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Performance Analysis of Parallel Relayed Power Line Communication

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Abstract - **This paper is representing the performance analysis of a power line communication (PLC) system where the channel is log-normally faded and system model consists of a parallel relaying channel for the signal transmission from source to destination, assuming binary shift keying modulation scheme. The channel is corrupted by impulsive noise and background noise, hence the additive noise is considered as Bernoulli-Gaussian process. Also the performance analysis of parallel relayed power line communication system is carried out with varying threshold and varying the number of relays in the system.**

1. INTRODUCTION

The power line communication is a technology, a method of communication in which the existing power lines through existing power grids infrastructure is used to transmit data along with the electricity. It is benefiting as there is no requirement of establishing or setting up a new network separately for the data transmission. The grid network plays a major role in PLC [1]. The power distribution network is the main source for transmission as the data which is to be transmitted travels on through power lines [2]. Traditional power grids which were discovered by N.Tesla were based on the concept of central power generation and then distribution. The biggest advantage of it was that if the central or the primary distribution stages were interrupted all the users are affected. Power failure is a great threat to our nation; therefore it is call of the hour for the up gradation of the distribution system. Also, because of the increasing industrialization and technology there is a simultaneous increase of the energy demand. There are a number of problems in the traditional grids, which were addressed by the induction of smart grids [1].

Smart grids allow communication between home appliances to save energy and reduce the cost [3]. A smart grid induces changes like distributed power generation where, power is generated at different locations and then it is consumed. Therefore, if at all failure or problem occurs in one part, only the consumers of that part are effected not the whole system. It also reduces peak power requirements or peak loads in case of central power distribution systems. In traditional grids, the power flow and information flow follows a broadcasting pattern whereas in this power is generated and transmitted from the starting point and domestic users at the end points. In smart grids the advanced metering infrastructures (AMI)is induced, where the monitoring of peak loads or normal loads of remote areas their respective billing and the tracking of electricity charges and control of appliances is also done. Apart from these advantages smart grids is also neat and clean technology. In smart grids, alternative energy or renewable energy systems can also be used. For example, wind mills and solar panel systems can also be used to generate power or electricity for users, thus reducing the central power load or thermal power loads. The consumers themselves can use these renewable energy systems to develop power at their location. In this way, they can meet their power requirements and also can serve as power providing units as the increased power would be transmitted to the power grids. This power providing amount is subtracted from their total power consumption and hence net power and its billing is done, this is called Net Metering [4].

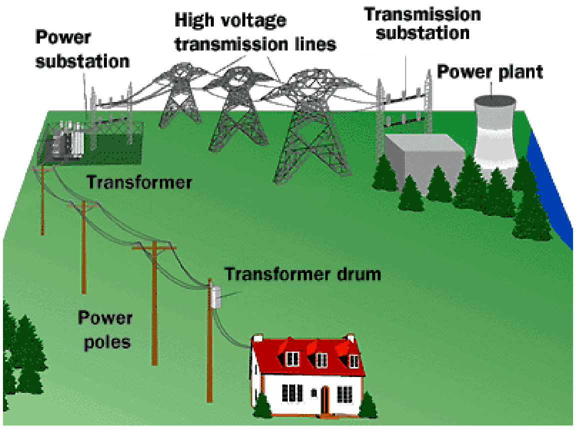

Fig.1 Generation of electricity and distribution to the end users.

PLC technology has proved a very promising and still developing technology [5]. PLC systems are being employed in home networking and in smart grids as well [6]. PLC as was not initially developed for data transmission and established only for electricity transmission, hence imposes a lot of difficulty and acts as a hostile medium for data transmission. PLC basically is of two types Narrowband PLC and Broadband PLC [7]. Narrowband PLC supports lower data rates and it also uses lower frequencies up to 500 KHz. The data rates supported by it may vary correspondingly depending upon the standards being used for PLC. Broadband PLC uses higher frequency range as up to 30 MHz but with lower ranges and higher data rates. It is used for last mile access also called as low voltage power line connecting users to substations.

