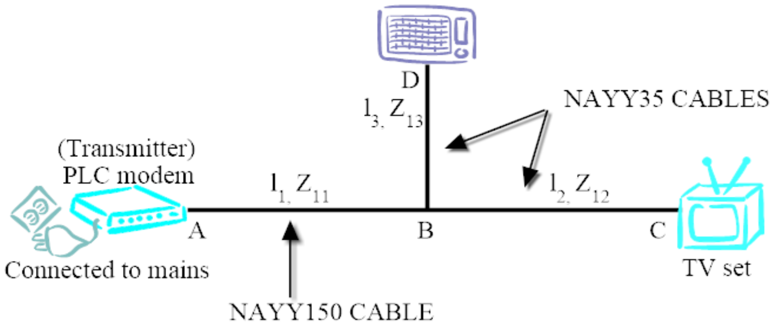

Figure4.Indoor power line network topology

Table II illustrates the lengths of the paths with their respective path delays and path gains obtained from simulation. The path delay which denotes the time taken to reach the receiver is in the order of 2. The results show that with increasing path length, the path delay also increases, roughly by two times. Also, the path gain in dB increases approximately by 3 times. As observed, the path gains' values are negative in dB indicating that the power of each path attenuates with increasing length.

Table II. Path Lengths With Their Respective Delays And Gains

Path number	Length of path, d_i (m)	Path delays, τi (μs)	Path gains, α_i (dB)
1	0	0	0
2	22	0.147	-4.721
3	52	0.347	-7.444
4	82	0.547	-10.17
5	112	0.747	-12.89
6	142	9.47	-15.61

In order to create impedance mismatching in the system, the load impedance $Z_D$at node D, is made to vary and its effects on weighting factors are observed. Values of 10 Ω, 40 Ω and 70 Ω are considered for the analysis. This is illustrated in Table III and as it can be observed, the load impedance does not have any effect on the first path since it is not reflected and thus no reflection coefficient. At 40 Ω, the weighting factors as from path number 4 can be neglected. This is due to the matching properties of the impedance of NAYY35 such that $Z_D \approx Z_{12.}$ However, the 10 Ω and 70 Ω impedances are different from Z_{12} resulting into a distortive effect of the received signal. Compared to 70 Ω, the 10 Ω impedance will create a greater distorted signal due to its negative echoed versions.

Table III. Evaluated Weighting Factors

Path number	Weighting factors, g_i		
	10 Ω	40 Ω	70 Ω
1	5.877	5.877	5.877
2	-1.23	-0.2431	0.2601
3	0.238	0.0101	0.0115
4	-0.054	-4.16e-4	5.096e-4
5	0.0113	1.72e-5	2.256e-5
6	-0.0024	-7.12e-7	9.984e-7

V. Simulation Framework

Simulations were carried out to undertake the following:

1. To examine the effect of varying loads in the PLC channel;
2. To evaluate the performance multipath Rayleigh fading channel in comparison with the FIR filter PLC model;
3. To analyze the performance of MIMO coding with varying transmit and receive antennas and code rates in the PLC channel; and
4. To compare the implemented system with previous works.

The blockdiagram of the implemented system is shown in Figure 5. The software *MATLAB/Simulink R2014a* is used to realize the overall system and the corresponding parameters are evaluated in *MATLAB R2014a* which are then transferred to the required blocks.

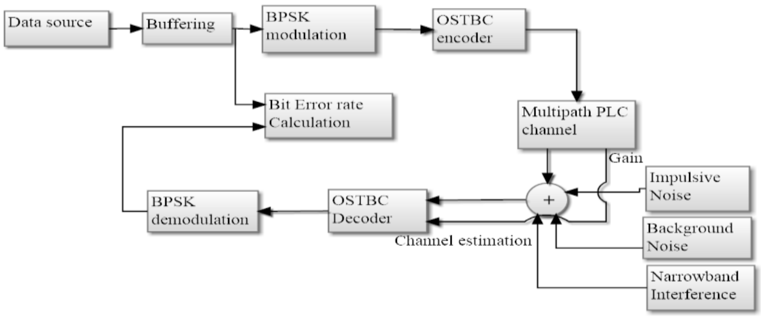

Figure5. Complete system model

Throughout the simulation process, the data rate and the packet size are taken to be 6 Mbps and 300 respectively. The BER results are obtained after analyzing one million symbols. A range of the SNR values were used to evaluate the BER. The signal power is taken to be 0.5 W. BPSK method is used for the simulation process before which, a buffer is added to make the sample time of input same as output. The details on the main blocks are given below.

5.1 Modeling of broadband indoor PLC channel

Based on the study carried out by Rajkumarsingh & Poonye (2014), it was said that the PLC channel model can be assumed to be an echo-based model. As matter of fact, it can be realized using an FIR filter whereby the numerator coefficients represent the weighting factors.

