Outage Probability Assessment of Power line Cooperative Communication (PLCC) System

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Abstract—*The requirement of high-speed data for various forms of application is increasing rapidly. Power Line communication (PLC), a technology which uses the existing power line network as a transmission medium, is a choice for this provision, owing to the ready presence of the medium. This channel (power line), is severely bewitched by noise and attenuation owing to the branches, length and the load connection on the line. Cooperative relaying, which transmits the same information through several nodes is deployed in this paper to combat the data outages caused by the channel's characteristics. Amplify-and-forward and decode-and-forward were the cooperative protocols deployed.The outage probability of each of the protocols were obtained, analysed and compared with the conventional direct link (without cooperation). Results shows that outage probability was drastically reduced on the cooperative links. The performances of the two cooperative links were close due to the noise mitigating circuit incorporated.This achievement in outage probability performance enhances the reliability of the PLC system.*

Keywords—Attenuation, channel response, cooperative relaying,transmitted power,outage probability.

I. INTRODUCTION

Power line communication (PLC) is a technology that implements the existing power line network, used for electric power provision, for broadband data transmission. The activity in PLC entails the transformation of the communication signal into a form that will enhance its transmission over the power line network. To achieve this activity, that is realizing communication via power line, requires basic PLC network elements. The two major elements are PLC modem and PLC base-station[1].The PLC modem is the interface between the subscriber's communication equipment and the power line medium while the PLC base-station provides a connection between the PLC access systems to its backbone network.

The power line poses a great deal of threat to data transmission on it, this is because of its topology nature. Therefore signal's transmission on it suffers from attenuation, multipath and noise effects. The choice of Orthogonal frequency division multiplexing (OFDM) as a modulation scheme solves some of the challenges of multipath and interference, but the challenges of the line branches, line mismatch and the length of the cable still persists.

Several techniques of mitigating the identified effects have been deployed ranging from use of repeaters to MIMO (within the wires of the cable) [2], [3], [4], [5], [6], but all of these techniques have one demerit or the other. Cost of deployment is a demerit in the use of repeaters while the presence of cross-talk among the wires is visible in MIMO. Noise in PLC is quite different from those of other communication technologies, it comprises of five (5) types, which can be grouped into two broad categories. These are background and impulsive noise, with impulsive noise having a power spectral density (PSD) greater than the background noise [7], [8].

In this paper, a model of the power line channel is adopted to compare the performance of a noiseless relay cooperated channel and a direct channel for achieving reliability in PLC. Forward error codes (FEC) techniques was proposed, combination of Reed-Solomon and Convolutional codes, for the noise mitigation. After this activity, two cooperative protocols, amplify-and-forward and decode-and-forward, were investigated on the noiseless channel. The performance of the system was evaluated using outage probability analysis of the three (3) transmission links. The remainder of the paper is arranged as follows; section 1 consist of the description of the system model, where in the set-up was presented. The PLC channel and noise description were described in section 2. Description of the PLC channel model and its noise characteristic is presented in section 3. In section 4, the proposed channel coding technique for noise mitigation was presented. Section 5 has the noise mitigation unit's simulation and result of the system. The PLC cooperative network system's descriptionwas presented in section 6. The formulation of the outage probability for each of the links was described in section 7. Section 8 contains the simulation process and result presentation and the paper was concluded in section 9.

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II. SYSTEM MODEL

The schematic diagram of the proposed system and its model are shown in Fig. 1 and 2. From Fig.2, the system model consists of three segments, the source, the relay and the destination segments. The source modem is a PLC base-station, which serves as the source of the information to be transmitter, this segment is depicted as an OFDM transmitter with noise mitigation system. The relay is both an OFDM receiver and transmitter with noise mitigation, while the destination modem is represented as an OFDM receiver. Each of these propagates its signal through the power line channel. The cooperative transmission protocol (CTP) is the process of cooperation that the relay passes her signal through before routing it to the destination, the types considered are amplify and forward and decode and forward. For the purpose of discussion, the system model is categorized into two sections, the noise mitigation and the cooperative sections.

III. PLC CHANNEL AND NOISE SCENARIO

The power line channel is modelled following bottom-up or top-down approaches. In most researches, the topdown approach is adopted for the power line channel. Philip's echo model and Zimmermann &Doestat model are the prominent of this approach [9], [10]. These models presents a transfer function for the power line channel. The obtained model's transfer function is as presented in (1), where g_i is a factor used for describing weight of the individual's path. It is also a product of transmission and reflection factors over a path length of d_i (i is the path's number).