The PLC system suffers from the additive noise. The additive noise in case of wireless channels is additive white Gaussian noise (AWGN). In PLC, the additive noise is a combination of both the kind of noises i.e., background noise and impulsive noise. Additive noise is represented by Bernoulli-Gaussian distribution. Apart from this the Bernoulli noise is also present in PLC, and the arrival of the impulsive noise follows a Poisson

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process [8]. The impulsive noise in PLC systems is caused by noise sources like electrical appliances such as vacuum cleaners, switched power mode supplies etc. Bernoulli- Gaussian distribution is used to model the impulsive noise because of its simplicity analytically. The spectral characteristics of this impulse source are represented by the Middleton class A distribution hence this distribution is very much used to model the impulsive noise in PLC provided in [9]-[10].

In [11] a multihop PLC system was analyzed where the channel is assumed to be log-normally faded in the presence of impulsive noise. In [6] the background noise is modeled using Nakagami–m distribution. In this measurements were taken over the range of frequencies 1 MHz to 30 MHz, it was concluded that the amplitude of background noise in time domain is represented by Nakagami-m distribution. In [12] the PLC system performance was analyzed over a Rayleigh fading channel. In [13] a maximum likelihood detector was calculated using the same distribution for background noise and correspondingly bit error rate was computed. In [14] the PLC system performance was analyzed over log-normal fading channel and the outage probability plotted.

2. EXISTING POWER LINE COMMUNICATION IMPLEMENTATIONS

The biggest advantage of power line communication is the infrastructure or the hardware which actually does not require a separate infrastructure as it makes use of the omnipresent power lines. It automatically reduces the cost of establishing the network hardware. The power line provides a higher degree of mechanical strength as compared to the normal telephone lines. Therefore, in adverse conditions these can withstand the damage in comparison to the telephone wires. The power lines have a large cross-sectional area than the telephone lines which results in a low resistance per unit length as the resistance is directly proportional to the area of cross section. Hence, it results in lesser attenuation. Power lines are well insulated so that there is less leakage. Largest spacing between conductors reduces capacitance, which reduces attenuation at higher frequency. Proper care has to be taken to guard these power lines and persons sing them. Reflections are also produced on lines connected to high voltage which increases attenuation. The noise introduced by the power lines is more as compared to the noise introduced in case of telephone lines [15].

The power line communication is being implemented in countries like China, Russia and USA. The two main regulatory agencies are federal communications commission (FCC) and European committees for electro technical standardization (CENELEC) [15] it basically regulates the band allocation, radiation emission and power transmission on band. In Europe, the allocated frequency band is 3 KHz to 1488 KHz. This frequency band is further subdivided into four bands as A, B, C and D bands. In china, the allocated frequency band is 3 KHz to 500 KHz as a single band. In USA, the allocated frequency band is 1 KHz to 490 KHz. The broadband over power line is being used by power companies to their area only because of a number of reasons. First reason is that we receive power ultimately at our residence after a number of power level changes right from the point of power generation, power transmission and then power distribution. Therefore, keeping the data signal through three different voltage levels (high voltage, medium voltage and low voltage) sustain or maintain is complex and also costly. The second reason is that the data signal when is passed over power lines it cannot pass over a transformer. Therefore by pass devices are used to pass the signal, hence the circuit system becomes complex and costly. Because of this, the data signals are separated before it is passed through transformer and then it is injected back to the power line. The noise that is impulsive noise also deteriorates the quality of signal.

3. SYSTEM MODEL

In dual hop communication, a transmitter /source sends the signal to a relay (R) node and in the next hop, the signal is transmitted to the destination node (D). If the multiple relays are incorporated into the network between S and D, then it is called as multi hop communication. If the multiple relays are incorporated parallel such that the receiver receives multiple copies of the signal is called parallel relaying. To receive better signal output from these received faded signals, we employ several combining techniques like maximal ratio combining, equal gain combining and selection combining. In equal gain combining technique, the receiver will combine all the SNR i.e., the overall SNR at D will be the sum of all individual SNR's. In maximal ratio combining, we give weights to each SNR and then combine all the SNR's. In selection combining, it will consider only the maximum SNR among all the SNR.