However, in view of the fact that fading is a major phenomenon that should be considered in a multipath channel, the PLC channel can also be modeled using a multipath channel with a Rayleigh fading distribution. This has been extensively studied by Celebi (2010). Intrinsically, in Simulink, the *MIMO multipath fading channel* block is utilized to implement the model whereby the discrete path delays and average path gains coefficients represent the path delays and path gains and which have been evaluated in Table II. The fading distribution is set to *Rayleigh* and the Maximum Doppler Shift parameter is assigned to 0 since there is no Doppler effect in a wired system. For the uncoded system fading model, it may necessary to introduce an equalizer to eliminate the ISI caused by fading effects.

5.2 Modeling of PLC noise

Impulsive noise can be modelled from a set of pulse trains with random amplitudes, pulse widths and phase delays as per specifications and as such, pulse generators are used.The period of the total pulse generators is determined using the following equation (Rajkumarsingh & Poonye, 2014):

$$Period = \sum_{i=1}^{num\_gen} t_{arr,i} \quad (8)$$

The total impulsive power is derived is shown in equation 9.

$$Total\_P_{imp} = \frac{1}{Period}\sum_{i=1}^{num\_gen} A_i^{\,2}.T_{w,i} \quad (9)$$

To generate narrowband interference, two sine wave generators are used whereby random amplitudes and frequencies are defined. The total sinusoidal power is defined as follows:

$$P_{sine} = \sum_{i=1}^{Num\_sine} \frac{A_i^{\,2}}{2} (10)$$

The sum of two Gaussian noise generators is used to model the background noise whereby their variances represent the average background power and they are based on the following assumption (Arzberger **et al.** 1997):

$$\sigma_1^{\,2} = 10\sigma_2^{\,2} \quad (11)$$

Background power is obtained from the subtraction of the sum of impulsive power and sinusoidal power from total noise power. Thus, for different values of SNR, the noise power is varied.

5.3 MIMO coding scheme with channel estimation

PLC channel is affected by multipath and fading and thus to combat these limitations, MIMO system can be applied. Berger *et al.* (2013) stated that MIMO greatly helps in achieving higher data rates and lower BER. MIMO uses the diversity coding technique whereby it uses multiple antennas at both receiver and transmitter side to send multiple copies of the transmitted signal which are independently faded.MIMO systems can be defined as a link in which the transmitting and the receiving ends are equipped with multiple antenna elements as illustrated in Figure 6. The core idea behind the MIMO system is the Space Time Block Codes (STBC) in which time is complemented with the spatial dimension inherent in the use of multiple spatially distributed antennas which means that data is coded with space and time (Santumon & Sujhatha, 2012).

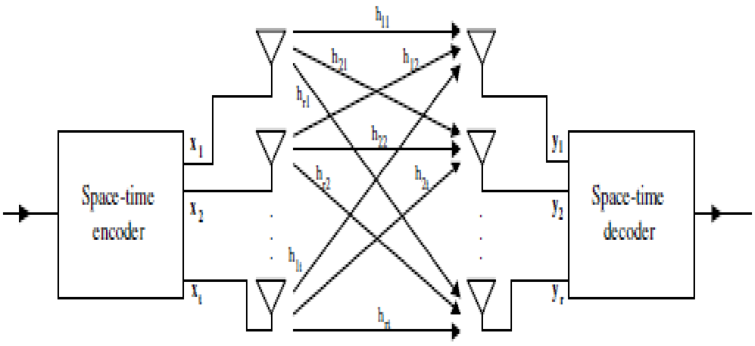

Figure6. Block diagram of MIMO system

The received vector is given by:

$$y = Hx + n \quad (12)$$

Where,
x is the transmitted signal
H is the channel gain matrix and
n is the noise vector

H can be described as $\begin{pmatrix} h_{11} & h_{12} & h_{1t} \\ h_{21} & h_{22} & h_{2t} \\ h_{r1} & h_{r2} & h_{rm} \end{pmatrix}$ with a N_t x N_r dimension where each entry $h_{i,j}$ denotes the phase shift and attenuation (transfer function) between the i_{th} transmitter and j_{th} receiver. Space Time Block Codes are a general version of Alamouti scheme (Alamouti, 1998). These codes are orthogonal and can attain full transmit diversity quantified by the number of transmit antennas. The data are built as a matrix which has its columns equivalent to the number of transmit antennas and its rows equivalent to the number of time slots necessary to transmit the data. At the receiver side, the signals received are first combined and then sent to the maximum likelihood detector where the decision guidelines are employed (Santumon & Sujhatha, 2012). The code rate which is denoted by the number of transmitted symbols over the number of time slots is 1 for the Alamouti scheme. It means that the Alamouti scheme achieves full diversity gain without sacrificing its data rate(Alamouti, 1998). However, for higher number of transmit antennas, full rate cannot be achieved and therefore it is necessary to sacrifice data rate. As such, the code rate can be ½ or ¾ depending on the encoding algorithm (Santumon & Sujhatha, 2012).