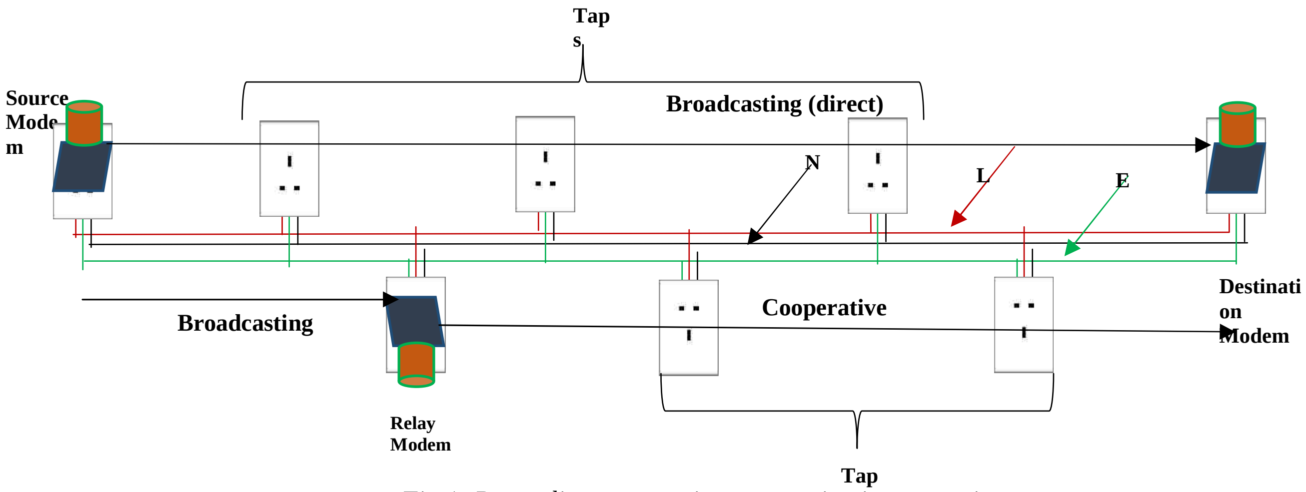

Fig.1: Power line cooperative communication scenario

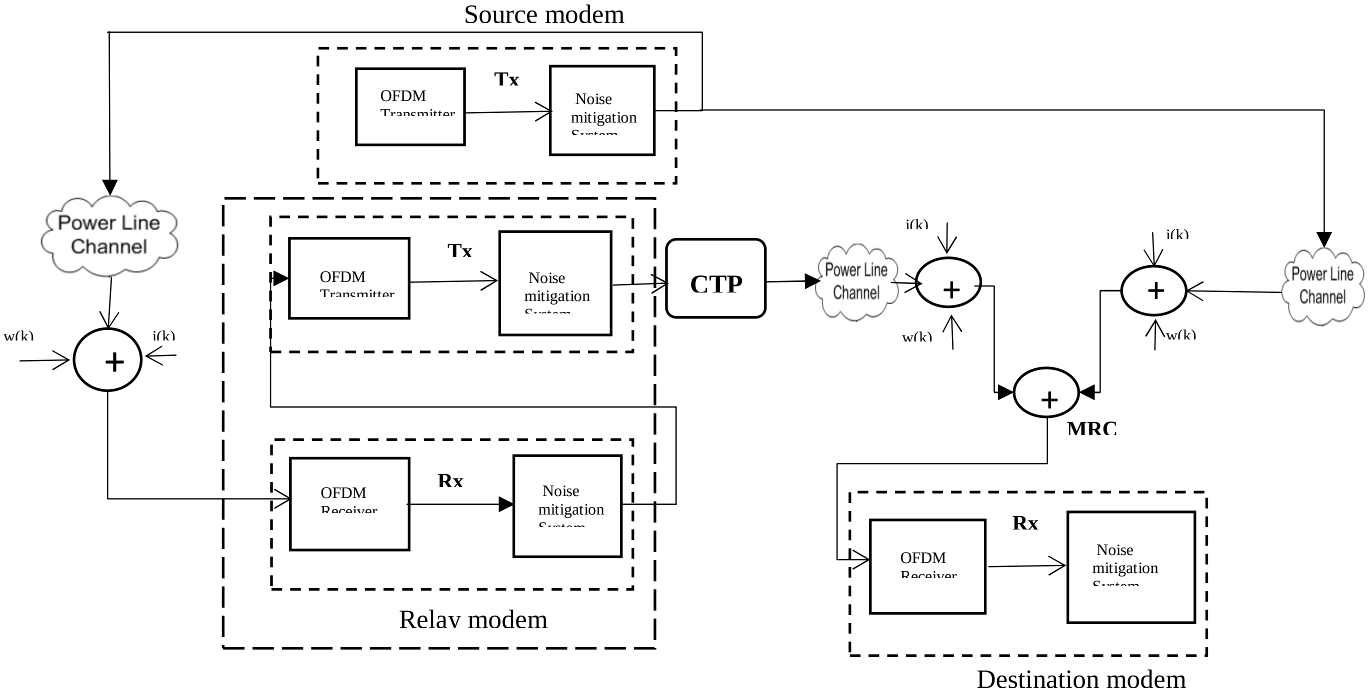

Fig.2: Cooperative Power Line Communication System Model

The knowledge of g_i and d_i is necessary for the determination of the input channel responses.

$$H(f) = \sum_{i=1}^{N} g_i \,.\, e^{-\left(\alpha_o+\alpha_1 f^k\right).d_i} \,.\, e^{-j2\pi f \frac{d_i}{v_p}} \tag{1}$$

The first exponential presents the attenuation factor while the second exponential is a description of the echo scenario. The factor $v_p$is the signal's propagation speed. Parameters α_o, α_1 and $k$are used to model the attenuation factor. These parameters α_o (offset attenuation), α_1 (increase of attenuation) and k (exponent of attenuation) are obtained from measurements of the magnitude of the frequency response. Channel modelling of the power line network has revealed that signals propagated over power line are liable to distortion owing to cable losses and multipath propagations. The term N defines the number of taps (branches) of the line being considered.

The characteristic of noise in PLC is quite different from those of other conventional communication systems. Therefore, the impediment suffered by signals as they propagate in the frequency range up to 30 MHz over the power line network is enormous. The noise in PLC can be classified into five categories [11]. They are coloured background noise, Narrow-band noise, Periodic Impulsive Noise Asynchronous to the Mains Frequency, Periodic Impulsive Noise Synchronous to the Mains Frequency and Asynchronous impulsive noise. The first three are cyclostationary, that is stationary at over long period of time, they are all considered as background noise [11], which is often represented as additive white Gaussian noise (AWGN). The last two types, being time-varying are called impulsive noise. Impulsive noise in PLC can be modelled by using Middleton's class A noise model, represented as:

$$i_k = b_k g_k \tag{2}$$

where b_k is the Poisson process designating the arrival of impulsive noise and g_k is the white Gaussian process with zero mean and variance, σ_w^2. Impulsive noise are transient characterized uniformly distributed disturbances over the useful transmission system passband. They can be caused by voltage spikes in equipment, voltage changes on adjacent pairs in a copper cable, tones generated for network signalling, maintenance and test procedures, lightning flashes during thunderstorms, and a wide variety of other phenomena. The probability density function of the impulsive noise is as described in (3)

$$f_X(x) = e^{-A} \sum_{m=0}^{\infty} \frac{A^m}{m\iota\sqrt{2\pi\sigma_m^2}} e^{\frac{-x^2}{2\sigma_m^2}} \tag{3}$$

$$\sigma_m^2 = \frac{m/A + \Gamma}{1+\Gamma}, \quad \Gamma = \sigma_g^2 / \sigma_i^2$$

