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Performance Assessment of Broadband over Powerline Cooperative System

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Abstract

The ubiquitous nature of the power line network presents broadband over powerline as the choice technology for this telecommunication generation. Its inherent challenges are a major drawback on its acceptability and deployment. Noise, attenuation and multipath are the major challenges of this system. In this paper, cooperative relaying was deployed to better the reliability of the system. The noise component was mitigatedbefore applying the cooperative protocols of amplify-and-forward (AF) and decode-and-forward (DF). This noise mitigation system improves the bit error rate performance of the system. The effect cooperative relayingon the performance of the broadband over powerline system was investigated. The performance metrics of the investigation are, channel capacity, symbol error rate (SER) and outage probability. The channel capacity of both cooperative links (AF & DF) yields enormous increase as compared to the direct link. A drastic reduction was achieved in symbol error rate while probability of outages was forced down on the links with cooperation, thus achieving the systems reliability. The DF cooperation protocol out performs the AF, while the noise mitigation system, brought the SER and outage probability of both protocols close. The relay located midway between the source and destination nodes renders the most improved performance. Hence, the cooperative relaying in broadband over powerline achieved some level of reliability.

Keywords*: Amplify-and-forward, channel capacity, decode-and-forward, symbol error rate, and outage probability*

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I. Introduction

Great deal of attention and exploration has been channelled towards the implementation of electric power lines for broadband transmission. The use of the existing and widespread power distribution network presents the broadband over powerline (BPL) as the choice for the provision of broadband services and networking in the home front.

The activity in BPL entails the transformation of the communication signal into a form that will enhance its transmission over the power line network. BPL network elements prepare and converts signals for the purpose of propagating it over the power line with good reception. Every BPL network is composed of two major devices [1]. This includes; BPL modem and BPL base-station.

The BPL modem is the interface between the subscriber's communication equipment and the power line medium, it provides connection. It connects the subscriber's equipment to the power grid following a specific coupling technique that has the advantage of feeding and receiving high-speed data on the power line network. It performs the functions the physical layer (modulation and coding), data-link layer (medium access control) and logical link control.

The BPL base-station provides a connection between the BPL access systems to its backbone network. The BPL base-station is responsible for the control operation of the BPL access network, this it does in a distributed manner.

The power line channel poses some technical challenges to broadband activities because it was originally meant for AC power distribution a 50/60 Hz respectively. Therefore, high speed broadband propagated over it is degraded significantly in form of attenuation. This attenuation is proportionate to the length of the cable [2]. As points branches from the power line network, further attenuations results. Therefore, the more the number of branches on the power line, the more the attenuation that will be experienced. Multipath is another impediment in the power line network. This is as a result of the mismatch that the line characteristic impedance experiences at the load end [3]. Thus, the power line channel can be considered as a harsh channel. This kind of channel requires a transmission scheme that can withstand this unfavourable condition. Orthogonal frequency division multiplexing (OFDM), a multicarrier modulation scheme, having robust response to multipath, selective fading and different kinds of interference, is the choice for PLC systems.

Several techniques have been deployed ranging from use of repeaters to MIMO (multiple input multiple utput) (within the wires of the cable) [4], [5], [6], [7], [8], 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.

Another pitfall in the PLC is the noise. There is peculiarity in the PLC noise issue in contrast to other communication media. It comprises of five different types of noise. These five noise in PLC can be categorised as background noise (AGWN) and impulsive noise, with impulsive noise having a power spectral density (PSD) greater than the background noise [9], [10]. In this paper, a model of the power line channel, power line cooperative system 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 were 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. Symbol error rate, outage probability and the channel capacity were the performance metrics used for evaluating the performance of the proposed system, while the direct line is reference.

II. System Model

The system model shown in Fig. 1, consists of three segments, the source, the relay and the destination segments. The source modem is a BPL base-station, which serves as the source of the information to be transmitted, 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.