We consider a parallel–relaying power line communication where a source (S) and destination (D) with multiple relays are shown in fig (1). These multiple relays are denoted by R_1, R_2 and so on. Hence, it's a dual hop network employing multiple relays. The relays are following a particular pattern in which the nodes can transmit and also receive data or signal simultaneously at the same time. These relays need not to transmit in the orthogonal time slots for their transmission or reception. If node R_i is transmitting in the frequency f_{i+1} and receiving signal in the frequency f_i, then there is no overlapping of frequency and we are assuming that all the 'M' relays are operating at different frequencies so that the signal from one relay(R) does not interfere with the signal from another relay. We know that the frequency selectivity of any fading channel depends entirely on the coherence bandwidth. If the signal bandwidth is smaller than the coherence bandwidth of the channel then the signal undergoes flat fading and conversely if the signal bandwidth is larger than the coherence bandwidth of the channel then the signal undergoes a frequency selective fading.

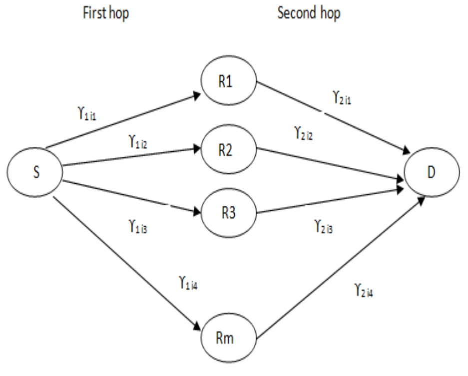

Fig.2 System model of a parallel relayed Power Line Communication system.

The coherence bandwidth measurements in response to a PLC channels are described in [16]. The system model which we are considering basically employs that the coherence bandwidth of the channel is more than the bandwidth of the signal. This assumption is valid for both type the narrowband and broadband transmission where coherence bandwidth is larger than signal bandwidth. Hence, the relay undergoes a flat- fading. The channels are assumed as independent as far as noise is considered; it is a mixture of both impulsive and additive white Gaussian Noise (AWGN).

The PLC system suffers from the additive noise. The additive noise is a combination of impulsive noise and background noise both. The additive noise is represented by Bernoulli-Gaussian Distribution. The impulsive noise in PLC systems is caused by noise sources like electrical appliances such as vacuum cleaners, switched power mode supplies etc. Bernoulli-Gaussian distribution is used to model the impulsive noise because of its simplicity analytically. The spectral characteristics of this impulse source are represented by the Middleton class A distribution hence this distribution is very much used to model the impulsive noise in PLC is literature. Apart from this the Bernoulli noise is also present in PLC and the arrival of the impulsive noise follows a Poisson process. In literature both the effects have been studied and the effect on PLC is also studied and it was observed that if the noise spectrum of a PLC is observed over certain time intervals then only background noise may be present while is some other parts both components are present. Hence at all the nodes or relays R_k, the noise is a mixture of independent impulsive noises and background noises. The total transmits power P_t is kept fixed. If P_t denotes the power transmitted by a relay R_k, then let P_{t-1} be the power received by this relay node. We are considering the data transmission by BPSK symbols i.e. unit energy symbols with equal probability of occurring. Let us assume the transmitted BPSK symbols by the source S be x and the channel gain be denoted by h then at the relay(R) the received signal can be denoted by

$$y = hx + N \quad (1)$$

Where, y is the received signal, x is the transmitted signal, h is the channel coefficient and N is the mixture of independent additive and impulsive noise.

Let the power of the received signal at node k be P_k, then eq (1) can be written as

$$y = \sqrt{P_{R_k}\, x\, h} + N \quad (2)$$

Where, $k = 1, 2......M$.

Also the received signal power P_{R_k} depends upon the transmitted signal power by the source P_s and R_k is the k_{th} relay node and the signal attenuation with physical distance d_i between the successive nodes. Let, P_L be the attenuation factor which is expressed in dB/distance. The transmitted and received powers can be expressed in watts and in dB, therefore the received signal power which is expressed in dB can be written as

$$P_{R_k}(dB) = P_{T_s}(dB) - P_L\,(dB/distance) \times d_i \quad (3)$$

Where k=1……. M

The power in decibels can be written as:

$$P(dB) = 10\log_{10} P \quad (4)$$

Also, for all the relay nodes (R) the received signal power Constraint can be written as:

$$P_{R_1} = P_{R_2} = P_{R_3} = P_{R_4} = P_R \quad (5)$$

The channel which we are considering follows a lognormal distribution. The fading amplitudes $h_1, h_2 \ldots.. h_n$ of the M-relay PLC systems are taken as independent and identically distributed (i.i.d) log-normal random variables, with its pdf defined by

$$f_{\Upsilon}(x) = \frac{1}{x\sqrt{2\pi\sigma_h^2}} \exp\left(-\frac{(lnx - \mu_h)^2}{2\sigma_h^2}\right) \quad (6)$$

where, the parameters μ_h and σ_h are the mean and standard deviation of the normal random variable G_j where, it is defined as $G_j = \ln(h_j)$. We assume here a unit energy fading channel as $E(h_j^2) = 1$ which implies that $\mu_h = -\sigma_h^2$.