σ_g^2 is the Gaussian noise power, σ_i^2 is the Impulsive noise power and A ≤1 is density of pulses regarded as impulsive index, which is defined as, $A = \frac{\eta\tau}{T_o}$, η =number of pulses, τ= length of pulses, T_o = 1 Sec.

IV. REED-SOLOMON AND CONVOLUTIONAL CODES

In channel coding, redundant information are added to data for the purpose of reliable recovery of the data even if there were errors while transmitting, storing or retrieving the data. This redundant information (bits) are called Error correcting codes (ECC). Reed-Solomon codes is one of such ECC. Reed-Solomon code is an example of algebraic codes. The Reed-Solomon encoder adds extra redundant bits to a block of digital data. That is, parity symbol is added to a k symbols data with s bits each to achieve n symbols codeword by the encoder, thus a parity of n-k symbols of s bits each is obtained. Both encoding and decoding is based on specified mathematics area of Galois fields or finite fields. Reed-Solomon codes are good for solving burst errors. Convolutional encoding usually goes with viterbi decoding. Two parameters are usually used in describing convolutional codes, the code rate and the constraints length. The ratio of the number of bits, k, into the encoder to the number of channel symbols, n, at the output of the encoder, k/n is called the code rate. The length of the encoder, denoted as K, is the constraint length parameter. Another parameter of the convolutional code is the number of cycles that the data goes through, m, it is the number of memory order introduced. The convolutional encoding with viterbi decoding is particularly suited for additive white Gaussian noise bewitched channel.

V. PLC Noise Mitigated System and Simulation

The proposed PLC noise mitigated system model is shown in Fig. 3. On the transmitter side, the random sequence of bits passes through two series of encoding. The first uses the RS codes while the second implements convolutional codes at different code rates for different scenarios. This is done to further achieve serenity in the channel. The encoded bits were interleaved using random interleaver to achieve a further mitigation against the

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busty impulsive noise in the power line channel. Mapping was then done using QAM before modulation using inverse discrete Fourier transform (IDFT).

