IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 17, Issue 6, Ser. I (Nov. – Dec. 2022), PP 13-20
www.iosrjournals.org

Mitigating Attenuation Through Selective Cooperative Relaying And Optimal Power Allocation In Broadband Over Powerline

[1]Aiyelabowo O. Peter and [2]Aderanti A. Taiwo
[1]Department of Electrical/Electronics Engineering, Federal Polytechnic, Ilaro, Ogun State
[2]Department of Electrical/Electronics Engineering, Gateway Polytechnic, Sapade, Ogun State

Abstract
Broadband data demand for various application is ever increasing. This has promoted the search for a technology, that will for its ubiquitous nature, provide this demand. Broadband over powerline is such technology. Because of its transmission medium (electrical power installation)broadband data suffers severe attenuation as they are propagated through it. In this paper, selective relaying and optimal power allocation are deployed in the broadband over powerline system to mitigate the attenuation. Three and five relays were deployed at different location between the source and destination nodes. Power allocation for the broadcasting and cooperative transmissions follows the optimal allocation algorithm of $\frac{1}{3}P_t : \frac{2}{3}P_t$. *The attenuation mitigation performance of the system was benchmarked with those of MIMO-PLC and PLC-Repeater, 77.2% improvement was achieved over the duo.*

***Keywords**: Broadband, MIMO-PLC, smart-grid, amplify-and-forward and decode-and-forward*

Date of Submission: 02-12-2022 Date of Acceptance: 14-12-2022

I. Introduction

Data communication technology is the heart of information exchange in smart grid (SG) systems. This technology finds its place in SG because the system because the system provides the necessary features for it. These features include reliability, security and privacy, broadband coverage and quality of service.

Broadband over powerline (BBPL), a technology that transforms the electrical power installations into transmission medium for information will provide the advantage of cost effectiveness and good broadband coverage for SG systems. Itsdeployment for applications of voice, video, multimedia, home-networking and internet will make it a veritabletechnology in the SG. The ubiquitouscharacteristic of the powerline, which is the medium for information transmission in BBPL, will enhance broad coverage of the SG since 95% of the world's human settlement has electric power distribution installation. This distribution line was intended for the provision of electrical power that will drive home appliances, hence transmission of broadband data over this installation will translate in its misuse. Because of this transmission of information on the medium (distribution line) results in attenuation of the signal. This attenuation is due to the noise inherent in the power line. The noise is both additive white gaussian (awgn) and impulsive. The attenuation suffered is to the tune of 10 dB. Hence the direct link on the power line suffers great attenuation. Sevaral systems has been designed to mitigate this attenuation. Prominent amongst them are MIMO-PLC(Lothar Stadelmeier, Dietmar Schill, Andreas Schwager,Daniel Schneider, 2008), (Versolatto & Tonello, 2011), (Canova et al., 2010) and repeater(An et al., 2007), (Cypress, 2011) systems. In this paper, selective cooperative relaying with optimal power allocation is presented for mitigation of attenuation in broadband over powerline.

Cooperative Relaying

Cooperative relaying (amplify-and-forward (AF) and decode-and-forward (DF)) was deployed in to mitigate this attenuation in BBPL. In this paper, selective relaying and optimal power allocation was deployed for further mitigation of the attenuation in BBPL.

In cooperative relaying system there are three major nodes, source (transmit) node, relay node and destination node. Two phases of transmission results in this system, the broadcasting (from source to destination) and cooperative (from relay to destination). The broadcasting transmission suffers attenuation because of the length of the channel. The relay receives the signal during the broadcasting session, (Garg et al., 2013),(Kaur & Bhattacharya, 2011) and (F. Gómez-Cuba, 2012).The signals transmitted from the source node and received at the relay nodes passes through some processing's. These processing's are provided for by the cooperative transmission protocol at the relay node. These protocols include, Amplify-and-Forward (AF), Decode-and-Forward (DF), Compressed-and-Forward (CF) and Code Cooperation (Hunter & Nosratinia, 2006), (Nguyen, 2011).

