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Development of a mathematical model for filtering unwanted signals in power line communication system

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ABSTRACT

Power Line Communication (PLC) is one of the technologies using existing power cables for the transmission of data and information. It has the ability to provide broadband access to homes and workspaces. However, the performance of PLC decreases due to the noise interference produced by the electrical devices which are connected to the power line. Therefore, there is the need for noise reduction model to minimize the noise effects and increase the performance of the PLC network. This study therefore developed a tractable and accurate mathematical model for power line communication that helps in filtering unwanted signal (noise) in the system based on experimental measurements. The impulsive noise was introduced and analyzed to detect the noise in the PLC system. The Adaptive notch filter using Least Mean Squares (LMS) algorithm was modeled for a PLC to reduce the periodic impulsive noise in the system using MATLAB and the Bit Error Rate (BER) in the system was investigated. The system was simulated with 26 nodes network by varying the distance between the nodes ranging from 10 to 100 metres. The performance evaluation of the PLC with adaptive LMS filtering was analyzed without and with impulsive noise. It was discovered that adaptive filter reduced the effects of impulsive noise by decreasing the BER and increasing the performance of PLC system. The simulation results of PLC system with adaptive notch filtering (noise) indicated better results when compared to PLC system without adaptive notch filtering.

Keywords: Power Line Communication, Impulsive Noise, Bit Error Rate, Least Mean Squares, Filtering, Mathematical Model, Adaptive Notch Filter.

1. INTRODUCTION

Power Line Communication (PLC) is one of the communication technologies that use Medium Voltage (MV) and Low Voltage (LV) distribution networks as the communication media for transmission of data and information. In recent time, applications of PLC in smart grid such as vehicle to grid communications, automatic meter reading, traffic light control, micro inverters and building automation among others has been receiving widespread attention [1]. However, the existing power cables were originally designed for supplying power to the electrical appliances and these electrical appliances produce noise. In addition to these, channel characteristics between the noise sources and a receiver vary synchronously as the mains voltage as shown in Figure 1. The channel fluctuations are the causes of the periodic features of the noise [2, 5].

This noise interference is one of the main impairments and a significant parameter that defines the nature and performance of PLC systems. It is therefore, required to study the channel noise characteristics of a PLC [3]. In general, at low frequency band, the noise is more energetic than at higher frequencies in PLC technology which results in performance degradation of PLC systems. The noise level is directly proportional to the number of electrical devices that are connected to the power lines. The behavior of noise is abrupt and therefore finding out a solution to reduce the effects of noise in order to improve the PLC network's performance require more than just using the existing reduction methods [4, 6, 9].

Some of the existing noise reduction techniques in PLC are clipping, blanking, nulling, Forward Error Correction (FEC) and filtering. However, these techniques sometimes cause distortion and might unable to reduce noise in PLC system [3]. Therefore, the noise reduction techniques which perform better than the existing techniques are needed. An additional element of a system operation using PLC technology should be filtered so as to separate the undesirable signals (noise, interference, disturbances) from the desired signal in the PLC channel. Therefore, the need for a low-current, compact, cost-effective and single-phase filter for distributed PLC home automation applications is thereby important. Hence, in order to study communications in a man-made impulsive noise environment, a simple filtering model (such as adaptive filter) that expresses the noise behavior in closed-form equations is essential [2, 7, 8, 11].