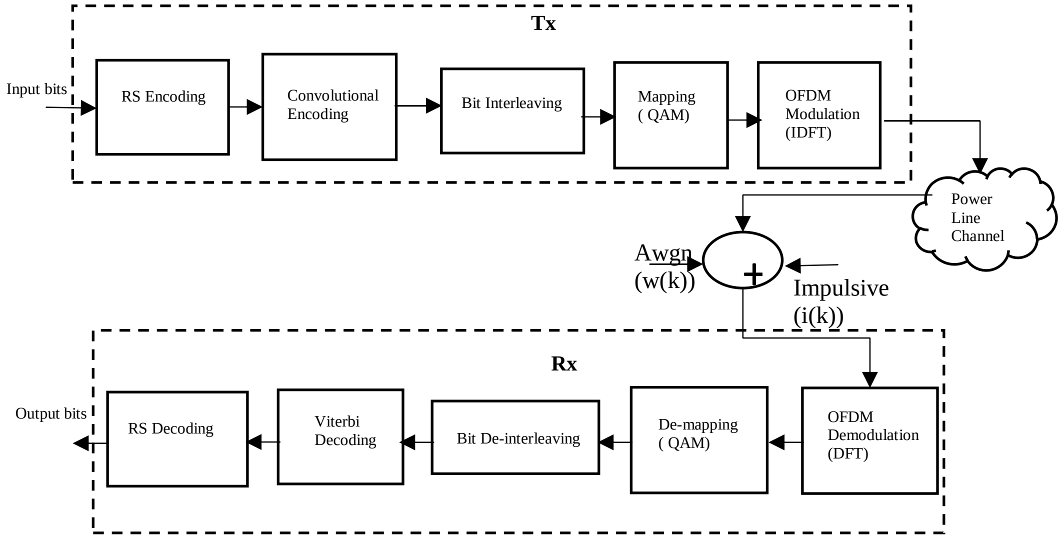

Fig.3: Noise mitigation system model

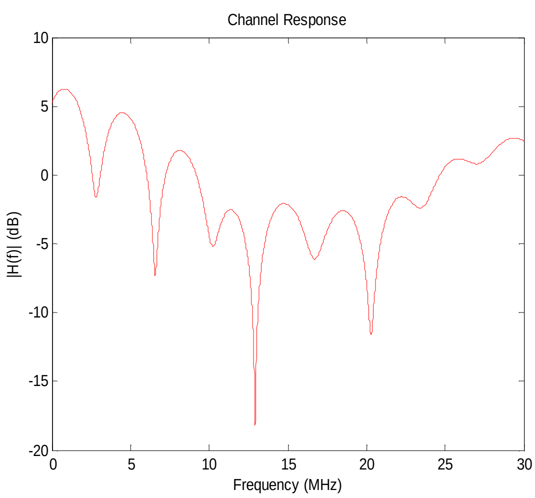

Fig.4: Power line channel response

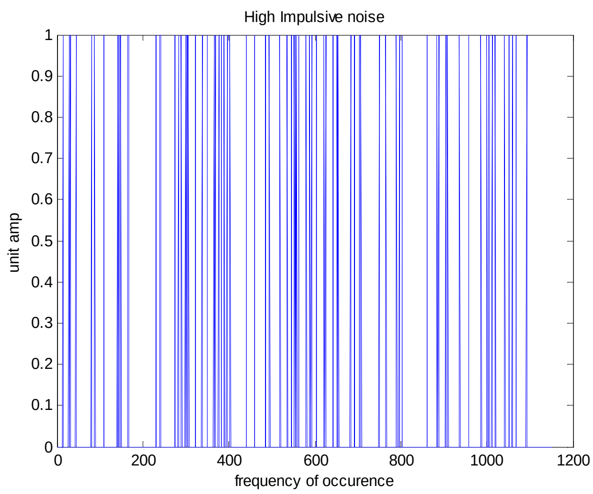

Fig. 5: High impulsive noise

In the receiver the opposite of the processes in the transmitter is carried out, namely; demodulation by means of discrete Fourier transform (DFT), de-mapping (QAM), de-interleaving, viterbi decoding and RS decoding.

The system model shown in Fig. 3 was simulated for the study of the systems' BER performance. The power line channel was simulated following (1). N, number of taps was fixed at 8, a_0 = 0, a_1 =1.6 x 10^{-10} and k =1. Other parameters, d_i and g_i were generated randomly following the number of taps and the length of the line (20 m). As stated earlier, noise in PLC is a combination of AWGN and impulsive noise, hence the impulsive noise simulated is a high one with A= 0.001. Fig. 4 and 5 shows the channel response of the simulated network and the impulsive noise. Reed-Solomon encoding was done at n = 64 and k = 48. The convolutional code rates of ½ was implemented for a 16-QAM modulation scheme. The generator polynomials (10101011, 10000101) was implemented in the encoder with a constraints of k = 8. The duo of the transmitter and the receiver uses 256 subcarriers to perform IFFT and FFT respectively with an OFDM symbol of 10. A cyclic prefix of 64 was inserted. The OFDM signal was passed through the power line channel described by the channel response in (1) over a frequency of 0-30 MHz. Impulsive noise is assumed to arrive in a Poisson distribution while the background noise is assumed to be Gaussian. Hence the total noise in the power line communication is a sum of impulsive and background noise, it was added to the OFDM signal. The OFDM in the receiver is demodulated by DFT, demapped respectively (QAM) and de-interleaved. After de-interleaving, the signal was viterbi decoded at different traceback depths of 4*k* = 32, 5*k* = 40 and 12*k* = 96 respectively.

The BER performance of the noise mitigation system was plotted on Fig.6. Three different curves was presented on the chart; PL channel with noise mitigated, AWGN channel with noise mitigated and PL channel with unmitigated noise. An observation of the curve shows generally that our model achieves a significant improvement in the performance of the system over the channel and in the face of the noise.

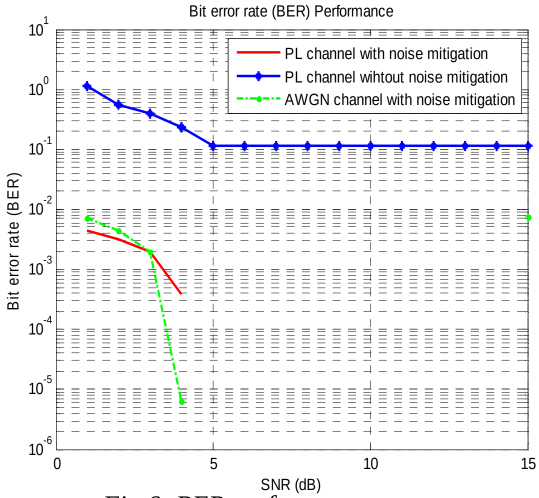

Fig.6: BER performance curve

For instance, at 3 dB SNR, Table 1 shows the number of bits that will be error when 1000 bits are transmitted. At SNR's above 5 dB, no bit will be in error throughout the transmission for both AWGN and PL channel with noise mitigation while the error persists on the channel without mitigation.

VI. PLC COOPERATIVE NETWORK SYSTEM

A typical PLC cooperative system is as shown in Fig. 1. Just as in cooperative activity in wireless systems, the source and the relay node transmits P_1 and P_2 powers respectively at both transmissions scenarios. The two transmission scenarios are broadcasting (direct) and cooperative as depicted in Fig. 1.

Table 1: Bits in error at 3 dB SNR

Channels	No of bits in error at SNR = 3 dB
PL with noise mitigation	2
PL without noise mitigation	40
AWGN with noise mitigation	2

During the first transmission (broadcasting) with an OFDM of symbol length, N, and cyclic prefix (CP) of length $l_{cp} \geq \max(l_{sd}, l_{sr}, l_{rd})$, the received signals at both the PLC destination and relay nodes is as shown in (11) & (12), while (13) describes the noise components.

$$y_{sr}^{pl} = \sqrt{\frac{P_1}{N}} h_{sr}^{pl} x + n_{sr}^{pl} \qquad (5)$$

$$y_{sd}^{pl} = \sqrt{\frac{P_1}{N}} h_{sd}^{pl} x + n_{sd}^{pl} \qquad (6)$$

$n_{sr}^{pl} = w_{sr} + i_{sr}$ and $n_{sd}^{pl} = w_{sd} + i_{sd}$ [12]

Where $P_1 = P/2$ (half of the source transmit power) is the power used for transmission during the first transmission phase and n_{sr}^{pl} and n_{sd}^{pl} are the noise at the source-destination and source-relay PL channels respectively. n_{sd}^{pl} n_{sr}^{pl} are constituted of coloured background noise and impulsive noise. *w* represents the coloured background noise and *i*, impulsive noise.

h_{sd}^{pl} and h_{sr}^{pl} are multipath channel between source-destination and source-relay paths respectively. These channels are modelled as depicted in (1).