The OSTBC decoder block has a simple decoding system based on maximum likelihood at the receiver (Kumar & Saxena, 2014). As shown in Figure 7, the estimated coefficients of the channel, i.e. the channel estimator and the combiner are given as input to the ML detector. The channel estimator is a significant part of the decoder whereby each transmitting and receiving antenna characterizes a channel coefficient. The decoder accepts and combines all the input signals along with the channel estimate from all the transmit antennas, so as to support the channel to approximate about the signal to extract the data encoded in the symbols (Santumon & Sujhatha, 2012).

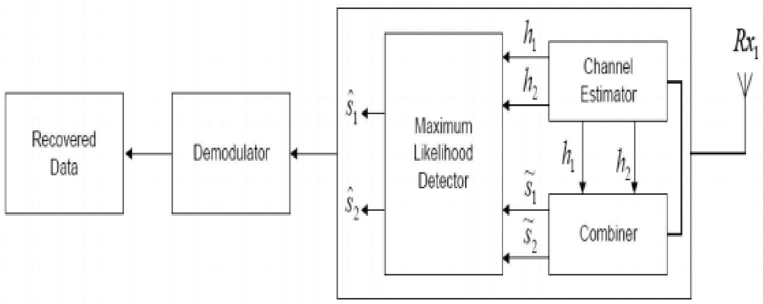

Figure7. Alamouti space time decoder

The ML detector selects a pair of signals ($\hat{s}_1$, $\hat{s}_2$) from the signal constellation to reduce the distance metric over all possible values of $\hat{s}_1$ and $\hat{s}_2$, which means that it takes the message ŝyielding the least distance between the received vector and theorized message(Santumon & Sujhatha, 2012). The ML detector chooses a pair of signals ($\hat{s}_1$, $\hat{s}_2$) from the signal modulation constellation that minimize the decision metric:

$$d^2 (r_1, h_1 \hat{s}_1 + h_2 \hat{s}_2) + d^2 (r_2, - h_1 \hat{s}_2^* + h_2 \hat{s}_1^*)$$
$$= | r_1 - h_1 \hat{s}_1 - h_2 \hat{s}_2|^2 + | r_2 + h_1 \hat{s}_2^* - h_2 \hat{s}_1^*|^2 \quad (14)$$

Where,
r =received vector
H = channel gain coefficient
d = distance metric

VI. Simulation Results

6.1 Performance of PLC channel (FIR filter) with varied load impedances (rate 1 BPSK)

The BER performance of the broadband indoor PLC system is compared using three different scenarios by varying the load impedances. As it can be observed in Figure 8, the 40 Ω system shows a better performance than that of 10 Ω and 70 Ω. At a BER of 10^{-3}, the 40 Ω system outperforms that with the 70 Ω load impedance by an SNR of 1 dB. However, the system's performance is improved as the load impedance varies from 10 Ω to 70 Ω by 4.75 dB at a BER of 10^{-2}. The variation observed in the BER performance is due to the evaluated weighting factors.

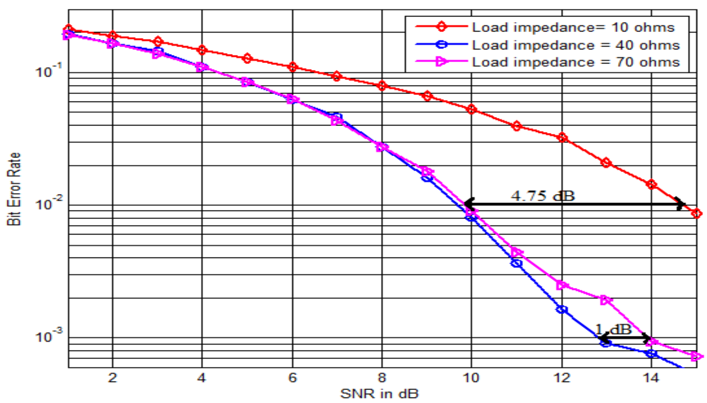

Figure8. Performance comparison with varied load impedances

6.2 Performance comparison with the two PLC channel models proposed

As it can be observed in Figure 9, the system's performance is improved with Rayleigh channel as compared to the Digital filter model.