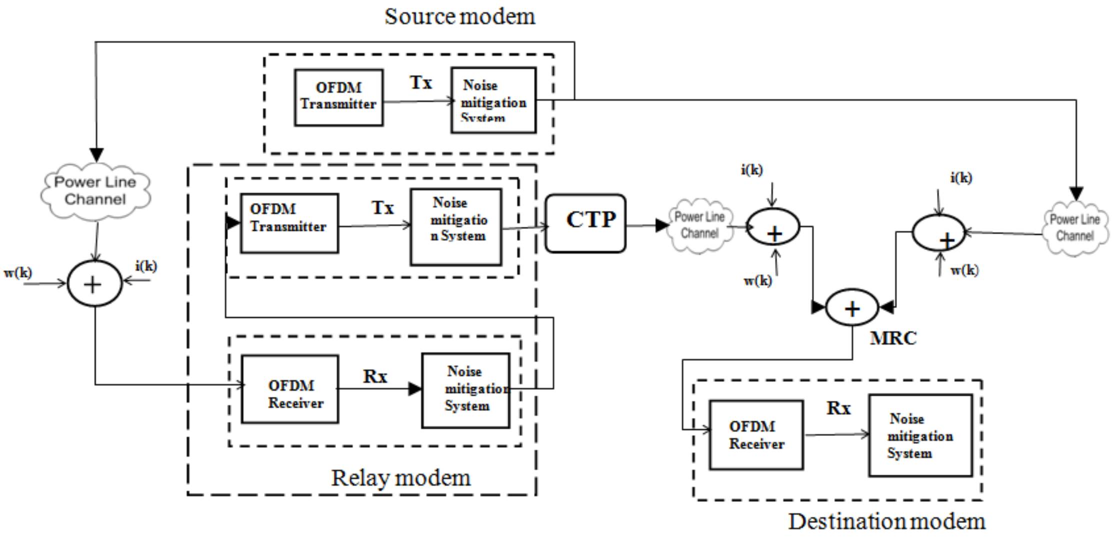

Figure 1: Cooperative Broadband over Powerline System Model

BPL Cooperative Network System

Broadband over powerline scenario is depicted in Fig. 2, comprising three (3) nodes. The source nodes transmit its signal in the broadcast (direct) transmission with power P1, while the relay nodes transmit its signal to the destination with power P2 in the cooperative transmission. The two transmission scenarios are as shown in Fig. 2.

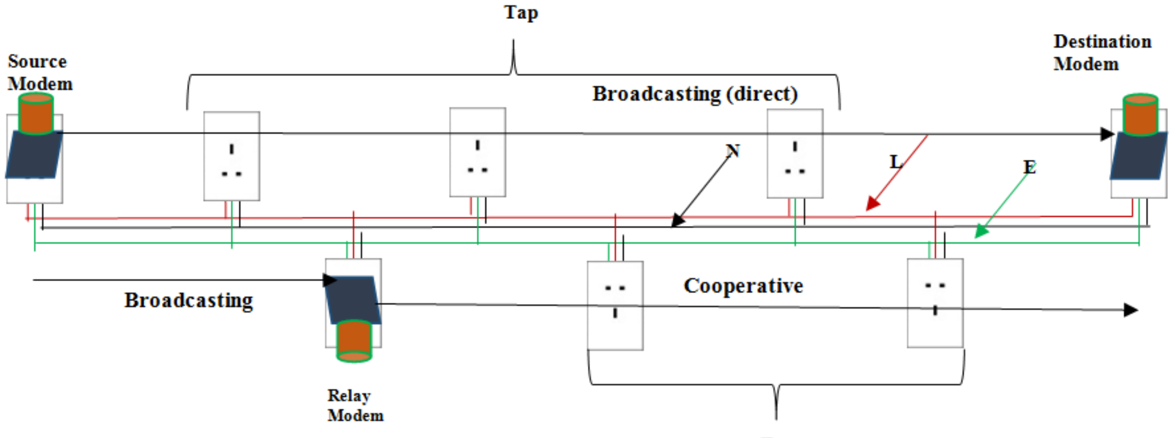

Figure 2: Cooperative broadband over powerline scenario

At the broadcasting phase with an OFDM of symbol length, N, and cyclic prefix (CP) of length $l_{cp} \geq \max(l_{sd}, l_{sr}, l_{rd})$, the expression in Eqs. (1) & (2) are the signals received at the destination and relay nodes while Eqn. (3) describes the noise components.

$$y_{sr}^{pl} = \sqrt{\frac{P_1}{N}} h_{sr}^{pl} x + n_{sr}^{pl} \qquad (1)$$

$$y_{sd}^{pl} = \sqrt{\frac{P_1}{N}} h_{sd}^{pl} x + n_{sd}^{pl} \qquad (2)$$

$$n_{sr}^{pl} = w_{sr} + i_{sr} \text{ and } n_{sd}^{pl} = w_{sd} + i_{sd} \text{ [11]} \qquad (3)$$

Where P_1 is the BPL source transmit power 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, which has a Gaussian amplitude and Poisson arrival. w represents the coloured background noise and i, impulsive noise.

The source-destination and source-relay multipath channels are described as h_{sd}^{pl} and h_{sr}^{pl} respectively.

In the cooperative transmission, the BPL relay modem, following the adopted cooperative protocol, processes it's received signal, transmits it through the BPL channel to the destination node. Eqn. 4 describe the signal received at the destination node during this cooperative transmission.

$$y_{rd}^{pl} = \sqrt{\frac{P_2}{N}} h_{rd}^{pl} q(y_{sr}^{pl}) + n_{rd}^{pl} \qquad (4)$$

P_2 being the BPL relay transmitted power and q the cooperative protocol deployed.