The noise in the relayed PLC systems can be modelled as the summation of the noise samples as

$$z_k = z_{A,k} + z_{B,k} z_{I,k} \quad (7)$$

For $k = 1, 2, 3.....M$ where, $z_{A,k}$ represent the AWGN samples with zero mean and variance σ_a^2 and σ_I^2 respectively and $z_{B,k}$ represents a Bernoulli random sequence independent of $z_{A,k}$ and $z_{B,k}$ with parameter p, also both the background noise and impulsive noise are assumed to be independent because both have different origin and the overall noise samples $z_1, z_2 \ldots.. z_n$ are independent identical distributed random variables and their pdf:

$$P_{Z_K}(x) = \sum_{j=1}^{M} \frac{P_j}{\sqrt{2\pi\sigma_j^2}} \exp\left(-\frac{x^2}{2\sigma_j^2}\right) \quad (8)$$

We know that the plc experiences a coloured background noise. But the assumption of i.i.d noise shall suffice for the analysis and we assume that if each node operates in different frequency under FDD, then the noise power $N_{o,i}$ at the k_{th} relay node is

$$N_{o,k} = E[z_k^2]$$

$$= E[z_{A,k}^2] + E[z_{B,k}^2]$$

$$= \sigma_A^2(1 + p\eta) = N_o \quad (9)$$

where, represents the ratio of impulsive noise to background noise. Now let us consider the instantaneous signal to noise ratio (Υ_k) which can be written as $\Upsilon_k = P_{R_k} h_k^2 \,/\, N_{o,k}$. As the fading amplitude is log-normally distributed, hence the instantaneous signal to noise ratio is also log-normally distributed and its pdf can be expressed as

$$f_{\Upsilon_i}(x) = \frac{1}{x\sqrt{2\pi\sigma_{\Upsilon}^2}} \exp\left(-\frac{(lnx - \mu_{\Upsilon})^2}{2\sigma_{\Upsilon}^2}\right) \quad (10)$$

for $x \geq 0$ and where the parameters are defined as

$$\mu_{\Upsilon} = 2(\mu_h) + ln\frac{P_{r_k}}{N_o}, and\ \sigma_{\Upsilon} = 2\sigma_h \quad (11)$$

Now, the cumulative distribution function (c.d.f) of the instantaneous signal to noise ratio (Υ_i) is therefore given by

$$F_{\Upsilon_{x,y}}(\Upsilon) = 1 - Q\left(\frac{ln\Upsilon - \mu_{\Upsilon}}{\sigma_{\Upsilon}}\right) \quad (12)$$

As our system model consists of two hops from source to relay and from relay to destination, hence the instantaneous cdf can be expressed for source to relay and from relay to destination using the above eq (12).
The equivalent cdf of a link from source to a relay and from a relay to destination can be written as

$$F_{\Upsilon_{eq,k}}^{DF}(\Upsilon) = \left(\min\left(\Upsilon_{S\,R_k}, \Upsilon_{R_k\,D}\right) < \Upsilon_{th}\right) \quad (13)$$

$$F_{\Upsilon_{eq,k}}(\Upsilon) = F_{\Upsilon_{S\,R_k}} + F_{\Upsilon_{R_k\,D}} - F_{\Upsilon_{S\,R_k}}.F_{\Upsilon_{R_k\,D}} \quad (14)$$

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where, $F_{\Upsilon_{S R_k}}$ and $F_{\Upsilon_{R_k D}}$ follows equation (12) and are independent identical distributed random variables. In this, if a relay is selected out of the M available relays in each transmission slot. The relay is selected in such a way that it has maximum SNR from S to D. We are considering DF protocol hence, the signal is received and is decoded at the relay (R) node and it is re-encoded and transmitted to the D.