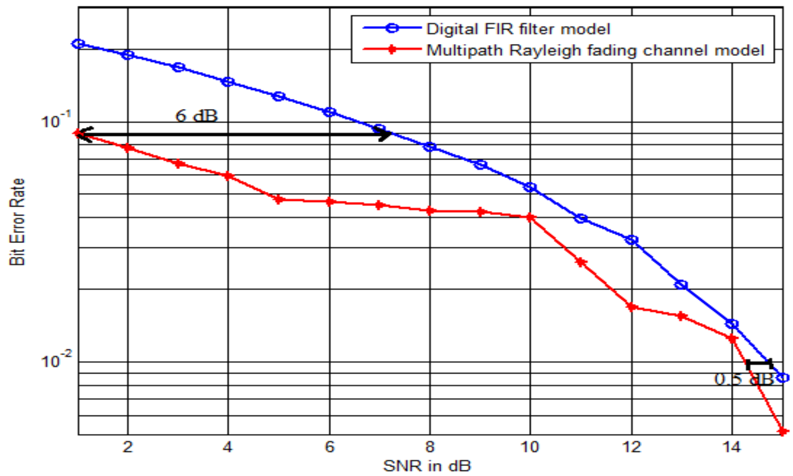

Figure 9. Performance comparison with two PLC channel models

At about a BER of 10^{-1}, there is a gap of 6 dB between the two curves. However, as the SNR increases, the gap decreases and at BER of 10^{-2}, the gap is seen to be about 0.5 dB. In other words, there is greater disparity at lower SNRs than at higher SNRs.

6.3 Performance of indoor PLC system with MIMO code rate 1 and BPSK modulation

The improved trend of the MIMO coded system using BPSK modulation, from 2 to 3 receive antennas, with a code rate of 1 can be observed in Figure 10. With the introduction of the Orthogonal STBC codes in the system, the performance of the 2x4 MIMO is improved roughly by 4.8 dB at a BER of 10^{-2}, as compared to the SISO system. Besides, a significant decrease of about 5 dB is observed for the 2x2 and 2x3 systems.Noticeably, the 2x2 reaches a BER of 10^{-4} at an SNR of 6 dB and the 2x3 and 2x4 with a steeper decrease at 5.5 dB and 5 dB respectively, having an SNR of 0.5 dB difference. Therefore, it can be said that the 2x4 system shows a better performance than that of the 2x2 and 2x3 systems, having a greater number of receive antennas with improved space-time diversity. It is clear that increasing diversity can overcome the deterioration of the channel due to impulsive, narrowband and background noises. It can also be seen from this figure that for an SNR below 5dB, the performance of the OSTBC codes are rather close. We might conclude here that if the BER performance is to be improved in this region, codes with higher space-time diversity should be used at the expense of coding complexity and throughput.

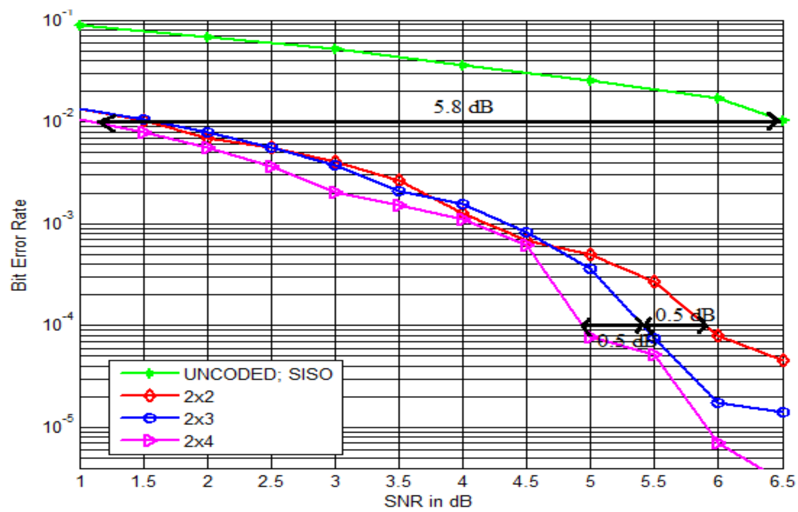

Figure10. Performance comparisons of varied receive antennas with OSTBC code rate of 1 and the SISO model

6.4 Performance analysis with varying code rates and antennaswith BPSK modulation

` As the number of transmit antennas becomes greater than 2, it can have a code rate of either ½ or ¾. As illustrated in Figure 11, the system's performance is analyzed with a code rate of ½. A significant improvement is observed in the 4x4 MIMO as compared to the 3x3 MIMO with an SNR decrease of 5.5 dB at a BER of 10^{-4}. Comparing the BER curves with 4 transmit antennas, it can be noticed that an SNR decrease of 1 dB occurs from 4x3 to 4x4 at BER of $10^{-5}$and 1.3 dB from 4x2 to 4x3. As expected, the BER curves having 4 transmit antennas reach the waterfall region quicker than that with 3 transmit antennas. The latter seem to have a flattening curve which is a less desirable performance.