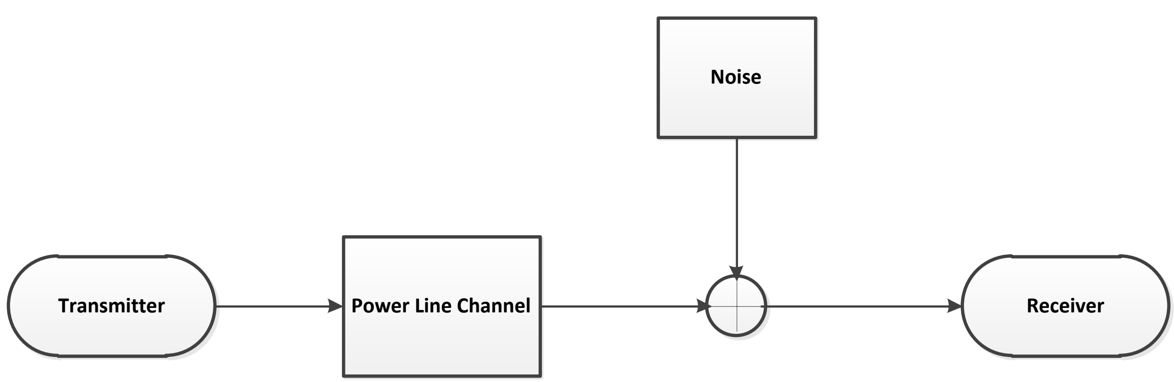

Figure 1: PLC Channel Characteristics between the Noise Sources and a Receiver

A. Power Line Communication System

Power Line Communication (PLC) system is defined as a process of sending data via electrical power supply networks in which both the signals (electrical and data) are transmitted in a single channel. PLC takes place in three basic blocks like the other communication systems [4]. Its major components are the transmitter, the channel and the receiver. The transmitter modulates the data and injects the data into the PLC channel. The channel transmits the data from the transmitter to the receiver while the receiver demodulates the data [10, 11].

PIC provides various services like home automation, internet access, among others. The PLC technology can be divided into two; Broadband PLC and Narrowband PLC. These are discussed as follows [5]:

i. Broadband Power Line Communication (BPLC): The BPLC operates at high frequency range of 1.8–250 MHz with data rates up to hundreds of megabits per second and is used to provide broadband internet access. BPLC has gained a lot of advantages in the last decade. It does not need any installation process and is capable of delivering data at a high speed.

ii. Narrowband Power Line Communication (NBPLC): This type of PLC operates at low frequency range from (3-500) kHz. The NBPLC with LV and MV power lines can be indoor or outdoor communications. NBPLC are capable of data rates up to 500 kilobits per second and more reliable, secured, cost-effective, reliable and more favored for home automation and smart metering.

The PLC is usually made of different types of conductor, joined at random and terminating into various loads of impedance. The amplitude and phase response of this transmission medium vary widely with frequency while the signal at the receiver arrived with very little loss over some frequencies. However, the channel transfer function itself is time varying since plugging in or switching off of devices connected to the network change the network topology [1, 5, 9].

B. Noise in Power Line Communication

Noise is any unwanted signal that causes an obstruction to the needed signal in a communication network. Noise disturbs the information or data sent by the transmitter to the receiver through the channel. In addition PLC network is susceptible to noise from devices linked to power supply infrastructure, such as; fluorescent tube lights, washing machine, drill, hair dryers, microwave ovens, computers among others. These devices generate noise on the power line communication network [6]. However, BPLC atmosphere is highly exaggerated by noise, attenuation and line impedance of channel. Therefore, to design a high speed power line communication system, a detailed study on the effects and characteristics of the noise channel is needed [1, 10, 11].

