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Relay Selection Strategy for Improving the Performance of Broadband Over Power Line Cooperative System

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Abstract: *Broadband applications vary from entertainment, medicine, internet browsing, multimedia, voip, which are the essentials of internet of things (IOT). Various technologies s have been deployed for the provision of these applications. All except the power line communication (PLC) technology requires a new installation. The PLC technology utilises the existing electrical network as is medium. Hence, broadband applications are provided by connecting to the electrical power socketoutlets. The power network (powerline) degrades the broadband signal as it traverses the line, owing to the characteristics off the line which is not designed for broadband signal propagation. This degradation results in noise and attenuation. Cooperative fixed relaying have been deployed to mitigate the degradation. In this paper, deployment of multiple relays for the purpose of selecting the relay with the best channel characteristic was considered for the cooperative scheme in broadband over power line system performance upgrade. A selection algorithm using the best instantaneous SNR was developed. The relay with the best instantaneous SNR is selected for cooperation of the source modem with the destination mode.. The channel capacity and attenuation performance were evaluated. Comparison of these metrics for the system was compared to those of the fixed cooperative relaying scheme and those of MIMO. The selective relaying scheme achieved an improved performance.*

Keywords*: Broadband, power-line, instantaneous SNR, channel-capacity, and attenuation.*

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I Introduction

An issue in the research world across all fields of engineering and economics is the numerous recurring challenges of achieving a balance between supply and demand. The upsurge in data requirements for various applications is such a challenge. Although various technologies have been deployed for this data requirement, it is still not matching or adequate for the demand. This technologies include wireless and wired. Due to cost of deploying these technologies, some potential consumers could not afford it. Another technology which is readily affordable, owing to its channel presence at the consumer end, is already deployed for the data provision. This technology is the power line communication (PLC) system, which utilizes the electric power network as its channel for broadband data transmission. However due to the nature of its medium, which includes, long length, branches across its length, the line's time varying characteristic and load terminations to mention a few, signal transmission through it suffers enormous degradation [1]. Various form of techniques have been deployed to mitigate these impairment on the line. Technique of MIMO[2]and repeaters [3]on the PL channel have been deployed for improving the throughput of the PLC. So also techniques of clipping, blanking and error correction codes have been implemented to mitigate impulsive noise on the channel. Recently, cooperative relaying customised for the PL channel [4]was used to achieve some level of performance improvement. In this system a relay was fixed at a location and made to cooperate the the source signal to the destination. The behaviour of the PL channel is time variant, it characteristics depends on the followings; time of the day, operating frequency, length of channel (distance between transmitter and receiver), branched line's length and terminal load impedance[5]. Hence fixed relaying may not achieve the optimal performance of the PL channel. Selective relaying, a technique of selecting the relay channel with the best performance for cooperation with the destination node, is implemented. Thus the relay modem offering the best channel characteristic is selected for implementing the cooperation protocol with the destination node.

In this paper, multiple relays are deployed with the relay modems randomly located between source and destination modem. This is done so as to select the relay modem that has the best cooperative tendency with the destination modem for the source modem. Selective algorithm for this PLC cooperative system was developed. Two types of cooperative protocol, amplify-and-forward (AF) and decode-and-forward (DF) were implemented in the system.

II System Model

Figure 1 shows the PLC multiple relays deployment. Three scenarios of deployment was implemented. These scenarios are, 3-relay, 5-relay and 7-relay.