Multiple cooperative relaying

In this case, more than one relay is deployed for the cooperation of the source with the destination node. In the first (broadcasting) phase, the source node transmits information to both destination and the
i-th (1st relay), this is modelled as,

$$y_{sd} = \sqrt{P_o} h_{sd} x + n_{sd} \quad (1a)$$

$$y_{sri} = \sqrt{P_o} h_{sri} x + n_{sri} \; 1 \le i \le N \quad (1b)$$

where $P_o$is the power transmitted at the source, x is the transmitted symbol, $h_{sd}$and $h_{sri}$are the channel fading coefficients between source-destination, and source- ith relay, respectively. The terms n_{sd} and n_{sri} denote the AWGN channel noise.

In the second phase, the first relay decodes the signal it received from the source, re-encodes it and transmits it to the other (2nd) relay and the destination. The second relay combines the signal received from relay 1 and the source as shown in (2)

$$y_{r2} + \sqrt{P_o} h_{sr2} Y_{sr2} + \sqrt{P_i} h_{r1r2} Y_{r1r2} \quad (2)$$

where the channel coefficient between the first and the second relay is represented by h_{r1r2} and the signal received at the second relay from the first relay, denoted as Y_{r1r2} is given as

$$y_{r1r2} = \sqrt{P_i} h_{r1r2} x + n_{r1r2} \quad (3)$$

The *(N+1)* phase, in our case, the third phase, and the second relay decodes, encodes and retransmits its signal to the destination. Hence the signal detected at the destination is a combination of the source and relay 2's signals expressed as,

$$y_d = \sqrt{P_o} h_{sd} y_{sd} + \sum \sqrt{P_1} h_{rid} yrid \quad (4)$$

Relay Selection Algorithms

In relay selection process, a communication pair selects relay(s) out of their common neighbours. Thus, the challenge of relaying when a selection of a specific relay is successful is reduced.

Relay selection is vital to the success of any cooperative diversity system. For a relay to be selected for transmission, it must be in the source transmission range to support the nodes communication.

Choosing a relay, partner or set of them in a cooperative communication is a challenging task. For its effectiveness for the improvement of overall performance of the network in terms of higher data rate/throughput, better bit error rate performance and lower power consumption, its challenging nature is traded off for this advantage. The performance indicesguide the selection of any relay. Prominent amongst these indices are channel state information (CSI), signal-to-noise ratio (SNR), packet error rate (PER). Relay selection algorithms can be classified into three major categories (Shah & Gharge, 2012), groupselection, which can be proactive selection and on-demand selection. But generally, the relay selection algorithm can be summarized into five categories, namely: Measurement-based, Performance-based, Threshold-based, and Table-based.

Channel capacity

Shannon, specified under proper assumption, the limit of data rates for the capacity of Additive White Gaussian Noise (AWGN) channel. Shannon-Hartley theorem states that considering all possible encoding techniques, the theoretical highest upper bound on the information rate (excluding error correcting codes) of clean (or arbitrarily low bit error rate) data (meaning channel capacity, *C*) that can be sent with a given average signal power *S* through an analogue communication channel subject to additive white Gaussian noise of power *N*(Dai & Poor, 2003), is:

$$C = B \log_2 \left(1 + \frac{S}{N} \right) bps \quad (5)$$

where, *C* is the channel capacity in bits per second; *B* is the bandwidth of the channel in Hertz, *S* is the total received signal power over the bandwidth, measured in watts or volt^2, *N* is the total noise or interference power over the bandwidth, measured in watts or volt^2, and *S/N* is the signal-to-noise ratio (SNR) or the carrier-to-noise ratio (CNR) of the communication signal power to the Gaussian noise interference power expressed as a linear power ratio.