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

BPL Amplify-and Forward (AF) Cooperation

AF in broadband over powerline is similar to that in wireless communication system, the only difference is in the channel characteristic. Their channels are bewitched with different noise, while the wireless channel suffers from awgn, powerline channel experience both awgn and impulsive noise. The term, β^{pl}, is the amplification factor used to strengthen the relay signal [12].

$$\beta^{pl} = \frac{\sqrt{P_2^{l}}}{\sqrt{P_1^{l} \left| h_{sr}^{pl} \right|^2 + N_x}} \qquad (5)$$

$$N_x = N_w + N_i \qquad (6)$$

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

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.

This signal amplified is then broadcasted by the relay node to the destination node during the cooperative phase.

$$y_{rd}^{pl} = \beta^{pl} h_{rd}^{pl} y_{sr}^{pl} + n_{rd}^{pl} \text{ and } n_{rd}^{pl} = w_{rd} + i_{rd} \qquad (7)$$

$$y_{rd}^{pl} = \frac{\sqrt{P_1^{t} P_2^{t}}}{\sqrt{P_1^{t} \left| h_{sr}^{pl} \right|^2 + N_x}} h_{rd}^{pl} h_{sr}^{pl} x + n_{rd}^{pl^i} \qquad (8)$$

$$n_{rd}^{pl^i} = \frac{\sqrt{P_2^{\prime}}}{\sqrt{P_1^{\prime} \left| h_{sr}^{pl} \right|^2 + N_x}} h_{rd}^{pl} n_{sr}^{pl} + n_{rd}^{pl} \qquad (9)$$

Where n_{rd}^{pl} the noise in the powerline is channel from the relay to the destination and h_{rd}^{pl} is the power line channel coefficient between relay and destination modem. These two signals, y_{sd}^{pl} and y_{rd}^{pl} are combined in the destination node in accordance with the selected combining technique. While amplifying the signal, noise is also amplified, this can pose a severe distortion. Mitigating the distortion before amplification will present a better performance.

$$Y_{out}^{AF} = y_{sr}^{pl} + y_{rd}^{pl} = \sqrt{P_1^{\prime}} h_{sr}^{pl} x + n_{sr}^{pl} + \frac{\sqrt{P_1^{\prime} P_2^{\prime}}}{\sqrt{P_1^{\prime} \left| h_{sr}^{pl} \right|^2 + N_x}} h_{rd}^{pl} h_{sr}^{pl} x + \frac{\sqrt{P_2^{\prime}}}{\sqrt{P_1^{\prime} \left| h_{sr}^{pl} \right|^2 + N_x}} h_{rd}^{pl} n_{sr}^{pl} + n_{rd}^{pl} \qquad (10)$$

BPL Decode and Forward (DF) Cooperation

In this protocol, the BPL relay modem performs the function of decoding and re-encoding of the signal received. The received signal is re-transmitted to the destination node after it has being properly decoded and re-encoded over the channel defined by the coefficient, h_{rd}^{pl}.

The signal received at the destination will be given as

$$y_{rd}^{pl} = \sqrt{\beta_2^{pl}} h_{rd}^{pl} x + n_{rd}^{pl} \qquad (11)$$

Where $\beta_2^{pl} = P_2^{t}$ when the BPL relay correctly decodes the transmitted signal and $\beta_2^{pl} = 0$ if otherwise. h_{rd}^{pl} and n_{rd}^{pl} are modelled as in BPL-AF. The output at the destination for decode and forward for correct decoding, is as represented in (12)

$$Y_{out}^{DF} = \sqrt{P_1^{\prime}} h_{sr}^{pl} x + n_{sr}^{pl} + \sqrt{P_2^{\prime}} h_{rd}^{pl} x + n_{rd}^{pl} \qquad (12)$$

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 signals were combined at the destination using the Maximum Ratio Combining (MRC), which 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. (www.rroij.com) The output of an MRC is defined in Eq, (13)

$$y_d[n] = h_{s,d}^{*}[n] y_{s,d}[n] + h_{r,d}^{*}[n] y_{r,d}[n] \qquad (13)$$

where h_{sd}^{*} is the conjugate of the source-destination channel gain and h_{rd}^{*}, the relay-destination channel gain's conjugate.