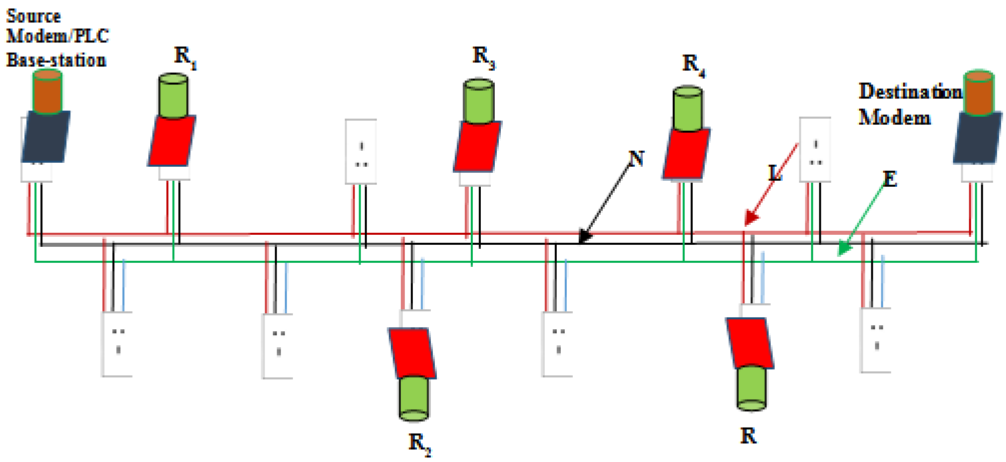


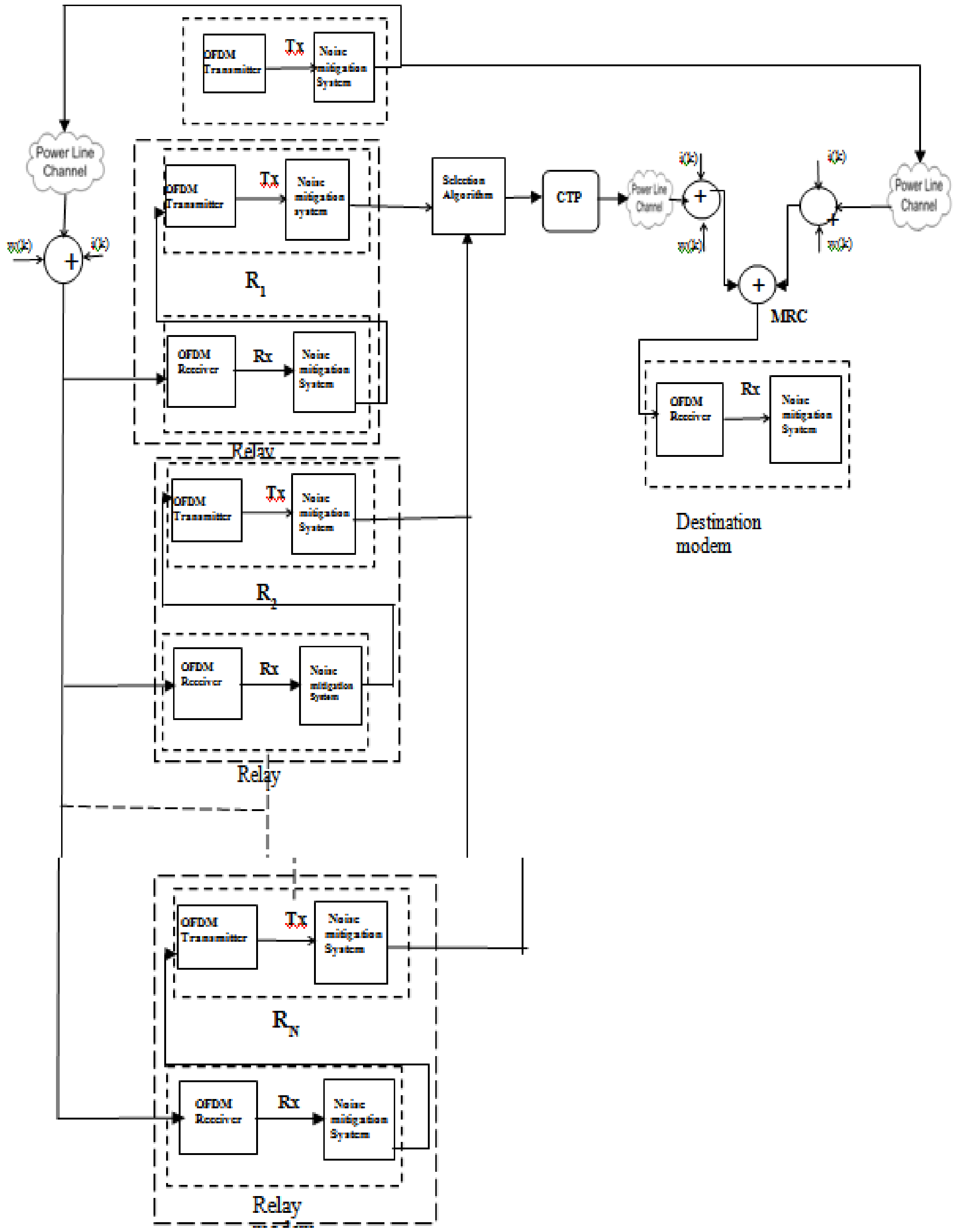
Figure 1: Multiple Relay PLCC Scenario

The system model is as shown in Figure 2. It consists of three segments, the source, the relay (multiple) and the destination segments. The relay segment comprises many relay modems placed between the source and the destination modems, the source is a PLC base-station, this segment is depicted as an OFDM transmitter with noise mitigation system. The relay (multiple) is both an OFDM receiver and transmitter with noise mitigation, while the destination modem is represented as an OFDM receiver. The cooperative transmission protocol (CTP) is the process of cooperation that the relay passes her signal through before routing it to the destination.