The channel capacity benefits of the two transmission protocols (Amplify and Forward (AF) and Decode and Forward (DF)) models on selective relayingare presented in equations 6 to 9. Analysis of the channel capacity description of the three set objectives are herein highlighted.

$$\lambda_{SAF}^{pl} = \lambda_{sd}^{pl} + \max_i \left(\lambda_{sid}^{pl} \right) = \frac{A_2^2}{B_2} \qquad (6)$$

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

$$\lambda_{SDF}^{pl} = \lambda_{sd}^{pl} + \max_i \lambda_{id}^{pl} = \frac{\left(\sqrt{P_1^t} \left| h_{sd}^{pl} \right|^2 \right)^2}{\left| h_{sd}^{pl} \right|^2} + \max_i \left(\frac{\left(\sqrt{P_2^t} \left| h_{id}^{pl} \right|^2 \right)^2}{\left| h_{id}^{pl} \right|^2} \right) \qquad (7)$$

$$\lambda^{*pl}_{SAF} = \lambda^{*pl}_{sd} + \max_i \left(\lambda^{*pl}_{sid} \right) = \frac{A_3^2}{B_3} \qquad (8)$$

$$A_3 = \left(\sqrt{P_1^*} \left| h_{sd}^{pl} \right|^2 + \max_i \left(\frac{\sqrt{P_1^* P_2^*}}{\sqrt{P_1^* \left| h_{si}^{pl} \right|^2 + N_x}} \left| h_{id}^{pl} \right|^2 \left| h_{si}^{pl} \right|^2 \right) \right) \text{ and } B_3 = \left(\left| h_{sd}^{pl} \right|^2 + \max_i \left(\left| h_{id}^{pl} \right|^2 \left(\frac{\sqrt{P_2^*}}{\sqrt{P_1^* \left| h_{si}^{pl} \right|^2 + N_x}} + 1 \right) \right) \right)$$

$$\lambda^{*pl}_{SDF} = \lambda^{*pl}_{sd} + \max_i \lambda^{*pl}_{id} = \frac{\left(\sqrt{P_1^*} \left| h_{sd}^{pl} \right|^2 \right)^2}{\left| h_{sd}^{pl} \right|^2} + \max_i \left(\frac{\left(\sqrt{P_2^*} \left| h_{id}^{pl} \right|^2 \right)^2}{\left| h_{id}^{pl} \right|^2} \right) \qquad (9)$$

where $P_1^* = \frac{P_1}{N}, P_2^* = \frac{P_2}{N}$

Attenuation

Transmitted signal loses their energy as they travel down through a line. These loses are due to the fact that energy gradually dissipates in the resistive parameter per unit length, on both series and parallel platforms. This lose is called Attenuation, which results in the gradual decrease in the level of the transmitted signal.

The attenuation in signal power at a specified distance, D, from the signal source on a line is often expressed in decibel as (Areni et al., 2016);

$$A = 10\, log_{10} \frac{P_o}{P_s} \qquad (10)$$

Where, P_o is the signal power at point the specified distance from the signal source and $P_s$is the signal power at the source.

At times, attenuation is expressed in terms of voltage as;

$$A = 20\, log_{10} \frac{V_o}{V_s} \qquad (11)$$

Where V_o is the voltage is measured at the specified distance from the source and $V_s$is the voltage at the source.

On the power line network, because of its time-variant characteristics, suffers a great deal of attenuation. The greatest of all losses on the line is the cable loss (Duche & Gogate, 2014), since the cable is the transmission medium, it is described as the power dissipated due to conductor and insulator properties of the cable. The attenuation suffered on the PL line increases with frequency (Duche & Gogate, 2014).

There are three causes of cable losses on the PL line, they are;

- ✓ Resistive loss
- ✓ Dieletric loss
- ✓ Radiated loss

Resistive loss are losses through the skin effect of the conductor, the variation of voltage across the dielectric of the cable is responsible for the dielectric loss, while radiated loss is very insignificant and often negligible.

The signal propagation constant, Υ, as signals travels through the cable is a function of the attenuation factor, α, which increases with the square root of frequency (Hooijen, 1998).

Cooperative Relaying in Broadband Over Powerline

Various researches have been conducted in the area of implementing cooperation in broadband over powerline towards better performance in applications and services such as internet surfing, video streaming, HDTV and internet of things (IOT).

An analysis of the suitability cooperative system in broadband over powerline for improved performance was carried out by Juan et al. (Valencia et al., 2014). He deployed AF and DF protocols in thesystem while implementing the combining techniques of equal gain combining (EGC), selection combining (SC) and maximal ratio combining (MRC) at the destination (receiver) end, over a frequency band of 1.75 to 100 MHz.