In the cooperative transmission, the PLC relay modem processes the received signal as prescribed by the adopted cooperative protocol, then forwards it through its channel to the PLC destination nodes. The signal received at the destination node at this second transmission is given as

$$y_{rd}^{pl} = \sqrt{\frac{P_2}{N}} h_{rd}^{pl} q(y_{sr}^{pl}) + n_{rd}^{pl} \qquad (7)$$

$$n_{rd}^{pl} = w_{rd} + i_{rd} \qquad (8)$$

$P_2 = P/2$ is the transmitted power at the PLC relay node during the cooperation phase and *q* represents the cooperative protocol deployed.

Let $\sqrt{\frac{P_1}{N}} = \sqrt{P_1^t}$ and $\sqrt{\frac{P_2}{N}} = \sqrt{P_2^t}$

a. PLC Amplify-and Forward Cooperation

This process in the PLC is similar to the one described in wireless communication system, except for the channel and the inherent noise. The signal received at both the destination and the relay nodes in the broadcasting phase is as described in (11) and (12). The relay received signal is made stronger by a factor β^{pl} [13]

$$\beta^{pl} = \frac{\sqrt{P_2^{\iota}}}{\sqrt{P_1^{\iota}\left|h_{sr}^{pl}\right|^2 + N_X}} \quad (9)$$

$$N_X = N_W + N_i \quad (10)$$

$$10\log_{10} N_w = N_0 + N_1 . e^{-\frac{f}{f_1}} \text{(dBmW/ Hz)} \quad (11)$$

Where N_X is the noise PSD in the power line channel a sum of the PSD's in the AWGN and the impulsive noises. The amplified signal is then transmitted to destination in the second transmission phase (cooperative). The signal received at the destination during this transmission will be;

$$y_{rd}^{pl} = \beta^{pl} h_{rd}^{pl} y_{sr}^{pl} + n_{rd}^{pl} \text{ and } n_{rd}^{pl} = w_{rd} + i_{rd} \quad (12)$$

$$y_{rd}^{pl} = \frac{\sqrt{P_1^{\iota} P_2^{\iota}}}{\sqrt{P_1^{\iota}\left|h_{sr}^{pl}\right|^2 + N_x}} h_{rd}^{pl} h_{sr}^{pl} x + n_{rd}^{pl^i} \quad (13)$$

$$n_{rd}^{pl^i} = \frac{\sqrt{P_2^{\iota}}}{\sqrt{P_1^{\iota}\left|h_{sr}^{pl}\right|^2 + N_x}} h_{rd}^{pl} n_{sr}^{pl} + n_{rd}^{pl} \quad (14)$$

Where n_{rd}^{pl} is the noise in the power line channel from the relay to the destination and h_{rd}^{pl} is the power line channel coefficient between relay and destination modem. The destination node will then combine the two signals, y_{sd}^{pl} and y_{rd}^{pl} following the chosen combining technique. Although this protocol has a drawback of amplifying noise along with signal, which can be unhealthy for power line communication, mitigating the noise before amplification will present a better performance.

$$Y_{out}^{AF} = y_{sr}^{pl} + y_{rd}^{pl} = \sqrt{P_1^{\iota}} h_{sr}^{pl} x + n_{sr}^{pl} + \frac{\sqrt{P_1^{\iota} P_2^{\iota}}}{\sqrt{P_1^{\iota}\left|h_{sr}^{pl}\right|^2 + N_X}} h_{rd}^{pl} h_{sr}^{pl} x + \frac{\sqrt{P_2^{\iota}}}{\sqrt{P_1^{\iota}\left|h_{sr}^{pl}\right|^2 + N_X}} h_{rd}^{pl} n_{sr}^{pl} + n_{rd}^{pl} \quad (15)$$

6.2 PLC Decode and Forward Cooperation

Noise in this protocol is as described in PLC amplify and forward. After decoding and encoding at the PLC relay node, the signal is re-transmitted to the destination through the channel with coefficient h_{rd}^{pl}. The signal could be correctly or wrongfully decoded. The signal received at the destination will be given as:

$$y_{rd}^{pl} = \sqrt{\beta_2^{pl}} h_{rd}^{pl} x + n_{rd}^{pl} \quad (16)$$

Where $\beta_2^{pl} = P_2^{\iota}$ if relay correctly decodes the transmitted signal and $\beta_2^{pl} = 0$ if otherwise. h_{rd}^{pl} and n_{rd}^{pl} are modelled as in PLC amplify and forward. The output at the destination for decode and forward for correct decoding, is as represented in (17)

$$Y_{out}^{DF} = \sqrt{P_1^{\iota}} h_{sr}^{pl} x + n_{sr}^{pl} + \sqrt{P_2^{\iota}} h_{rd}^{pl} x + n_{rd}^{pl} \quad (17)$$

Since the noise characteristics of the channels are same, it is assumed that,

$n_{sd}^{pl} = n_{sr}^{pl} = n_{rd}^{pl}$ and the noise PSD's of the channels are also same,

$N_{sd}^{pl} = N_{sr}^{pl} = N_{rd}^{pl} = N_X$

The two signals at both transmission phases are summed at the destination using maximum ratio combining (MRC) technique. Maximum Ratio Combining *(MRC)* assumes that the receiver knows perfectly the channel's phase shift and attenuations. Each input signal is then multiplied by its corresponding conjugated channel gain. The output of an MRC is defined in (18):

$$y_d[n] = h_{s,d}^{*}[n]\, y_{s,d}[n] + h_{r,d}^{*}[n]\, y_{r,d}[n] \quad (18)$$

where h_{sd}^{*} is the conjugate of the source-destination channel gain and h_{rd}^{*}, the relay-destination channel gain's conjugate. Eqns. (19) and (20) are the destination's output for both cooperation protocols.