The relays are sandwiched between the source modem and the destination modem as in Fig. 1. Each of these propagates its signal after it has processed it through the power line channel. The relay selection algorithm flows a set of instruction to select the best relay. All of these modems are PLC modem.

The source modem is the source of the information to be transmitted. This section is made up of an OFDM transmitter followed by noise mitigation system. The noise mitigation system's function is to combat the effect of the power line noise characteristics. It does this by passing the random sequence of bits through two series of encoding. The first uses the Reed-Solomon (RS) codes [6] while the second implements convolutional codes at different code rates for different scenarios.

This is performed to further achieve serenity in the channel. The encoded bits were interleaved using random interleaver. The bits contained in the data block, which is the encoder output, is shuffled and distributed over a number of bursts. This is for the purpose of combatting the busty impulsive noise in the power line channel. Mapping was then performed using QAM, before modulation using inverse discrete Fourier transform (IDFT). In the receiver the opposite of the processes in the transmitter is carried out, namely; demodulation by means of discrete Fourier transform (DFT), demapping (both PSK and QAM), de-interleaving, viterbi decoding and RS decoding. Reed-Solomon codes was deployed to combat the burst errors produced by the impulsive component of the noise while the convolutional encoding with Viterbi decoding mitigates the effect of the white guassian noise.



PLCC Network System Description

During the first transmission (broadcasting) with an OFDM of symbol length, N, and cyclic prefix (CP) of length $l_{cp} \geq \max\left(l_{sd}, l_{sr}, l_{rd}\right)$, the received signals at both the PLC destination and relay nodes is as shown in Equations 1 and 2.

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

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

where P_1 is the PLC 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.
The signal received at the destination node at this second transmission is given as;

$$y_{rd}^{pl} = \sqrt{\frac{P_2}{N}} h_{rd}^{pl} q(y_{sr}^{pl}) + n_{rd}^{pl} \quad (3)$$

PLCC Amplify-and-Forward (AF) Analysis
The signal received at both the destination and the relay nodes in the broadcasting phase is as described Equations (1) and (2). The relay received signal is made stronger by a factor β^{pl} [7]

$$\beta^{pl} = \frac{\sqrt{P_2'}}{\sqrt{P_1' \left| h_{sr}^{pl} \right|^2 + N_x}} \quad (4)$$

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;

$$y_{rd}^{pl} = \beta^{pl} h_{rd}^{pl} y_{sr}^{pl} + n_{rd}^{pl} \quad (5)$$

$$y_{rd}^{pl} = \frac{\sqrt{P_1' P_2'}}{\sqrt{P_1' \left| h_{sr}^{pl} \right|^2 + N_x}} h_{rd}^{pl} h_{sr}^{pl} x + n_{rd}^{pl^i} \quad (6)$$

The destination node will then combine the two signals, y_{sd}^{pl} and y_{rd}^{pl} following the Maximum Ratio Combiningtechnique.
PLCC Decode-and-Forward (DF) Analysis
In this protocol, the relay modem decodes and re-encodes the signal received. Its channel and noise are as described in PLCC AF. 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 received at the destination will be given as;

$$y_{rd}^{pl} = \sqrt{\beta_2^{pl}} h_{rd}^{pl} x + n_{rd}^{pl} \quad (7)$$

Where $\beta_2^{pl} = P_2'$ if relay correctly decodes the transmitted signal and $\beta_2^{pl} = 0$ if otherwise.
DF for correct decoding, is as represented in Equation 8.

$$Y_{out}^{DF} = \sqrt{P_1'} h_{sr}^{pl} x + n_{sr}^{pl} + \sqrt{P_2'} h_{rd}^{pl} x + n_{rd}^{pl} \quad (8)$$

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.