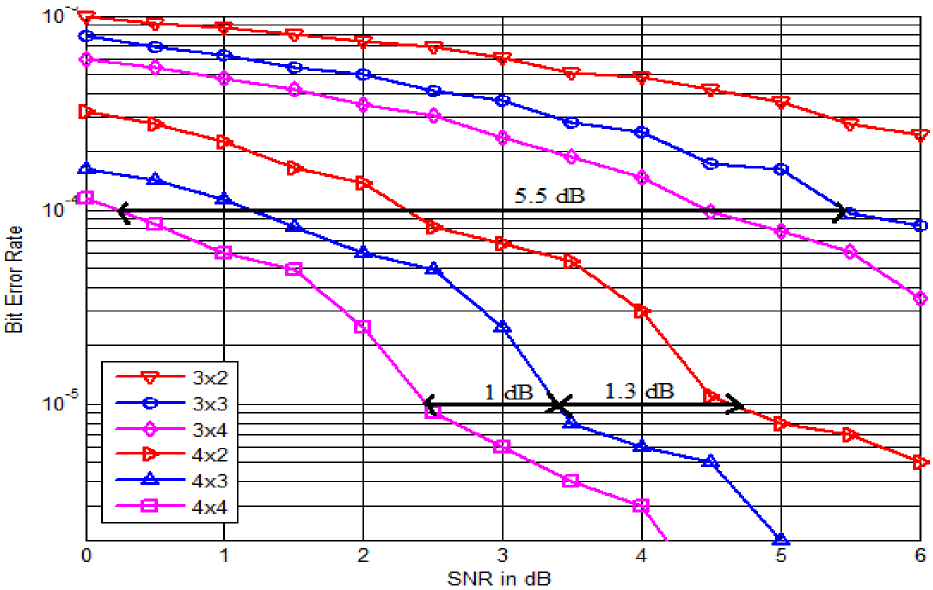

Figure11. Performance comparisons with OSTBC and code rate ½ with BPSK modulation

As far as the ¾ rate coded system is concerned, a visible aspect is that the ½ rate coded system enters the waterfall region at relatively smaller SNR than the ¾ rate coded system, meaning that it encounters a greater improvement at the expense of lower data transmission. As observed in Figure 12, the performance of 4x4 MIMO yields into an advance of 5 dB compared to the 3x3 MIMO at a BER of 10^{-4}.
Furthermore, with greater number of receive antennas, the system performs better, improving by SNR 1 dB and further 1.3dB. An abrupt decrease of BER is observed for the 4x2 MIMO around 2dB. For 3 transmit antennas, it can be seen that they have a rather flattening BER curve and enter the waterfall region at high SNRs. It can be deduced that the ¾ rate coded system is less desirable due to its degradation which may be accounted for the increase in transmitted symbols and hence more prone to errors. However, relative to SISO systems, the ¾ rate coded system shows a greater progress (Kumar & Saxena, 2014).

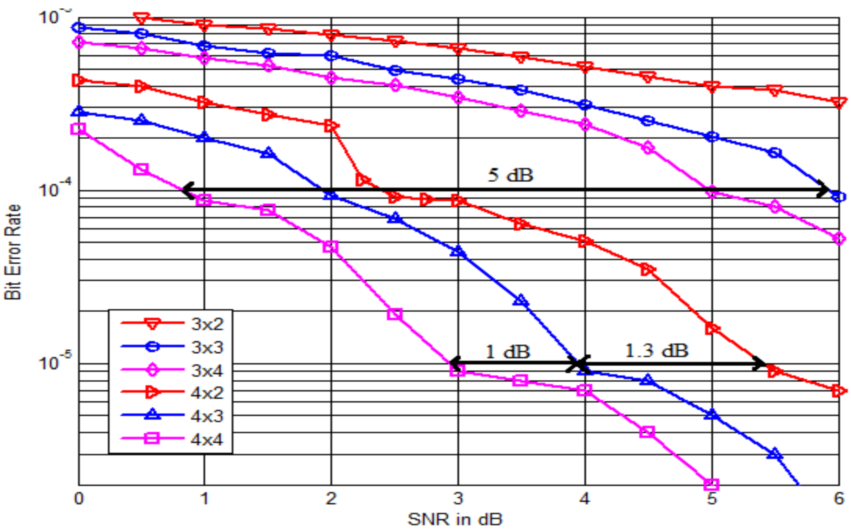

Figure12. Performance comparisons with OSTBC and code rate ¾ with BPSK modulation

6.5 Performance comparison with previous works

6.5.1 Previous work with STBC with narrowband interference and impulsive noise

The performance comparison between the 2x3 OSTBC with coding rate 1 and with BPSK modulation and that evaluated by Papaioannou *et al.* (2004) is realized in this section. The previous work analyzes the PLC channel which is modeled as a flat fading channel with 3x3 STBC codes using BPSK modulation scheme. The coding rate is employed is also 1. Moreover the power line channel is corrupted with AWGN and impulsive noise.

The effectiveness and the efficiency of the implemented system are evaluated using the BER and the throughput performance of both systems.As it can be seen from Figure 13, at a BER of 10^{-4}, the STBC system is severely degraded by 12 dB as compared to the 2x3 OSTBC system. The improvement in the implemented system can be accounted by the use of OSTBC codes along with channel estimation. Moreover higher throughput is obtained with the 2x3 OSTBC at a lower SNR as can be observed from Figure 14. In addition, the 2x3 OSTBC system has less coding complexity as compared to the 3x3 STBC system. However, this comparison cannot be fully done as the PLC modeling is not similar since the previous work implemented the PLC as frequency flat and this paper considered PLC as frequency selective.