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

(14)

$$Y_{out}^{MRCDF} = \left(\sqrt{P_1'}\left|h_{sd}^{pl}\right|^2 + \sqrt{P_2'}\left|h_{rd}^{pl}\right|^2\right)x + \left(\left|h_{sd}^{pl}\right|^2 n_{sd}^{pl} + \left|h_{rd}^{pl}\right|^2 n_{rd}^{pl}\right) \tag{15}$$

The resultant SNR in all the subcarriers for amplify-and-forward protocol can be estimated by

$$\lambda_{AF}^{pl} = \frac{A^2}{B} \tag{16}$$

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

While for the decode-and-forward, SNR for all subcarriers is described by

$$\lambda_{DF}^{pl} = \frac{\left(\sqrt{P_1'}\left|h_{sd}^{pl}\right|^2 + \sqrt{P_2'}\left|h_{rd}^{pl}\right|^2\right)^2}{\left(\left|h_{sd}^{pl}\right|^2 + \left|h_{rd}^{pl}\right|^2\right)} \tag{17}$$

$$\lambda_D^{pl} = \frac{\sqrt{P_1'}\left|h_{sd}^{pl}\right|^2}{N_x} \tag{18}$$

Channel capacity benefit

Assuming that the PSD of the noise in the PLC is constant in each subcarrier, the channel capacity is expressed by

$$C = \frac{B}{N}\sum_{k=0}^{N-1}\log_2(1+\lambda_u^{pl}) \tag{19}$$

where B ranges from 0 – 30 MHz (frequency bandwidth) and $u \in \left(AF, DF, D\right)$.

Symbol Error Analysis.

For Amplify-and-forward SER analysis, the SER is formulated according to [13], when the received SNR at the destination with QAM modulation, as;

$$\chi_{AF} = \left[\frac{4K}{\pi}\int_0^{\pi/2} - \frac{4K^2}{\pi}\int_0^{\pi/4}\right]\frac{1}{1+\frac{b_{QAM}}{2\beta_0\sin^2\theta}}\left\{\frac{\left(\beta_1-\beta_2\right)^2 + \left(\beta_1+\beta_2\right)\frac{b_{QAM}}{2\sin^2\theta}}{\Delta^2} + \frac{\beta_1\beta_2 b_{QAM}}{\Delta^3\sin^2\theta}\,\text{In}\left(\frac{\beta_1+\beta_2+\frac{b_{QAM}}{2\sin^2\theta}+\Delta}{4\beta_1\beta_2}\right)^2\right\}d\theta \tag{20}$$

where $\beta_0 = N_x \big/ P_1'\left|h_{sd}^{pl}\right|^2$, $\beta_1 = N_x \big/ P_1'\left|h_{sr}^{pl}\right|^2$, $\beta_2 = N_x \big/ P_2'\left|h_{rd}^{pl}\right|^2$, and $\Delta^2 = \left(\beta_1-\beta_2\right)^2 + 2\left(\beta_1+\beta_2\right)s + s^2$, while $s = b_{QAM} \big/ \left(2\sin^2\theta\right)$. Other terms are defined as, $K = 1 - \frac{1}{\sqrt{M}}$, $b_{QAM} = 3/(M-1)$ and $Q(u) = \frac{1}{2\pi}\int_u^{\infty}\exp(-\frac{t^2}{2})dt$.

In the decode-and-forward protocol, the relay can either decode the source signal correctly or incorrectly. At these instances, during the cooperation phase the relay power $P_2' = P_2'$ for correct decoding and $P_2 = 0$ otherwise. The SER is formulated as [13]

$$\chi_{DF} = F_2\left(1+\frac{b_{QAM}P_1'\left|h_{sd}^{pl}\right|^2}{2N_x\sin^2\theta}\right)F_2\left(1+\frac{b_{QAM}P_1'\left|h_{sr}^{pl}\right|^2}{2N_x\sin^2\theta}\right) + F_2\left(\left(1+\frac{b_{QAM}P_1'\left|h_{sd}^{pl}\right|^2}{2N_x\sin^2\theta}\right)F_2\left(1+\frac{b_{QAM}P_2'\left|h_{sr}^{pl}\right|^2}{2N_x\sin^2\theta}\right)\right) \times \left[1-F_2\left(1+\frac{b_{QAM}P_1'\left|h_{sr}^{pl}\right|^2}{2N_x\sin^2\theta}\right)\right] \tag{21}$$

Where $F_2\left(x\left(\theta\right)\right)=\frac{4K}{\pi}\int_0^{\frac{\pi}{2}}\frac{1}{x\left(\theta\right)}d\theta-\frac{4K^2}{\pi}\int_0^{\frac{\pi}{4}}\frac{1}{x\left(\theta\right)}d\theta$, $N_x=N_w+N_i$, N_w and N_i are Gaussian and impulsive noise PSD’s respectively.

For direct link, the SER was formulated as,

$$\chi_D = F_2\left(1+\frac{b_{QAM}P_1\left|h_{sd}^{pl}\right|^2}{2N_x\sin^2\theta}\right) \tag{22}$$

F_2 is as defined in previous case.