$$Y_{out}^{MRCAF} = \left(\sqrt{P_1'} \left| h_{sd}^{pl} \right|^2 + \frac{\sqrt{P_1' P_2'}}{\sqrt{P_1' \left| h_{sr}^{pl} \right|^2 + N_x}} \left| h_{rd}^{pl} \right|^2 \left| h_{sr}^{pl} \right|^2 \right) x + \left(h_{sd}^{pl} n_{sd}^{pl} + \frac{\sqrt{P_2'}}{\sqrt{P_1' \left| h_{sr}^{pl} \right|^2 + N_x}} h_{rd}^{pl} n_{sr}^{pl} + h_{rd}^{pl} n_{rd}^{pl} \right) \quad (9)$$

$$Y_{out}^{MRCDF} = \left(\sqrt{P_1'} \left| h_{sd}^{pl} \right|^2 + \sqrt{P_2'} \left| h_{rd}^{pl} \right|^2 \right) x + \left(\left| h_{sd}^{pl} \right|^2 n_{sd}^{pl} + \left| h_{rd}^{pl} \right|^2 n_{rd}^{pl} \right) \quad (10)$$

Selective PLCC Relay Selection Algorithm

In multiple relaying, the relay that offers the best performance is selected for the cooperation of the source modem with the destination node. It is then required to develop an algorithm that will yield optimality of the systems' performance. The algorithm developed follows the best relay channel SNR. The algorithm entails these steps
Source node transmits signal to destination and multiple relay nodes using half of the transmit power available in the source node (direct link) [8].

- The SNR of the relay channels to the source node are determined, for 3, 5 and 7 relay deployments.

$$\lambda_i^{pl} \text{ for } i = 1,2,3$$

$$\lambda_j^{pl} \text{ for } j = 1,2,..,5$$

$$\lambda_k^{pl} \text{ for } k = 1,2,\ldots,7$$

- These SNR values is made available to the source node.
- The source node selects the relay with the best SNR.
- The selected relay uses the other half transmit power to transmits its processed signal to the destination node (cooperative link). This implements equal power allocation (EPA).

SPLCC Channel Capacity Analysis

Having applied maximal ratio combining (MRC) at the destination, the resultant SNRs' in all the subcarriers for both cooperative protocols for all relaying schemes are expressed in Equations 11 and 12.

$$\lambda_{SAF}^{pl} = \lambda_{sd}^{pl} + \max_i \left(\lambda_{sid}^{pl}\right) = \frac{A_2^2}{B_2} \qquad (11)$$

$$A_2 = \left(\sqrt{P_1^t}\left|h_{sd}^{pl}\right|^2 + \max_i\left(\frac{\sqrt{P_1^t P_2^t}}{\sqrt{P_1^t\left|h_{si}^{pl}\right|^2 + N_x}}\left|h_{id}^{pl}\right|^2\left|h_{si}^{pl}\right|^2\right)\right) \text{ and } B_2 = \left(\left|h_{sd}^{pl}\right|^2 + \max_i\left(\left|h_{id}^{pl}\right|^2\left(\frac{\sqrt{P_2^t}}{\sqrt{P_1^t\left|h_{si}^{pl}\right|^2 + N_x}} + 1\right)\right)\right)$$

$$\lambda_{SDF}^{pl} = \lambda_{sd}^{pl} + \max_i \lambda_{id}^{pl} = \frac{\left(\sqrt{P_1^t}\left|h_{sd}^{pl}\right|^2\right)^2}{\left|h_{sd}^{pl}\right|^2} + \max_i\left(\frac{\left(\sqrt{P_2^t}\left|h_{id}^{pl}\right|^2\right)^2}{\left|h_{id}^{pl}\right|^2}\right) \qquad (12)$$

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

$$C = \frac{B}{N}\sum_{k=0}^{N-1}\log_2(1+\lambda_u^{pl}) \qquad (13)$$

where B ranges from 0 – 30 MHz (frequency bandwidth) and $u \in \left(SAF_i, \text{SDF}_i\right)_{i=3.5.7}$.

Attenuation Analysis

The attenuation analysis is carried out on both the selective and the fixed schemes of the broadband over power line. For all schemes the attenuation is analysed at a percentage power transmission of 20%. Therefore, the attenuation characteristic of all the links at the destination is investigated. The power received at the destination for all links were determined using the SNR equations of both AF and DF protocols for the links.

III Results and Discussion

Selective PLCC Channel Capacity Performance Evaluation Three multiple relay scenarios was investigated in this section (3, 5, and 7 relays). The channel capacity performances of these multiple relay scenarios for the two cooperative protocols and those of the fixed PLCC (AF/DF), MIMO-PLC and the PLC repeater is shown in Fig. 3.