A dual-hop amplify-and-forward relay assisted PLC system was investigated, following an information-theoretic perspective, for channel capacity improvement in the presence of only coloured background noise by Xilin et al. (Cheng et al., 2013). Opportunistic decode-and-forward over in-home broadband over powerline network was investigated for power saving by Salvatore et al. (D'Alessandro et al., 2011). In his work, cooperative system was considered for the provision of power saving, quality of service and extended coverage in the networks.

Ankit et al in (Dubey & Mallik, 2015) proposed the improved PLC performance with AF relaying. Theoretical approach was also implemented in describing the system performance. A multi-armed bandit approach was proposed for best relay selection in the PLC system by Babak Nikfar et al in (Nikfar & Vinck, 2017). The approach achieved performance improvement in the PLC, but the noise considered in the network is only synchronous impulsive.

System Model

The system model consists of three segments, the source, the relay (multiple) and the destination segments. Th relay segment of two deployment scenarios, 3 relays, and 5 relays. In each scenario they are sandwiched between the source modem and the destination modem following these location placements, 5 m, 10 m, and 15 m away from the destination modem. The relay (multiple) is both an OFDM receiver and transmitter equippedwith noise mitigation system, while the destination modem is represented as an OFDM receiver. This setup is shown in Fig. 1. The relay selection algorithm flows a set of instruction to select the best relay. All of these modems are BBPL modem. The cooperative transmission protocol (CTP) are AF and DF. The system noise was mitigated before the cooperative.

In multiple relaying, the best performing relay is selected for cooperation between the source modem and the destination node. An algorithm that will yields optimality in the systems' performance was developed. The best relay channel SNR was the algorithm driving parameter. 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) (Garg et al., 2013).

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

$$\lambda_i^{pl} fori = 1,2,3$$

$$\lambda_j^{pl} forj = 1,2,..,5$$

$$\lambda_k^{pl} fork = 1,2,\dots,7$$

- 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 optimal power allocation (OPA) not equal power allocation (EPA).