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] i.e.

$$P_{out}=P\left[0\le\lambda_t\le\lambda_{th}\right]=\int_0^{\lambda_{th}}P_{\lambda_t}\left(\lambda_t\right)d\lambda_t \tag{23}$$

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 (23).

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 (web.stanford.edu) amplify-and-forward link can be derived using [16] as

$$\begin{aligned}P_{out\_AF}&=\Pr\{\lambda_{AF}^{pl}<\lambda_{th}^{pl}\}=\Pr\{\lambda_{AF}^{pl}<\lambda_{th\_AF}^{pl}\}\\&=\int_0^{\lambda_{th\_AF}^{pl}}P_{\lambda_{AF}^{pl}}(\lambda_1)\int_0^{\lambda_{th\_AF}^{pl}-\lambda_1}P_{\lambda_{sd}^{pl}}(\lambda_2)d\lambda_2d\lambda_1\\&=\int_0^{\lambda_{th\_AF}^{pl}}P_{\lambda_{AF}^{pl}}(\lambda_1)P_{\lambda_{sd}^{pl}}(\lambda_{th\_AF}^{pl}-\lambda_1)d\lambda_1\end{aligned} \tag{24}$$

where $P_{\lambda_{AF}^{pl}}(c)$ represents the PDF of the AF path SNR described in Eq. (24).

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

$$\begin{aligned}P_{out\_\mathrm{D}F}&=\Pr\{\lambda_{DF}^{pl}<\lambda_{th}^{pl}\}=\Pr\{\lambda_{DF}^{pl}<\lambda_{th\_\mathrm{D}F}^{pl}\}\\&=P_{\lambda_{sr}^{pl}}(\lambda_{th\_DF}^{pl})+[1-P_{\lambda_{sr}^{pl}}(\lambda_{th\_DF}^{pl})]\times\int_0^{\lambda_{th\_\mathrm{D}F}^{pl}}P_{\lambda_{sd}^{pl}}(\lambda_1)\int_0^{\lambda_{th\_\mathrm{D}F}^{pl}-\lambda_1}P_{\lambda_{rd}^{pl}}(\lambda_2)d\lambda_2d\lambda_1\\&=P_{\lambda_{sr}^{pl}}(\lambda_{th\_DF}^{pl})+[1-P_{\lambda_{sr}^{pl}}(\lambda_{th\_DF}^{pl})]\times\int_0^{\lambda_{th\_\mathrm{D}F}^{pl}}P_{\lambda_{sd}^{pl}}(\lambda_1)P_{\lambda_{rd}^{pl}}(\lambda_{th\_DF}^{pl}-\lambda_1)d\lambda_1\end{aligned} \tag{25}$$

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

$$\begin{aligned}P_{out\_\mathrm{D}}&=\Pr\{\lambda_D^{pl}<\lambda_{th}^{pl}\}=\Pr\{\lambda_D^{pl}<\lambda_{th\_\mathrm{D}}^{pl}\}\\&=\int_0^{\lambda_{th\_\mathrm{D}}^{pl}}P_{\lambda_{sd}^{pl}}(\lambda_1)d\lambda_1\end{aligned} \tag{26}$$

The spectral efficiency was set at R = 1 b/s/Hz, while the threshold SNR is $\lambda_{th}^{pl} = \lambda_{th\_AF}^{pl} = \lambda_{th\_DF}^{pl} = \lambda_{th\_D}^{pl} = 2^{2R} - 1$. The power of 2 is for the bi-transmission scheme of the system.

III. Results and Discussion

The system channel capacity was simulated on Matlab for various link configurations using (19) for three different relay locations 5 m away from source, mid-way between source and destination nodes (10 m) and 15 m away from source node. Between the source node and all relay locations has four (4) taps while the direct link (source to destination) has eight (8) taps in all, having a length of 20 m. The channel gains were defined for all channels. $P_1 = P/2$ was used for the broadcasting phase 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* over 0 – 30 MHz frequency band. OFDM parameters as in the noise mitigation simulation were maintained. The simulation parameters are as shown in Table 1.

Table 1: Simulation Parameters

Parameters	Value	Parameters	Value
N (Number of taps)	20	Bandwidth	0 – 30 MHz
α_0 (offset attenuation)	0	Code rate (CC)	1/2
α_1(increase of attenuation)	1.6×10^{-10}	K (CC constraints)	8
k (exponent of attenuation)	1	IFFT Subcarriers	256
A (Impulsive noise index)	0.001	OFDM symbols	10
n (Reed-Solomon)	64	Cyclic prefix	64
k (Reed-Solomon)	48	Modulation scheme	16-QAM
N_o	-125	N_1	35
f_1	3.6	P	-12.5dBmW
R	1	Length of Network	20 m

Cooperative BPL Channel Capacity Performance Evaluation

Three relay locations were investigated, 5 m, 10 m (midway) and 15 m away from the PLC source modem. The performance of the PLCC (power line cooperative communication) system, with AF and DF cooperative protocols and those of MIMO-PLC, PLC-repeater and the conventional PLC is presented in Fig. 3.