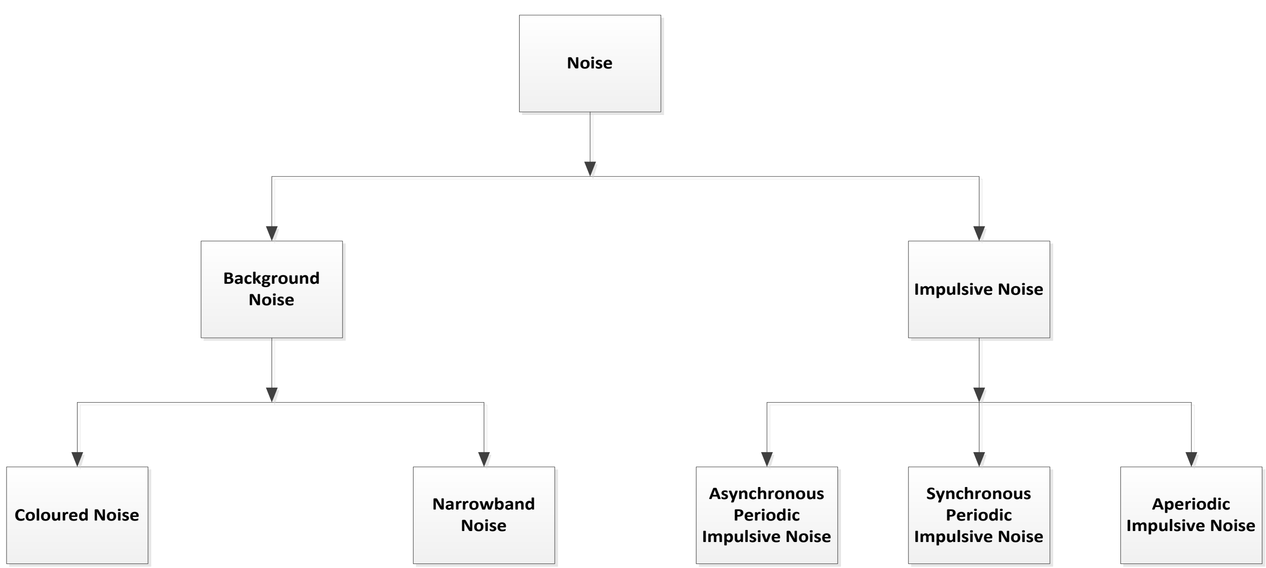

Figure 2: Noise over PLC channel

According to Tayel and Hasanien (2017) in the low voltage power line, noise could be categorized into two as background noise and impulsive noise. These can be further broken down into five general classes as; coloured background noise, narrowband noise, periodic impulsive noise asynchronous to main frequency, periodic impulsive noise synchronous to main frequency and aperiodic impulsive noise as shown in Figure 2. Coloured background noise is occurred as a result of trimmings of multiple sources of noise with low power. Narrowband background noise which consists of amplitude modulated sinusoidal signal occurred as a result of broadcasters and radio stations. Periodic impulsive noise is an impulsive noise which is asynchronous to mains frequency and occurred as a result of switched-mode power supplies. Synchronous periodic impulsive noise to mains frequency occurred as a result of switching actions of rectifier diodes found mostly in electrical appliances. Aperiodic impulsive noise is an impulsive noise caused by switching transients in the power network [6, 8, 9, 11].

Noise can also be classified as; gaussian noise, time variant noise, and time invariant continuous noise. Gaussian noise is a kind of random signal with different intensity at different frequencies. It is considered as a background noise and its main source is the connection of the network which added to the main signal thereby reducing the system performance. Time-variant noise is a noise that has an envelope that changes synchronously as the mains absolute voltage. Time-invariant continuous noise is also a background noise caused by superimposition of many appliances that create disturbances for a long period of time. In low frequency range this type can be modeled by Gaussian model [1, 5, 8, 11].

C. Noise Reduction Techniques

The type of noise that normally occurs in PLC is impulsive noise which is a noise with alpha-stable behavior. This noise in the power line network causes high Bit Error Rate (BER). The noise is mainly generated from electrical appliances connected to the power line and it's hard to predict in the transmitted data over PLC. This impulsive noise is the cause of the low quality of PLC system which affects data transmission between the nodes. Therefore, there is a need for noise reduction techniques to subside the harmful effects of impulsive noise in order to enhance the performance of the PLC network [2, 3, 6, 9].

The effects of this noise can be minimized using a level limiter and other existing noise reduction techniques such as time domain (clipping), time/frequency domain, and error correction code. Bayesian learning technique, recursive detection technique, adaptive filtering technique and Discrete Multi-Tone Transceiver (PLC-DMT) are the other mitigation techniques used for noise reduction in PLC network. These techniques were used because of their simplicity [1, 4, 7, 8].

D. Power Line Channel Filters

The basic function of filters in PLC network is to suppress the undesirable component frequencies that may occur in the control signal. In order to design filters that can be used for de-noising in PLC, the design filters should have details of discrete model of power line noise. This model is necessary for designing the receiver and the modulation schemes in PLC [7].