The single relay selection is according to the equation

$$\Upsilon_{eq}^{max} = \arg\max[\,\Upsilon_{eq_i}] \qquad (15)$$

$$\text{for } i \,\epsilon[1, 2, ...M]$$

4. PERFORMANCE ANALYSIS

Performance of any wireless or wired communication can be measured on the basis of the signal to noise ratio (SNR) and SNR depends on the type of fading the signal has undergone. These are various performance matrices like error probability, outage probability and SNR. SNR as already mentioned above is itself a performance parameter. The signal with high SNR has better performance. Error probability is a matrix dependent on modulation choice and not on channel. Outage probability is a matrix dependent on the channel and not on the modulation choice. The outage probability is the probability that the received instantaneous SNR is below some specified threshold values. For a channel if we set a threshold value for its SNRΥ_{th}, then it is a parameter to check whether received signal SNR is higher than threshold or not i.e. $Prob[\Upsilon_{rec} < \Upsilon_{th}]$. It is assumed that the threshold remains same for all the available relay links.

A. *Outage Probability Of Single (i_{th}) relay end to end*

Consider $\Upsilon_{S R_i}$ as the instantaneous signal to noise from source(S) to any relay link (R_i) and let the instantaneous signal to noise ratio from relay (R_i) to destination (D) as

$\Upsilon_{R_i D}$. The equivalent cdf of any source to destination (say k) through any relay link can be expressed as

$$P_{out}(\Upsilon_{eq}) = Pr(\Upsilon_1 < \Upsilon_{th}) + Pr(\Upsilon_1 > \Upsilon_{th}).Pr(\Upsilon_2 < \Upsilon_{th})$$

$$= F_{\Upsilon_1}(\Upsilon_{th}) + [1 - F_{\Upsilon_1}(\Upsilon_{th})]F_{\Upsilon_2}(\Upsilon_{th})$$

$$= F_{\Upsilon_1}(\Upsilon_{th}) + F_{\Upsilon_2}(\Upsilon_{th}) - F_{\Upsilon_1}(\Upsilon_{th}).F_{\Upsilon_2}(\Upsilon_{th}) \quad (16)$$

where, Υ_1 and Υ_2 are signal to noise ratio from source to relay and relay to destination respectively.

B. *Outage Probability Of Maximum Selection Protocol*

The maximum selection protocol is selected as per the relay is selected. The CDF of the highest end-to-end SNR ($\Upsilon_{eq_i}^{\max}$) for the PLC is

$$F_{\Upsilon_{eq}^{\max}}(\Upsilon) = \Pr\left(\max\left(\min\left(\Upsilon_{S\,R_i,R_iD}\right) < \Upsilon_{th}\right)\right)$$

for independently non identical distribution, the equivalent cdf can be written as for M number of relays as

$$F_{\Upsilon_{eq}^{\max}}^{DF}(\Upsilon) = \prod_{i=1}^{M} F_{\Upsilon_{eq_i}}(\Upsilon)$$

C. *Results*

The performance analysis has been carried out in MATLAB simulating environment. In this paper, we obtain an equivalent signal to noise ratio and plot the outage probability. In the first plot, Fig.3 a plot between outage probability and average SNR is carried out. We conclude that if we increase the value of σ_h, keeping the threshold values constant, the system performs better. The system performs much better when the number of relays are increased from 1 to 2. Also if we further decrease the value of threshold from 8dB to 5dB the system performs much better, but for the increasing number of relays the system has again proved to be better.

In the second plot, Fig. 4 again a plot of outage probability and average signal to noise ratio has been drawn, where we keep the value of σ_h, constant and correspondingly varying the values of Υ_{th} from 5 to 6 dB we found that for the same number of relays, the system with small threshold value performs better than the one with higher value of threshold. In the other plot even on increasing the threshold value, the system performs better than the earlier ones. Hence, in a nut shell we can conclude that the system performs better with higher values of threshold and much better with the increased values of number of relays.

In the next plot, Fig.5 it is clear from the plots that by keeping the threshold values constant the system performs better with the increasing number of relays. When the threshold value is decreased, the system performs much better for more number of relays. The more projected the curve towards x-axis the better the system performance than the above curves. Hence, it can be concluded that with increasing number of relays the system performs better because it serves the purpose of diversity. The diversity is currently in a developmental phase. The purpose of employing diversity is that it uses the combination from different sources or paths to construct the signal at destination.