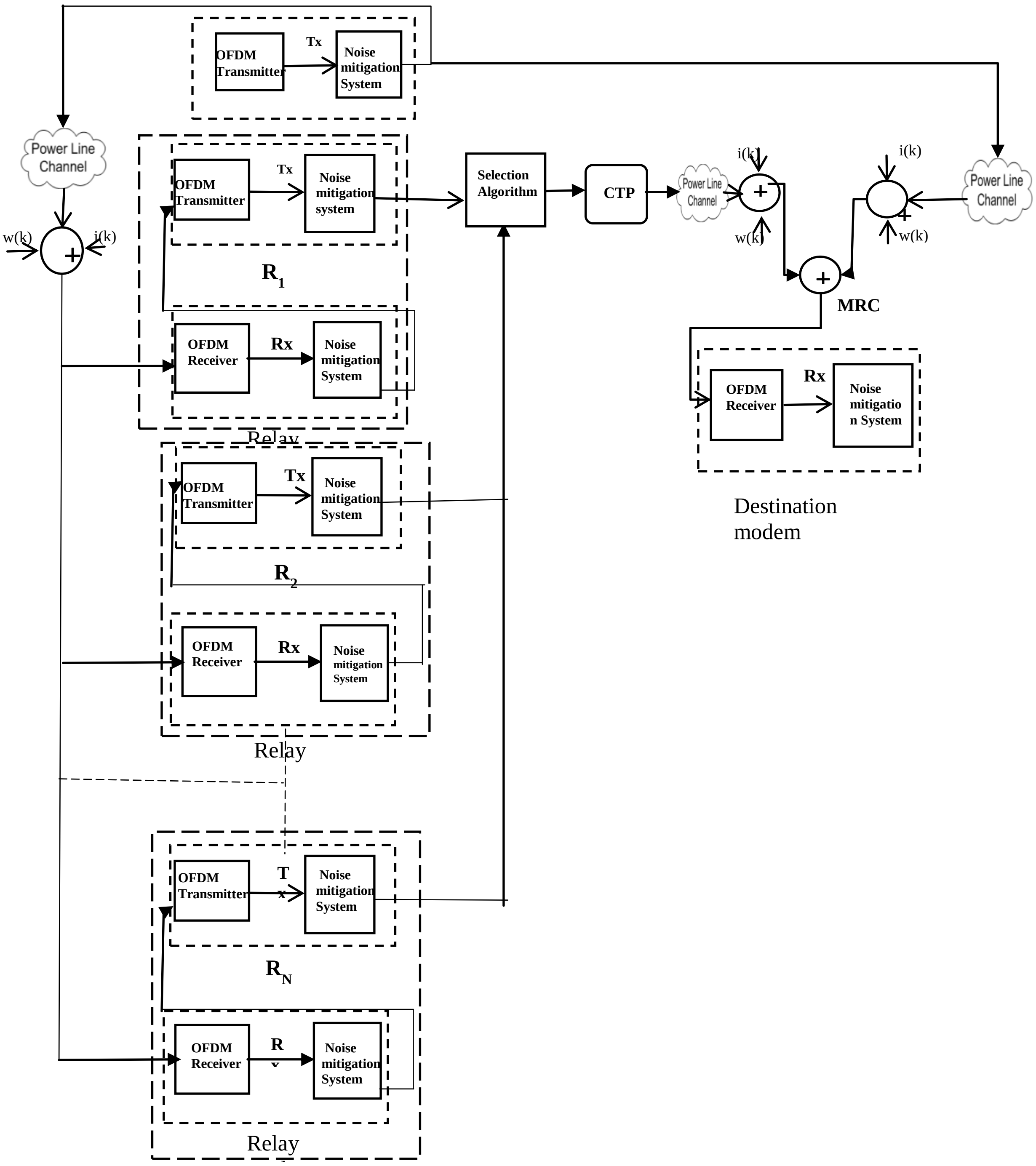

Figure 1:System Model

Optimal power allocation

The particle swarm optimization (PSO) technique was deployed for the heuristic process. Transmittable power (P_t) represents the particle in the PSO and the target is channel capacity (*CC*). The PSO was used to either minimize or maximize P_1 and P_2 for optimality of the channel capacity.

The objective function for both P_{min} and P_{max} used to perform the optimization are as given in Equations 3.16 and 3.17.

$$P_{\min} = \sum_{i=1}^{n} P_t(i) - \frac{1}{n} P_t(i) \qquad (13)$$

$$P_{\max} = \sum_{i=1}^{n} P_t(i) + \frac{2}{n} P_t(i) \qquad (14)$$

The PSO was simulated using the objective function described in Equations 13 and 14 for minimizing/maximizing the source power and relay power accordingly.

Five different power levels were identified following the EMC policy for the simulation. They are:

-12 dB, -11.25 dB, -12.3 dB, -11.98 dB and -12.35 dB (Vukicevic, 2008).

One thousand samples over one thousand iteration was used to perform the simulation.

The simulationsconverges around the five power levels used for the simulation and Table 1 shows the simulation result, which is the allocated power to source and relay (a function of the individual levels of power), for optimal performance.

Table 1: Optimization Simulation Result

Optimization Result	Power Levels (dB)				
	-12	-11.25	-12.3	-11.98	-12.38
$P_{s(min)}$	-4.000	-3.750	-4.100	-3.993	-4.126
$P_{r(max)}$	-8.000	-7.500	-8.200	-7.987	-8.253

The result reveals that the source power is minimized while the relay power is maximized for optimal power performance. The optimized power expressed as a ratio of the available transmittable power is;

$$P_s = \frac{P_{s(min)}}{P} = \frac{-4.000}{-12} = \frac{1}{3}$$

and

$$P_r = \frac{P_{r(max)}}{P} = \frac{-8.000}{-12} = \frac{2}{3}$$

Therefore, for optimal system's performance, the source power was minimized from $\frac{1}{2}P_t$ to $\frac{1}{3}P_t$ and the relay power maximize from $\frac{1}{2}P_t$ to $\frac{2}{3}P_t$, hence power ratio allocation for optimal performance is P_s: $P_r = \frac{1}{3} : \frac{2}{3}$.