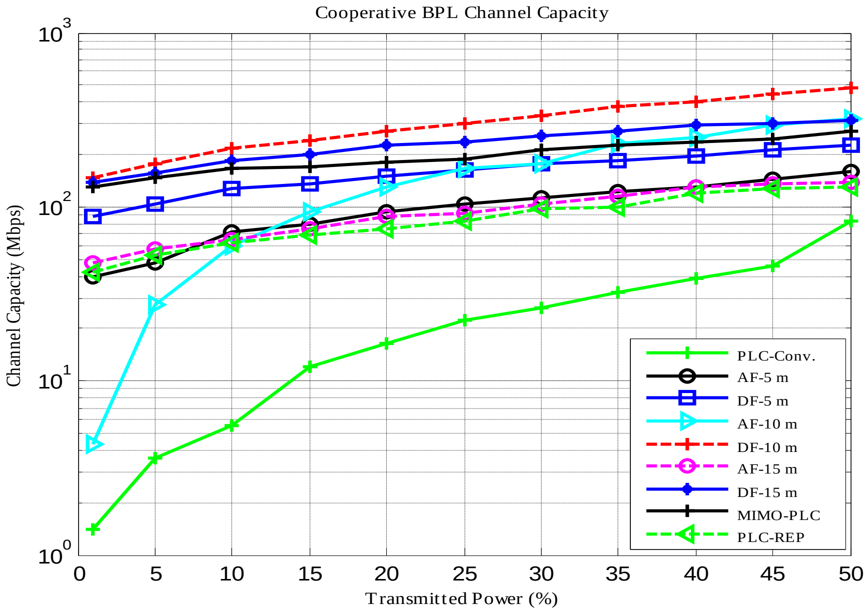

Figure 3: Cooperative BPL Channel Capacity Performance

Amongst the three relay placement locations, the 10 m away (midway) presents the best performance, hence it was chosen for performance comparison with the benchmarks. The DF link yielded a better channel capacity than the MIMO-PLC link, achieving 71% improvement, while it achieved 233% improvement over the PLC-repeater link. On the AF link, the MIMO-PLC link outperformed the AF link, until 35% and above transmitted power when it achieved improvement in channel capacity over the MIMO-PLC link, it achieved 7% improvement over the MIMO-PLC link.

The performance evaluation of the links is as shown in Fig. 4.

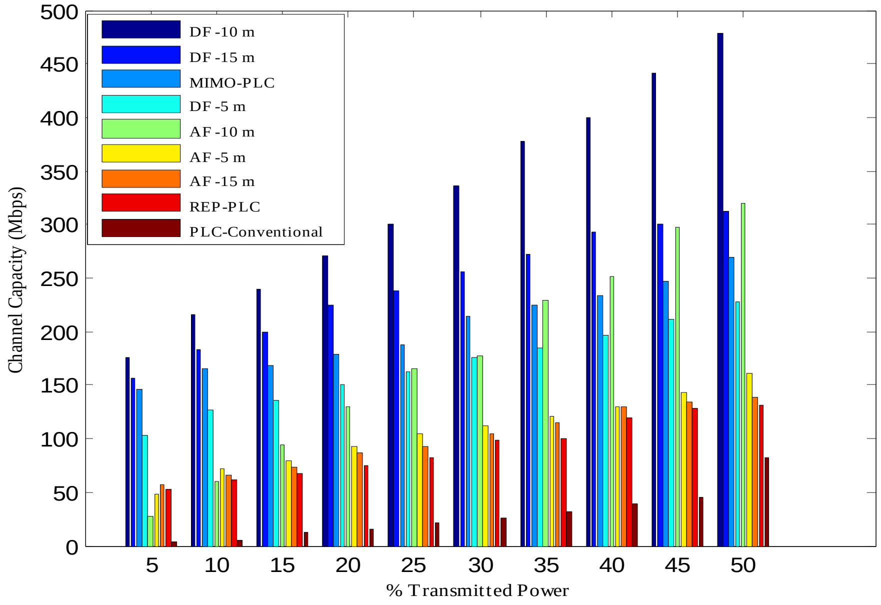

Figure 4. Cooperative BPL Channel Capacity Performance Comparison

From Figure 4, at all levels of power transmission, the PLC-DF link achieved tremendous improvement in channel capacity. When 10% of the source power was used for transmission, the PLC-DF (10 m) link achieved 50 Mbps channel capacity improvement over the MIMO-PLC link.