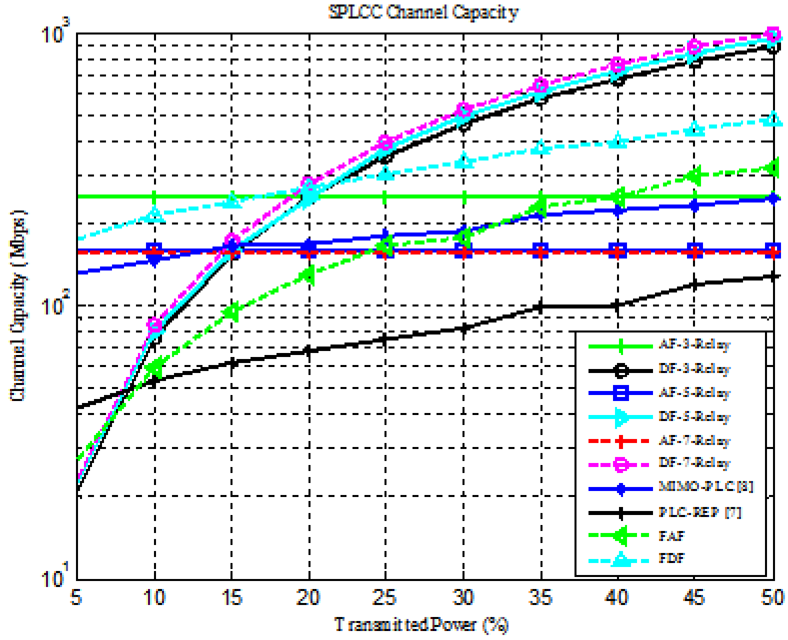


Figure 3: SPLCC Channel Capacity Performance

The comparison of the various links channel capacity is presented in Fig. 4. The Figure reveals that the 3-SAF (3 relay deployment) offers the best channel capacity improvement at lower percentage of transmitted power below 40%, yielding a constant value of 248.3 Mbps. At higher percentage transmitted power, the fixed relaying scheme renders better performance, but due to the EMC policy, this level may not be reached. For instance, at 20% of transmitted power, the 3 relays scheme achieved a 57.45% and 38.71% improvements over the fixed relaying and MIMO-PLC schemes respectively and greater improvement over the PLC-repeater.

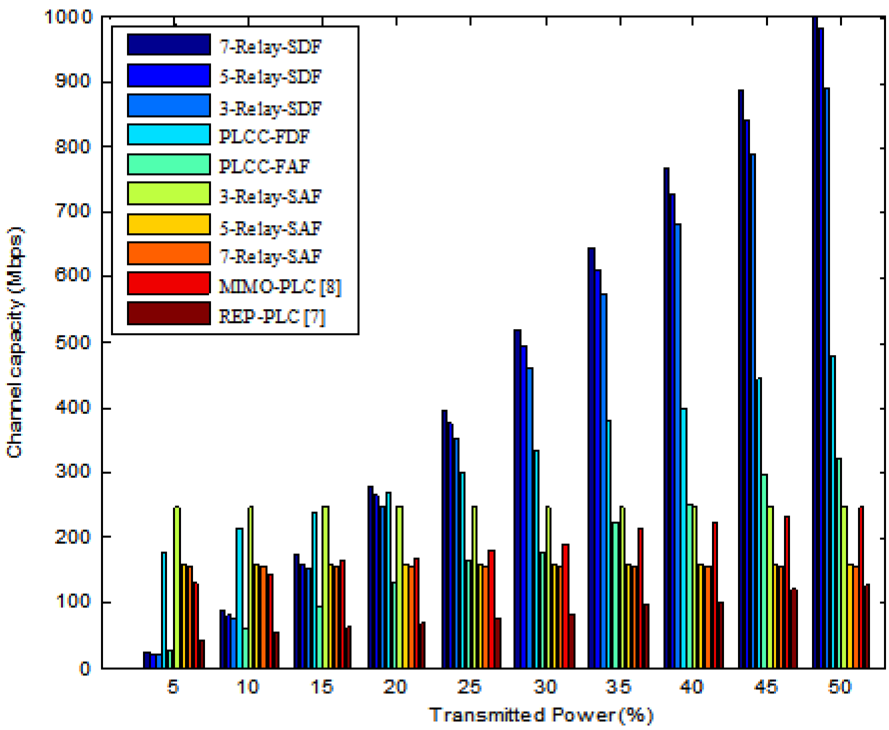


Figure 4: SPLCC Channel Capacity Performance Comparison

The 5-SAF on this protocol achieved a channel capacity improvement over the fixed relaying scheme at lower percentage of transmitted power but deteriorate as the transmitted power increases.