Attenuation Analysis

The attenuation of all the systems developed in the thesis is analysed in this section. The attenuation analysis is done over the 20 m length network. For all schemes other than the Fixed PLCC, the attenuation is analysed at a percentage power transmission of 20%. For the Fixed PLCC, two percentage power transmissions were considered, 20% and 40%. 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.

II. Result and Discussion

The characteristic of the links attenuation with optimal power allocation scheme is shown in Figure 2. The savings in attenuation with respect to MIMO-PLC and PLC-repeater is shown in Table 2.

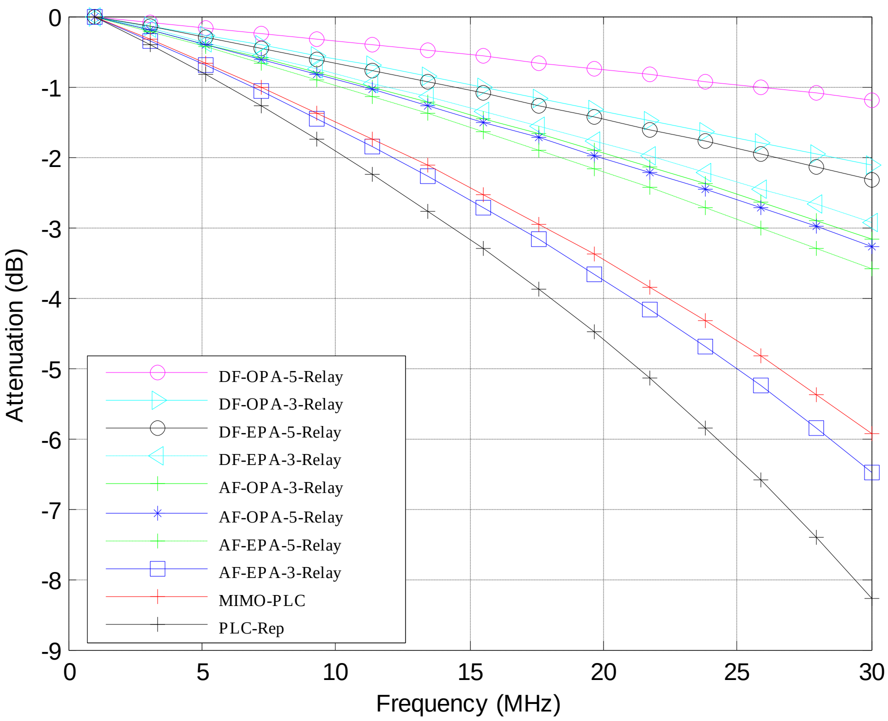

Figure 2: SBBPL-OPA Attenuation Characteristic

Table 2: SBBPL-OPA Percent Attenuation Improvement @ 15 MHz

Links	MIMO-PLC (%)	PLC-Repeater (%)
DF-5R	77.2	82.5
DF-3R	60	69.52
AF-3R	42.54	55.99
AF-5R	40.72	54.59

From the links attenuation improvement in Table 2, the OPA on the two cooperative protocols (AF/DF) yielded appreciable improvement. The 5-relay deployment OPA achieved 77.2% and 82.5% attenuation saving over the MIMO-PLC and PLC-repeater links respectively. All of these improvements were due to selective relaying deployed and the channel capacity enhancement of the cooperative links.

III. Conclusion

The inherent noise of the power line is the cause of severe attenuation on broadband data transmissionon it. Selective relaying, a cooperative system, and optimal power allocation was implemented in the BBPL. These techniques mitigate the attenuation better than the MIMO and repeater techniques. This effects yields increase in the viability of the broadband over power line for smart-grid system. Broadband data can then traverse the medium with less attenuation.

References

[1]. An, P., Chen, X., Wang, J., Zhou, S., & Shan, X. (2007). Analysis on Application of Repeater Technology in Powerline Communications Networks. 2007 IEEE International Symposium on Power Line Communications and Its Applications, 273–277. https://doi.org/10.1109/ISPLC.2007.371136

[2]. Areni, I. S., Palantei, E., Suyuti, A., Adnan, Yusnita, W. S., & Susanti, H. (2016). Attenuation measurement of laboratory-based PLC implementation. Internetworking Indonesia Journal, 8(1), 55–58.