Cooperative BPL Symbol Error Rate Performance

As stated in the methodology, three different relay locations were investigated for symbol error rate performance on the PLCC system with the AF and DF protocols. The performance of the links are as shown in Fig. 5. The 10 m relay location offered the best performance.

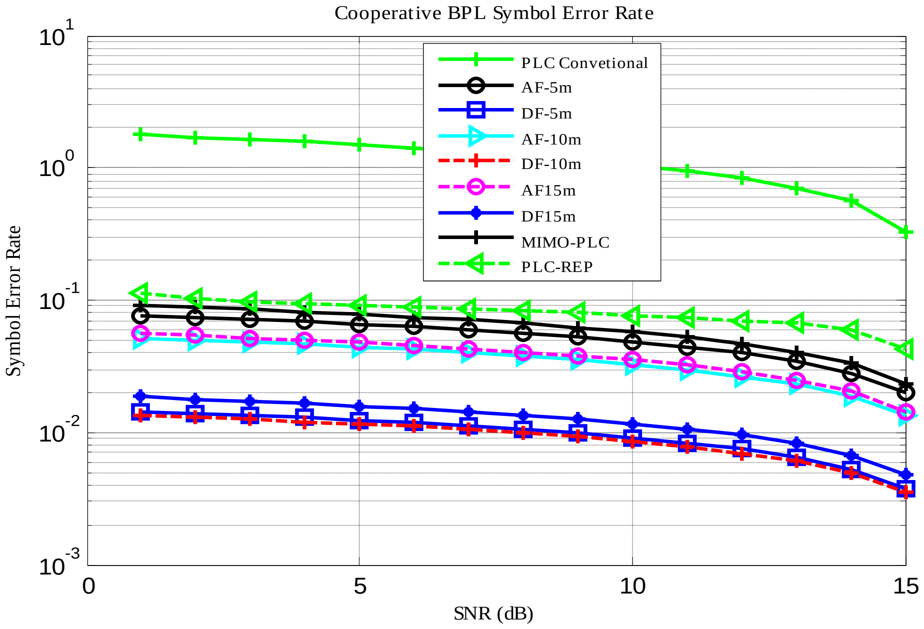

Figure 5: Fixed Symbol Error Rate Performance

Fig. 6 shows that cooperative links, AF and DF presents an exceptional performance in contrast to the MIMO-PLC link, this is as a result of the noise mitigation system developed to mitigate the noise in the system. At 6 dB SNR, for 100 symbols transmitted, 8 symbols are in error with the MIMO-PLC link, while 4 and 1 symbol(s) are in error for PLC-AF and PLC-DF links respectively. This resulted in 50% and 70% symbol error rate improvement, owing to the noise mitigation system incorporated in the system.

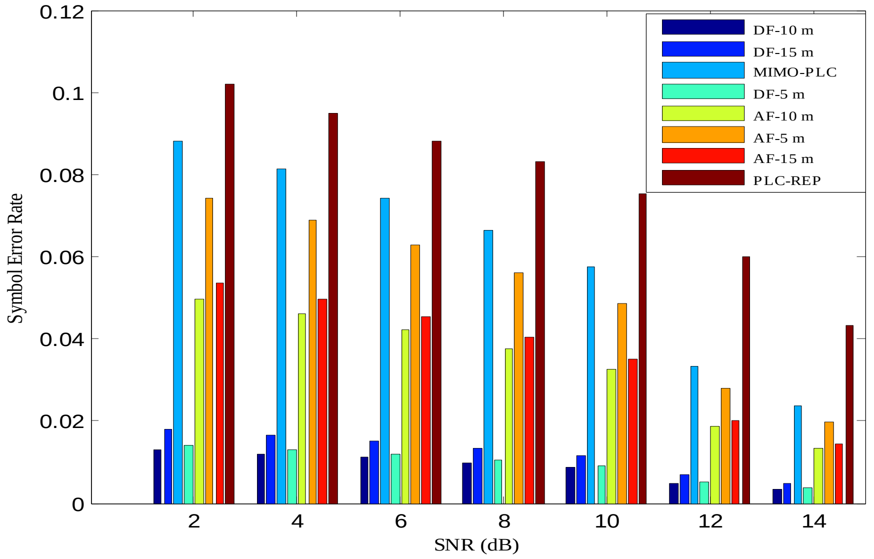

Figure 6: Symbol Error Rate Performance Comparison

The SER comparison reveals that for the AF cooperative protocol, the selective relaying achieved a reduction in symbol error rate over all the SNR range.