$$Y_{out}^{MRCAF} = \left(\sqrt{P_1^{\iota}}\left|h_{sd}^{pl}\right|^2 + \frac{\sqrt{P_1^{\iota} P_2^{\iota}}}{\sqrt{P_1^{\iota}\left|h_{sr}^{pl}\right|^2 + N_X}} \left|h_{rd}^{pl}\right|^2 \left|h_{sr}^{pl}\right|^2 \right) x + \left(h_{sd}^{pl} n_{sd}^{pl} + \frac{\sqrt{P_2^{\iota}}}{\sqrt{P_1^{\iota}\left|h_{sr}^{pl}\right|^2 + N_X}} h_{rd}^{pl} n_{sr}^{pl} + h_{rd}^{pl} n_{rd}^{pl} \right) \quad (19)$$

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$$Y_{out}^{MRCDF} = \left(\sqrt{P_1^{\iota}} \left| h_{sd}^{pl} \right|^2 + \sqrt{P_2^{\iota}} \left| h_{rd}^{pl} \right|^2 \right) x + \left(\left| h_{sd}^{pl} \right|^2 n_{sd}^{pl} + \left| h_{rd}^{pl} \right|^2 n_{rd}^{pl} \right) \quad (20)$$

Having applied MRC at the destination, the resultant SNRs' in all the subcarriers for both cooperative protocols are expressed in (21) and (22) respectively and (23) described the SNR for the direct conventional link (without cooperation). $\lambda_{AF}^{pl} = \lambda_{sd}^{pl} + \lambda_{srd}^{pl} = \frac{A^2}{B}$

(21)

$$A = \left(\sqrt{P_1^{\iota}} \left| h_{sd}^{pl} \right|^2 + \frac{\sqrt{P_1^{\iota} P_2^{\iota}}}{\sqrt{P_1^{\iota} \left| h_{sr}^{pl} \right|^2 + N_x}} \left| h_{rd}^{pl} \right|^2 \left| h_{sr}^{pl} \right|^2 \right)$$ and

$$B = \left| h_{sd}^{pl} \right|^2 + \left| h_{rd}^{pl} \right|^2 \left(\frac{\sqrt{P_2^{\iota}}}{\sqrt{P_1^{\iota} \left| h_{sr}^{pl} \right|^2 + N_x}} + 1 \right)$$

$$\lambda_{DF}^{pl} = \lambda_{sd}^{pl} + \lambda_{rd}^{pl} = \frac{\left(\sqrt{P_1^{\iota}} \left| h_{sd}^{pl} \right|^2 + \sqrt{P_2^{\iota}} \left| h_{rd}^{pl} \right|^2 \right)^2}{\left(\left| h_{sd}^{pl} \right|^2 + \left| h_{rd}^{pl} \right|^2 \right)} \quad (22)$$

$$\lambda_D^{pl} = \lambda_{sd}^{pl} = \frac{\sqrt{P_1^{\iota}} \left| h_{sd}^{pl} \right|^2}{N_x} \quad (23)$$

VII. OUTAGE PROBABILITY ANALYSIS

Outage probability is defined as the probability that the instantaneous error rate exceeds a specified value or equivalently that the (instantaneous) combined signal-to-noise ratio (SNR), falls below a certain specified threshold,[14]:

$$P_{out} = P\left[0 \le \lambda_t \le \lambda_{th}\right] = \int_0^{\lambda_{th}} P_{\lambda_t}\left(\lambda_t\right) d\lambda_t \quad (24)$$

where $P_{\lambda_t}\left(\lambda_t\right)$ is the probability density function (pdf) of λ_t.

Therefore, cumulative distribution function (cdf) of λ_t obtained at λ_{th} is P_{out}. An approach to finding the outage probability, according to [15], is to first find the pdf of λ_t and then integrate over that pdf as in (24).

Therefore, the whole communication system is in outage state when the maximum average mutual information, $I_D < R$,where R is the spectral efficiency. In information theory, I_D depends on the instantaneous SNR, λ_u^{pl} $(u \in AF, DF, D)$, of the MRC combined *signal at the destination.*The outage probability of the source node is

$P_{out} = \Pr\{\lambda_u^{pl} < \lambda_{th}^{pl}\}$, $(u \in AF, DF, D)$

where λ_{th}^{pl} is the threshold decided by *R*.

The outage probability for the amplify-and-forward link can be derived using [16] as:

$$P_{out\_AF} = \Pr\{\lambda_{AF}^{pl} < \lambda_{th}^{pl}\} = \Pr\{\lambda_{AF}^{pl} < \lambda_{th\_AF}^{pl}\}$$
$$= \int_0^{\lambda_{th\_AF}^{pl}} P_{\lambda_{AF}^{pl}}(\lambda_1) \int_0^{\lambda_{th\_AF}^{pl} - \lambda_1} P_{\lambda_{sd}^{pl}}(\lambda_2) d\lambda_2 d\lambda_1$$
$$= \int_0^{\lambda_{th\_AF}^{pl}} P_{\lambda_{AF}^{pl}}(\lambda_1) P_{\lambda_{sd}^{pl}}(\lambda_{th\_AF}^{pl} - \lambda_1) d\lambda_1 \quad (25)$$

where $P_{\lambda_{AF}^{pl}}(c)$ represents the PDF of the amplify-and-forward path SNR described in (21).