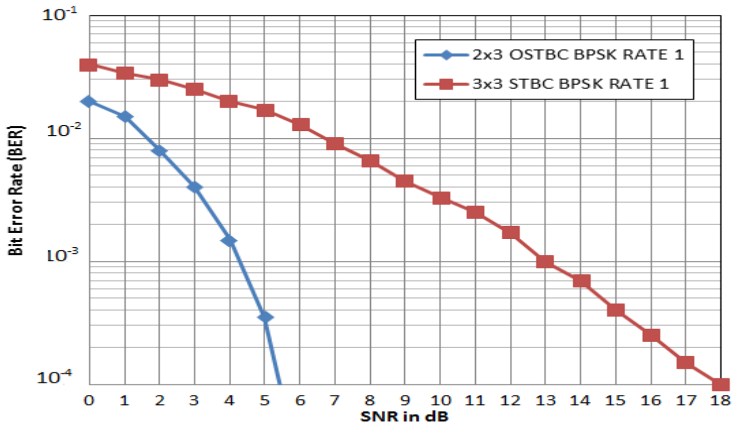

Figure13. BER performance comparison with 3x3 STBC with narrowband interference and impulsive noise

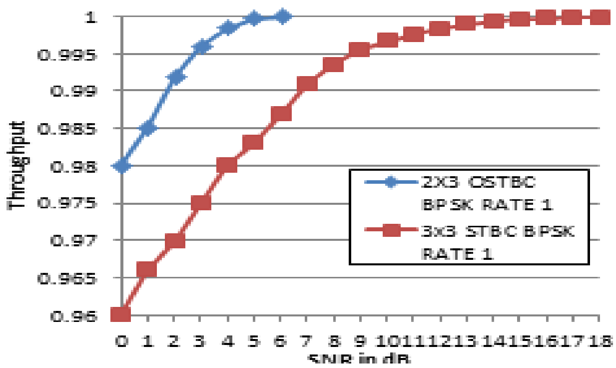

Figure14. Throughput performance comparison with 3x3 STBC with narrowband interference and impulsive noise

6.5.2 Previous work with 4x4 OSTBC in Rayleigh Fading channel(Santumon & Sujatha, (2012))

The 4x4 OSTBC, rate ½ coded with BPSK modulation is compared with the 4x4 OSTBC using QPSK modulation proposed by Santumon & Sujatha, (2012). Both systems have been evaluated in a Rayleigh fading channel. However, the system proposed in this paper is geared towards the PLC channel rather than the wireless channel and thus includes impulsive, narrowband and background noises. The implemented system and that proposed by Santumon & Sujatha (2012)is comparedwith code rates of ½ and ¾. It can be observed from Figure 15 that the performance of the implemented system with rate ½ and BPSK modulation is close to that of the OSTBC with code ¾ and with QPSK modulation. The advantage of the implemented system is that coding complexity is less and the disadvantage is that the throughput is less. The implemented system also shows a degradation of about 4 dB at a BER OF 10^{-4}compared to the rate ½, 4x4 OSTBC with QPSK modulation. This degradation in BER performance is due to the fact that the system is further affected adversely by impulsive, narrowband and background noises present in the PLC channel.

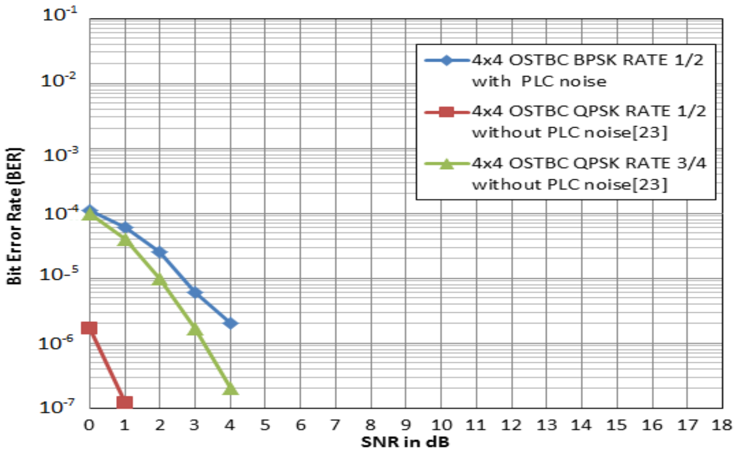

Figure15. BER performance comparison with 4x4 OSTBC in Rayleigh Fading channel (Santumon & Sujatha, (2012)

6.5.3 Previous with 4x 4 OSTBC in Rayleigh Fading channel, AWGN and interleaver(Kumar & Saxena, 2014)

The performance of the 4x4 OSTBC code rate ½ with BPSK modulation is also compared with the 4x4 OSTBC rate ½ with AWGN and interleaver system proposed by (Kumar & Saxena, 2014). It can be seen from Figure 16 that for an SNR below 3 dB, the latter performs better than the implemented system. One probable reason is that the system suggested by Kumar & Saxena(2014) employs interleaving as well. The system is also observed to perform better than the system by Santumon & Sujatha (2012) for an SNR below 2 dB for the same reason.