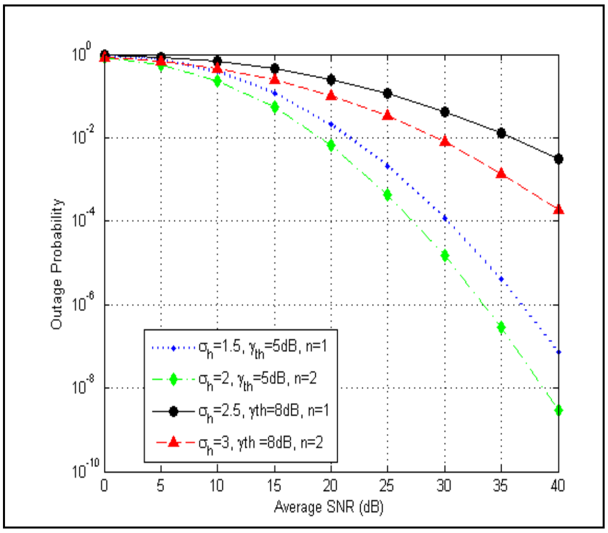

Fig. 3 Plot of Outage Probability vs. average SNR, keeping the values of Υ_{th} constant and the value of σ_h varying.

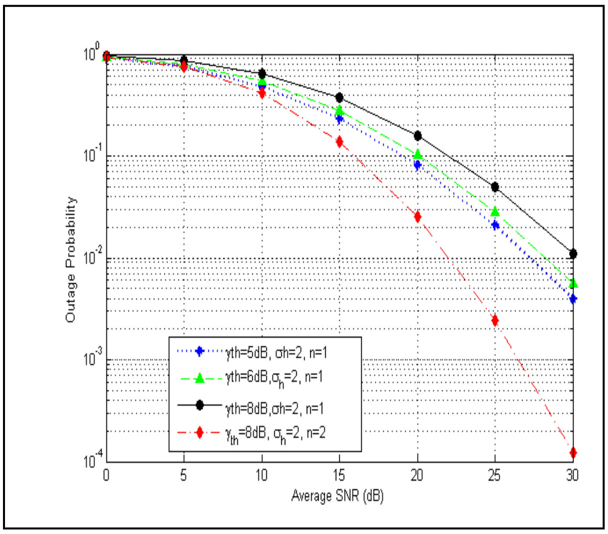

Fig.4 Plot of Outage Probability vs. average SNR, keeping the values of σ_h constant and the value of Υ_{th} varying.

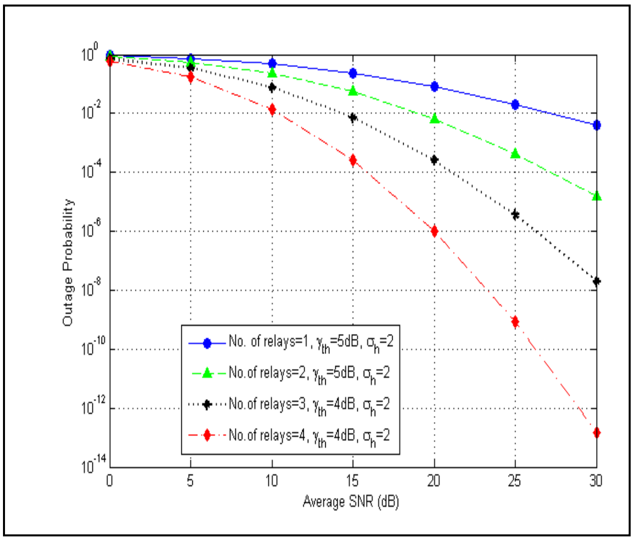

Fig.5 Plot of Outage Probability vs. average SNR, keeping the values of σ_h and Υ_{th} constant and the number of Relays varying.

5. CONCLUSION

In this paper, we have studied how the signal propagates from source to destination through multiple relays. In a multihop communication, the purpose of extension is solved whereas in a parallel relay communication, where a single source and a destination are being served by multiple relays, the purpose of diversity is solved. Also as we increase the number of relays the system performance is much better. It is observed from the results that the parallel relays PLC system outperforms a conventional PLC system with direct transmission between transmitter and receiver.

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