The outage probability for the decode-and-forward cooperation is described as:

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$$P_{out\_DF} = \Pr\{\lambda_{DF}^{pl} < \lambda_{th}^{pl}\} = \Pr\{\lambda_{DF}^{pl} < \lambda_{th\_DF}^{pl}\}$$

$$= P_{\lambda_{sr}^{pl}}(\lambda_{th\_DF}^{pl}) + [1 - P_{\lambda_{sr}^{pl}}(\lambda_{th\_DF}^{pl})] \times \int_0^{\lambda_{th\_DF}^{pl}} P_{\lambda_{sd}^{pl}}(\lambda_1) \int_0^{\lambda_{th\_DF}^{pl} - \lambda_1} P_{\lambda_{rd}^{pl}}(\lambda_2) d\lambda_2 d\lambda_1 \quad (26)$$

$$= P_{\lambda_{sr}^{pl}}(\lambda_{th\_DF}^{pl}) + [1 - P_{\lambda_{sr}^{pl}}(\lambda_{th\_DF}^{pl})] \times \int_0^{\lambda_{th\_DF}^{pl}} P_{\lambda_{sd}^{pl}}(\lambda_1) P_{\lambda_{rd}^{pl}}(\lambda_{th\_DF}^{pl} - \lambda_1) d\lambda_1$$

In the case of the direct link, the outage probability is described as:

$$P_{out\_D} = \Pr\{\lambda_D^{pl} < \lambda_{th}^{pl}\} = \Pr\{\lambda_D^{pl} < \lambda_{th\_D}^{pl}\}$$

$$\int_0^{\lambda_{th\_D}^{pl}} P_{\lambda_{sd}^{pl}}(\lambda_1) d\lambda_1 \quad (27)$$

VIII. SIMULATION AND RESULTS

The three relay locations are, 10 m away from source, mid-way between source and destination nodes (20 m away from source) and 30 m away from source node. All relay placements have four taps between it and source. The direct link (source to destination) has eight (8) taps in all and a length of 40 m. The various channel responses of the relay location scenarios and direct link on the power line channel are shown on Fig. 7. The channel gains were defined for all the channels. As stated earlier the modulation scheme deployed is the QAM-16, therefore M was set at 16 (2^4). During the broadcasting phase, $P_1 = P/2$ was used while the other half is used for the cooperation phase, hence, $P = P_1 + P_2$. In conformity with electromagnetic compatibility requirement, P was chosen for 12.5 *dBmW*. OFDM parameters as in the noise mitigation simulation were maintained. The noise PSD N_x, a sum of AWGN and impulsive noises were appropriately defined, taken, N_o = -125, N_1= 35 and f_1 = 3.6. The spectral efficiency was set at $R = 1$ *b/s/Hz*, while the threshold SNRis $\lambda_{th}^{pl} = \lambda_{th\_AF}^{pl} = \lambda_{th\_DF}^{pl} = \lambda_{th\_D}^{pl} = 2^{2R} - 1$. The power of 2 is for the bi transmission scheme of the system.

The outage probability formulations for the three links (AF, DF and D), using (25), (26) and (27) were simulated for performance investigation. The performances of the three links for the three relay location scenario is presented on Fig.8. Results extracted from the three plots, for the three relay placement is shown in Table 2. From the Table, the mid-way (20 m away from source node) relay location out-perform the other relay location configurations. The table reveals that increase in SNR resulted in further reduction in the probability of outage, this is the case for all schemes. In the amplify-and-forward link, the 10 m away relay location seems to achieve a better performance than the 20 m away location, the difference in performance is very negligible, while in the decode-and-forward, the 20 m away location achieved the best outage performance. Both cooperative links presents an outstanding performance in contrast to the direct (conventional) link. The performances of both cooperative links is close due to the mitigation system incorporated. For example, at 5 dB SNR, the probability of outage on the PLC direct link is 10.4 %, while for amplify-and-forward and decode-and-forward are 0.007 % and 0.0005 % respectively.The best result was achieved with the decode-and-forward cooperation in the PLC system, but the amplify-and-forward also achieved an appreciable performnance.