Cooperative BPL Outage Probability Performance

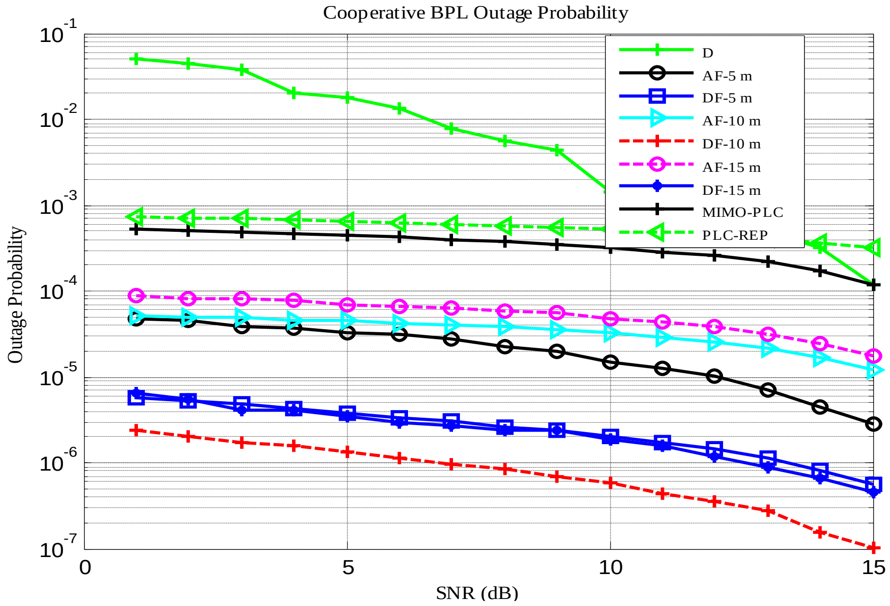

Figure 7: Cooperative BPL Outage Probability Performance

The performances of the three relay location scenarios (AF/DF), MIMO-PLC and PLC-repeater is as shown in Fig. 7, while the comparison of the outage probability performance for the links is presented in Fig. 8. The cooperative links, AF and DF presents an outstanding performance in contrast to the MIMO-PLC link. Examination of Fig. 8 reveals that probability of outage on the PLC-DF link is almost eliminated, while it is very low on the PLC-AF in comparison with the MIMO-PLC link.

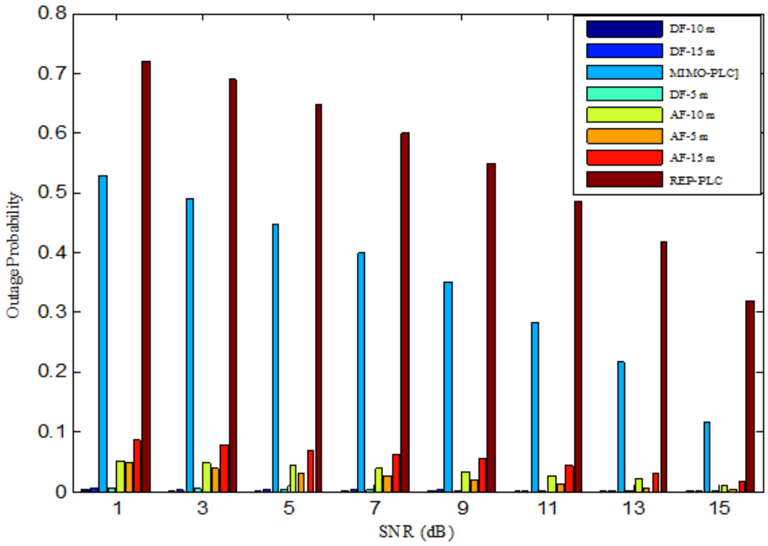

Figure 8: Cooperative BPL Outage Probability Performance Comparison

This reduction in outage probability is as a result of the noise mitigation system incorporated. At 5 dB SNR, the PLC-AF and PLC-DF achieved 95.7% and 105% improvements over the MIMO-PLC scheme respectively.

IV. Conclusion

In this paper, a technique deployed to achieve reliability ii the power line communication (PLC) system is presented. The technique is a, modem (relay) cooperating with the source modem for signal transmission to the destination. The key contribution is in the system reliability achieved, for which system's channel capacity, outage probability and symbol error rate were parameters investigated. Two cooperative channels, amplify-and-forward and the decode-and-forward, along with the direct channel (without cooperation), were examined for those parameters mentioned. The cooperative links were seen to attain outstanding reliability over the direct link. The noise mitigation system incorporated contributed enormously to the drastic reduction in the systems symbol error rate and outage probabilities of both cooperative links, achieving performances that are close.

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