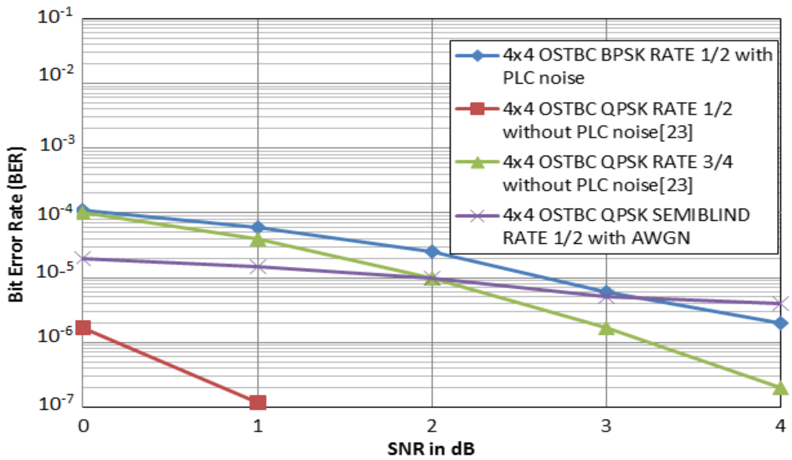

Figure16. BER performance comparison with 4x4 OSTBC in Rayleigh Fading channel, AWGN and interleaver

VII. Conclusion

In this paper, two channel models, the digital FIR filter and Multipath Rayleigh Fading Channel models were used to model the PLC channel and their BER performance were investigated. The FIR filter considered the weighting factors whereas the Rayleigh fading channel considered the path delays and path gains of the channel. The results obtained, showed that at high SNRs, the BER curve of the Rayleigh model follows closely that of the echo-based FIR filter model. Hence, in this respect the PLC channel can be modeled as a multipath channel with its paths having a Rayleigh distribution. Regarding the indoor PLC-MIMO system, it has been shown that compared to the SISO model, a 2x4 MIMO undergoes an improvement of 4.8 dB at BER of 10^{-2} and it improves by 1 dB compared to the 2x2 MIMO, indicating that the increase in number of receive antennas improves the BER performance. Upon comparing the code rates and varying the number of transmit and receive antennas, it is observed that there is a significant improvement of 5.5 dB of the 4x4 MIMO compared to the 3x3 MIMO at BER of 10^{-4} and the ½ rate coded system proves to be more remarkable than the ¾ rate coded system.

Comparing the 2x3 OSTBC rate 1 coded with 3x3 STBC rate 1 coded yields an improvement of 12 dB at BER OF 10^{-4}, due the effect of channel estimation and the use of orthogonal STBCs.The performance of the 4x4 OSTBC rate ½ coded with BPSK in a PLC channel corrupted with impulsive, narrowband and background noises is found to be close to that of the 4x4 OSTBC rate ¾ coded using QPSK modulation in the absence of PLC noise. The difficulties in the PLC channel have thus been overcome by increasing diversity, reducing code rate and using BPSK modulation at the expense of coding complexity and throughput.It is found that interleaving might be helpful to improve the performance of the proposed system in future works.

References

[1]. ALAMOUTI, S. (1998). A simple transmit diversity technique for wireless communications. *IEEE Journal on Selected Areas in Communications***16**, 1451-1458.

[2]. ARZBERGER, M., DOSTERT, K., WALDECK, T. & ZIMMERMANN, M. (1997). Fundamental Properties of the Low Voltage Power Distribution Grid. Proc. International Symposium on Power-Line Communications & Its Applications (ISPLC). Retrieved 15 February 2013 from http://www.isplc. org/docsearch/Proceedings/1997/pdf/0541_001.pdf

[3]. BERGER, L.T, PAGANI, A. P &.SCHNEIDER, D.M. (2013). *MIMO Power Line Communicatons. IEEE Communications Surveys & Tutorials* **17** (1), 106-124.

[4]. BERGER, L.T., SCHWAGER, A. & ESCUDERO-GARZAS, J.J. (2013). Power Line Communications for Smart Grid Applications. *Journal of Electrical & Computer Engineering*, 1-17.

[5]. BHATNAGAR, M., MATHUR, A. &. PANIGRAHI, B. (2014). PLC Performance Analysis Over Rayleigh Fading Channel Under Nakagami-m Additive Noise. *IEEE Communications Letters***18** (6), 909-912.