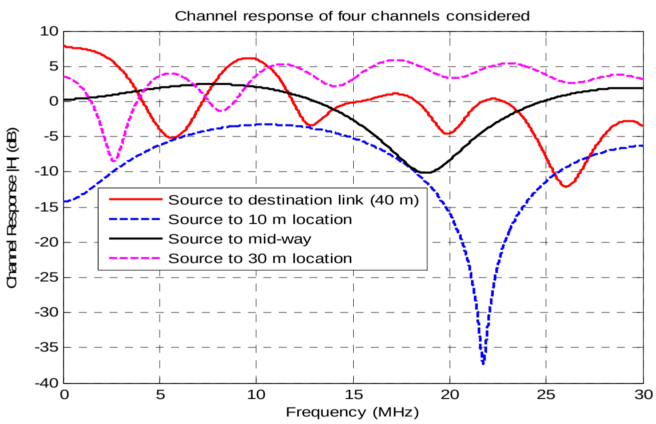

Fig.7: Relay locations channel responses

Table 2: Outage probability performance

SNR (dB)	Direct Link			Amplify-and-forward			Decode-and-forward		
	10 m away	Mid-way (20 m away)	30 m away	10 m away	Mid-way (20 m away)	30 m away	10 m away	Mid-way (20 m away)	30 m away
1	0.7924	0.1566	0.9096	7.800e-5	7.957e-5	8.876e-5	1.715e-5	8.819e-6	2.451e-5
5	0.2882	0.1044	0.3841	7.389e-5	7.505e-5	8.351-5	1.456e-5	6.950e-6	2.059e-5
10	0.1156	0.0595	0.1885	6.707-5	7.043e-5	7.711e-5	1.202e-5	5.841e-6	1.683e-5
15	0.0637	0.0436	0.0604	5.777e-5	6.521e-5	7.062e-5	1.011e-5	4.807e-6	1.368e-5
20	0.0378	0.0242	0.0461	5.115e-5	5.368e-5	6.666e-5	7.640e-6	3.857e-6	1.162e-5
25	0.0229	0.0179	0.0245	3.964e-5	4.605e-5	5.886e-5	5.407e-6	3.151e-6	9.153e-6
30	0.0127	0.0078	0.0086	2.929-5	3.949e-5	4.834e-5	3.982e-6	2.378e-6	7.081e-6
35	0.0062	0.0023	0.0048	1.835e-5	2.293e-5	3.840e-5	2.717e-6	1.705e-6	5.149e-6
40	2.699e-3	9.473e-4	0.0017	9.677e-6	1.005e-5	2.301e-5	1.785e-6	1.081e-6	3.354e-6
45	7.404e-4	1.090e-4	1.428e-3	2.411e-6	1.751e-6	1.37e-5	8.390e-7	3.983e-7	1.482e-6
50	3.952e-7	3.819e-7	9.326e-8	2.828e-9	4.4e-9	2.410e-6	1.182e-7	4.731e-8	2.381e-7

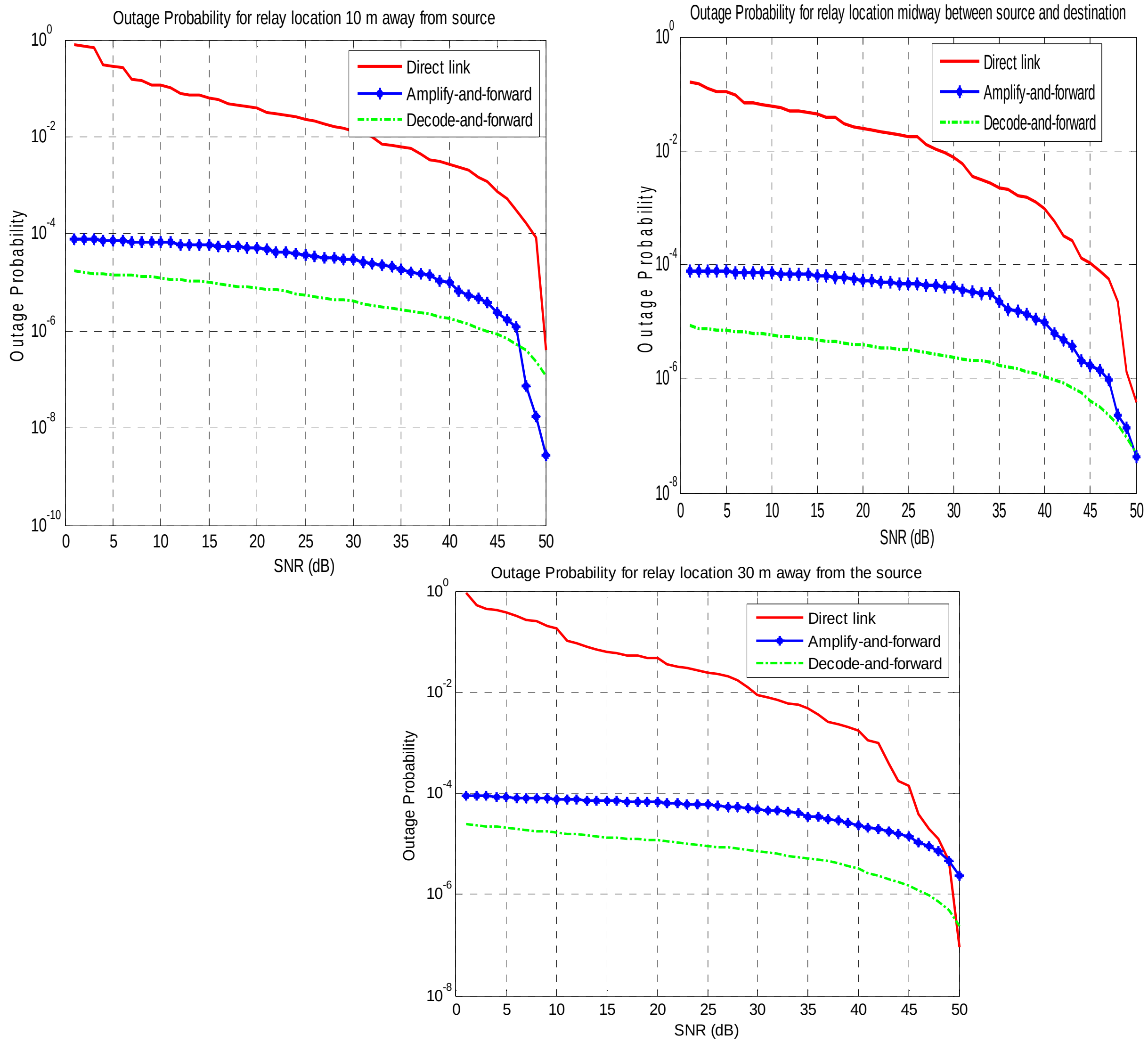

Fig.8: Outage probability performance

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IX. CONCLUSION

In this paper, the outage probability of a power line cooperative system is studied. This outage probability was analysed over frequency-selective PLC channel, embellished with cooperative relaying. The outage probability of the cooperative links and the conventional direct link were computed. With the signal attenuation model, the cooperative links of the PLC system was compared with the direct link (conventional) PLC. Results shows that both cooperative links provides drastic reduction in the probability of outage in the PLC system than the direct link PLC, the decode-and-forward yielding the best outage probability performance. The noise mitigation system incorporated yielded a close performance of the two cooperative transmission protocols. Relay location study reveals that a midway (centre) location between source and destination nodes presents the best outage probability performance. This achievement in outage probability results in the reliability of the PLC system.

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