[3]. Canova, A., Benvenuto, N., & Bisaglia, P. (2010). Receivers for MIMO-PLC channels: Throughput comparison.2010 IEEE International Symposium on Power Line Communications and Its Applications, 114–119.

[4]. Cheng, X., Cao, R., & Yang, L. (2013). Relay-aided amplify-and-forward powerline communications. IEEE Transactions on Smart Grid, 4(1), 265–272.

[5]. Cypress. (2011). AN62487 - Cypress Powerline Communication (PLC) Repeater Implementation. Www.Cypress.Com › Documentation › Application Notes, 001, 1–17.

[6]. D'Alessandro, S., Tonello, A. M., & Versolatto, F. (2011). Power savings with opportunistic decode and forward over in-home PLC networks. 2011 IEEE International Symposium on Power Line Communications and Its Applications, 176–181.

[7]. Dai, H., & Poor, H. (2003). Advanced signal processing for power line communications. Communications Magazine, IEEE, 919.
[8]. Dubey, A., & Mallik, R. K. (2015). PLC System Performance With AF Relaying. 63(6), 2337–2345.
[9]. Duche, D., & Gogate, P. V. (2014). Signal Attenuation in Powerline Communication Channel AFFECTING COMMUNICATION THE. International Journal of Emerging Trends & Technology in Computer Science (, 3(2), 123–130.
[10]. F. Gómez-Cuba, R. A.-C. and F. J. G.-C. (2012). A Survey on Cooperative Diversity for Wireless Networks. IT Professional, 14(5), 34–39. https://doi.org/10.1109/MITP.2012.71
[11]. Garg, J., Mehta, P., & Gupta, K. (2013). A Review on Cooperative Communication Protocols in Wireless World. International Journal of Wireless & Mobile Networks, 5(2), 107–126. https://doi.org/10.5121/ijwmn.2013.5209
[12]. Hooijen, O. (1998). On the relation between network-topology and power line signal attenuation. IEEE International Symposium on Power Line Communications and Its Applications, ISPLC. http://www.isplc.org/docsearch/Proceedings/1998/pdf/0452_001.pdf
[13]. Hunter, T., & Nosratinia, A. (2006). Diversity through coded cooperation. IEEE Transaction on Wireless Communications., 5(2), 283–289.
[14]. Kaur, G., & Bhattacharya, P. P. (2011). A Survey on Cooperative Diversity and Its Applications in variuos wireless networks. International Journal of Computer and Engineering Survey, 2(4), 133–152.
[15]. Lothar Stadelmeier, Dietmar Schill, Andreas Schwager,Daniel Schneider, J. S. (2008). MIMO for inhome power line communications. 7th International ITG Conference on Source and Channel Coding (SCC), 1–6.
[16]. Nguyen, H. (2011). Cooperative Transmission Techniques in Wireless Communication Networks [University of Saskatchewan].
[17]. Nikfar, B., & Vinck, A. J. H. (2017). Relay Selection in Cooperative Power Line Communication : A Multi-Armed Bandit Approach. Journal of Communications and Networks, 19(1), 1–9.
[18]. Shah, V., & Gharge, A. (2012). A Review on Relay Selection Techniques in Cooperative Communication. International Journal of Engineering and Innovative Technology, 2(5), 65–69.
[19]. Valencia, J., Oliveira, T. R., & Ribeiro, M. V. (2014). Cooperative power line communication: Analysis of Brazilian In-Home channels. 18th IEEE International Symposium on Power Line Communications and Its Applications, 301–305.
[20]. Versolatto, F., & Tonello, A. M. (2011). A MIMO PLC random channel generator and capacity analysis. 2011 IEEE International Symposium on Power Line Communications and Its Applications, 66–71.
[21]. Vukicevic, A. (2008). Electromagnetic compatibility of power line communication systems, 1–30.

Aiyelabowo O. Peter, et. al. "Mitigating Attenuation Through Selective Cooperative Relaying And Optimal Power Allocation In Broadband Over Powerline." *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)* 17(6), (2022): pp 13-20.