[6]. CELEBI, H.B. (2010). Noise & multipath characteristics of power line communication channels. *Graduate Theses & Dissertations, Florida.* Retrieved 13 February 2014 from http://scholarcommons .usf.edu/etd/1594/

[7]. CHOE, S. (2012). Multipath Channel Model for MIMO-based Broadband Power Line Communications. The First International Conference on Communications, *Computation, Networks & Technologies*, Korea, 25- 30.

[8]. CORTÉS, J.A., DÏEZ, L., CAÑETE, F.J. & SÁNCHEZ-MARTÍNEZ, J.J. (2010). Analysis of the Indoor Broadband Power-Line Noise Scenario. *IEEE Transactions on Electromagnetic Compatibility***52** (4), 849-858.

[9]. DUCHE, D. & GOGATE, V. (2014). Signal Attenuation in PowerLine Communication Channel. *International Journal of Emerging Trends & Technology in Computer Science***3** (2), 123-130.

[10]. FAMILUA, A.D. (2012). Error pattern/behavior of noise in in-house CENELEC A-B& PLC channel. *Power Line Communications & Its Applications (ISPLC)*, 114-119.

[11]. HENDRE, V.S. & MURUGAN, M. (2013). Performance of precoded orthogonal space time block code MIMO system for mobile WIMAX system. *Communications & Signal Processing (ICCSP), 2013 International Conference*, 5-8.

[12]. KUMAR, R. & SAXENA, R. (2014). Performance Analysis of MIMO-STBC Systems with Higher Coding Rate Using Adaptive Semiblind Channel Estimation Scheme. *The Scientific World Journal*.

[13]. LIU, E., GAO, Y., BILAL, O. & KORHONEN, T. (2005). Broadband Characterization of Indoor Powerline Channel & its capacity consideration. IEEE International Conference on Communications, 2005. *ICC 2005*, 901-905.

[14]. MATHUR, M. B. A. (2014). PLC Performance Analysis over Rayleigh Fading Channel under Nakagami-m Additive Noise. *IEEE Communications Letters***18** (12), 2101-2104.

[15]. MENG, H., GUAN, Y. & CHEN, S. (2005) Modelling & analysis of noise effects on broadband power-line communications. *IEEE Transactions on Power Delivery***20** (2), 630 - 637.

[16]. MLYNEK, P., MISUREC, J., KOUTNY, M. & SILHAVY, P. (2012). *Two-port Network Transfer Function for Power Line Topology Modelling. Radio Engineering* **21** (1), 356-363.

[17]. MOORE ANDREW. W. (2009). *Digital Communications 1*. Retrieved 22 January 2015 from https://www.cl.cam.ac.uk/teaching/0809/DigiCommI/dc1.pdf

[18]. PANDEY, K. & SAAD, M. (2014) .Modelling of indoor power line for home application using broadband. *International Journal of Enhanced Research in Science Technology & Engineering***3**(4), 173-178.

[19]. PAPAIOANNOU, A., D.PAPADOPOULOS, G. & PAVLIDOU, F.N. (2004). Performance of Space-time Block coding over the power line channel in comparison with the wireless channel. *8th International Symposium on Power-Line Communications & its Applications (ISPLC)*, 362-366.

[20]. RAJKUMARSINGH, B. & POONYE, N.S. (2014). Modelling of Power Line Communication Channel for Automatic Meter Reading System with LDPC codes. *GSTF Journal of Engineering Technology (JET)***3** (1), 61-68.

[21]. SANTUMON, S.D. & SUJATHA, B.R. (2012). Space-Time Block Coding (STBC) for Wireless Networks. *International Journal of Distributed & Parallel Systems (IJDPS)***3** (4), 183-195.

[22]. SINGH, V.P. (2012). Analysis of Power Line Communication Channel Model using Communication Techniques. *North Dakota*. Retrieved 20 October 2014 from http://library.ndsu.edu/tools/dspace/load /?file=/repository/bitstream/h&le/10365/22737/Varinder%20Pal%20Singh.pdf?sequence=1

[23]. TAN, B. & THOMPSON, J.S. (2012). Powerline Communications Channel Modelling Methodology Based on Statistical Features. Retrieved 22 October 2014 from https://arxiv.org/pdf/1203.3879.pdf

[24]. ZIMMERMANN, M. & DOSTERT, K. (1999) .A Multi-Path Signal Propagation Model for the Power Line Channel in the High Frequency Range. *Proceedings of the 3rd International Symposium on Power-Line Communications, Lancaster, UK*, 45-51.

[25]. ZIMMERMANN, M. & DOSTERT, K. (2000). An Analysis of the Broadband Noise Scenario in PowerLine Networks. *Proceedings of the International Symposium on Power Line Communications & Its Applications (ISPLC '00), Limerick, Ireland*, 131-138.

Bhimsen Rajkumarsingh,"Modeling of Power Line Communications for Indoor System Using MIMO coding scheme" International Journal of Engineering Science Invention(IJESI), vol. 6, no. 12, 2017, pp. 35-47.