All scenarios of selective relaying scheme on the DF link offered a better channel capacity performance over both fixed relaying and MIMO-PLC schemes at 25% transmitted power and above.

The FDF only achieved a better performance at the lower transmitted power, but as the power percentage rises, the SDF scheme outperformed the FDF scheme, the 7-SDF offering the best performance. The percentage performance of the selective relaying schemes over the fixed relaying scheme at 30% transmitted power is presented on Table 1. The channel capacity performance improves as the transmitted power percentage rises.

Table 1: SDF % Channel Capacity Improvement over FDF At 30% Transmitted Power

Relay deployment	**% Improvement**
3-SDF	37.3
5-SDF	46.13
7-SDF	54.67

SPLCC Attenuation Investigation

The investigation plot is shown in Figure 5. The multiple relay links are compared with those of fixed relaying, MIMO-PLC and PLC-repeater.

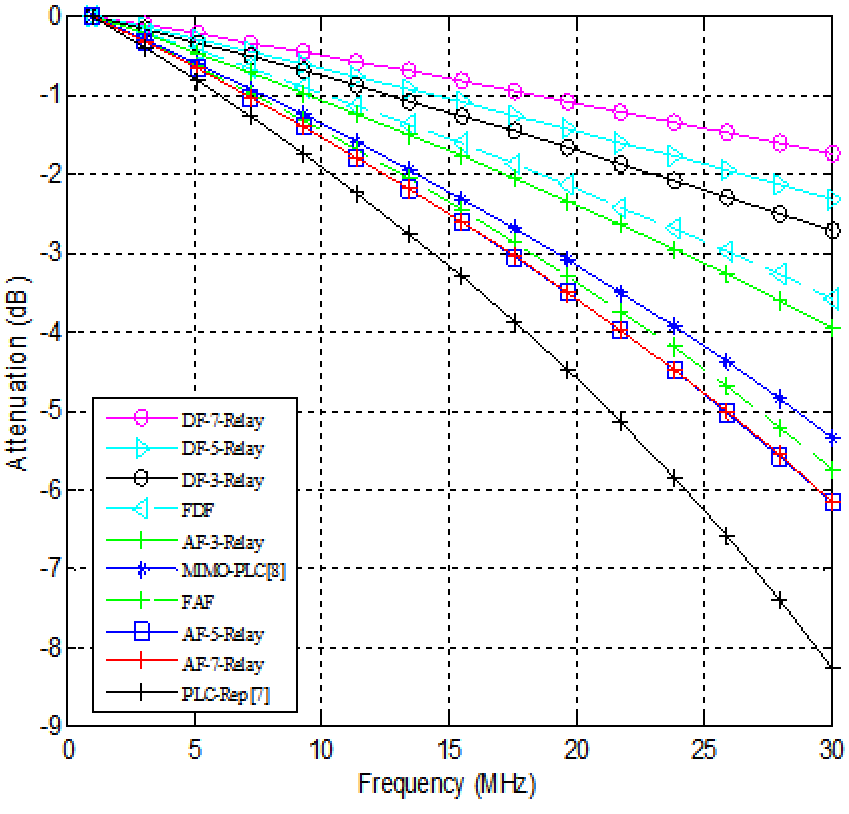


Figure 5: SPLCC Attenuation Characteristic

Table 2: SPLCC (EPA) Percent Attenuation Improvement @ 15 MHz

Links	MIMO-PLC (%)	PLC-Repeater (%)
DF-7R	64.1	74.79
DF-5R	52.8	67.96
DF-3R	45.1	61.48
AF-3R	23.26	46.1

The Table 4.8 shows that at 15 MHz frequency, the DF link with 7 relay deployment achieved the highest saving in attenuation, a 64.1% over the MIMO-PLC link while attenuation saving over the PLC-repeater link is 74.79%.

IV Conclusion

The effect of selective relaying in the cooperative broadband over power line link have been investigated in this work. Three scenarios of multiple relay deployment was examined, these are 3, 5, and 7 relays. The relay with the best instantaneous SNR is chosen for cooperation of the source relay with the destination relay in all the deployments. The 7 relay deployments renders a 54.7% improvement in channel capacity over the fixed relaying system. On attenuation, a reduction of the 7 relay deployment achieved a 64.1% reduction in attenuation over the MIMO scheme and achieved 34% reduction over the fixed relaying scheme. These achievements improved the performance of the broadband over power line system.

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