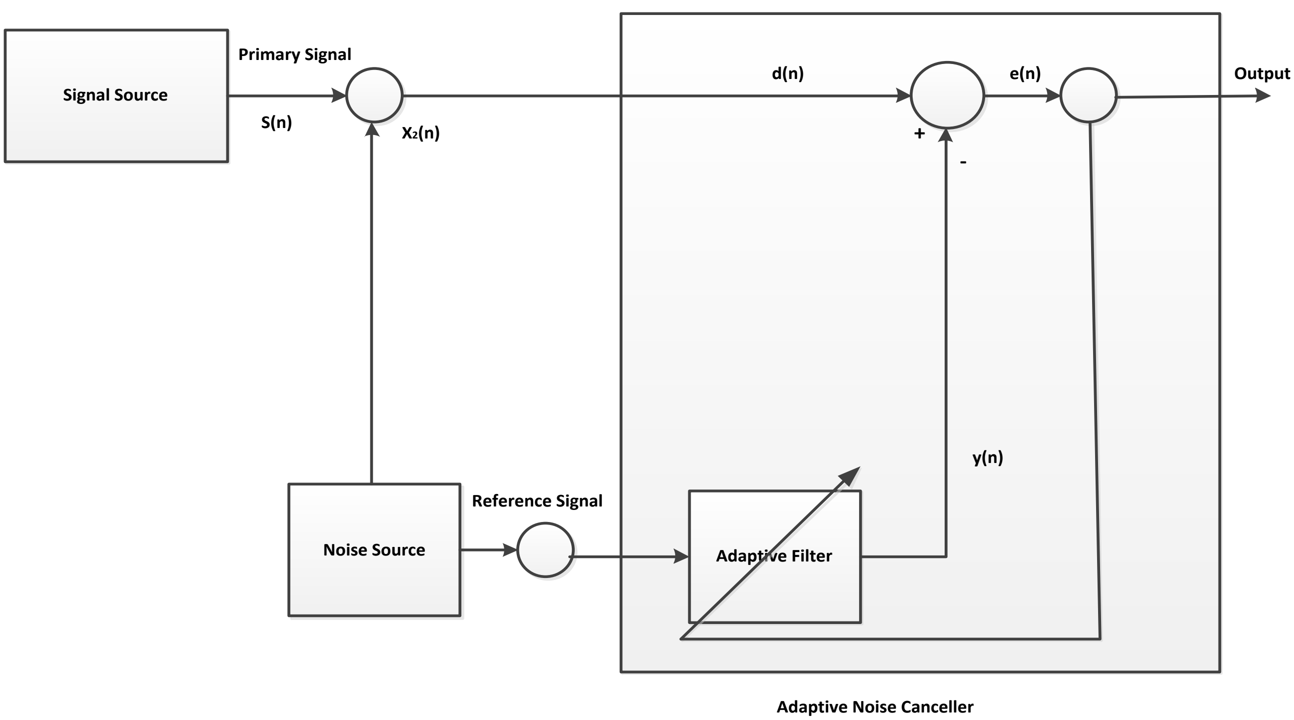

Figure 3: Adaptive Noise Cancellation System

By considering an appropriate criterion such as; the amplitude and phase, the type of elements that are used, the shape of the frequency characteristics, the technology in the system execution and level, filter systems can be categorized into different groups. Thus, there are different filters such as; low-pass, high-pass and band-pass including broadband, narrowband and band-stop which can suppress any signals in a specific frequency band [3, 5].

In addition, one of the most employed filters in PLC is adaptive filter. Adaptive filters or adaptive noise canceller are filters whose tap weight vectors vary with time as shown in Figure 3 [5]. In this filter, the reference signal is adaptively filtered and subtracted with input signal, which resulted as the estimated signal. The Orthogonal Frequency Division Multiplexing (OFDM) transmitted signals are interfered with periodic impulsive noise when signals are transmitted through the power line cables. However, with implementation of adaptive filtering using Least Mean Square (LMS) algorithm, these corrupted signals can be recovered. By using adaptive filtering the BER of PLC systems are reduced and thus system performance improves [5, 8, 11].

Adaptive filters system consists of two inputs; primary input signal $d(n)$ which is the desired transmitted signal that corrupted with periodic impulsive noise and reference input signal $X(n)$ which is the undesired noise that must be filtered out in the system. The uncorrupted signal produced with adaptive filter using LMS algorithm filtered is given as [5]:

$$e(n) = s(n) + x1(n) - y(n) \tag{1}$$

Then the output $y(n)$ is subtracted from the primary input to produce the system output $e(n)$.

2. MATERIALS AND METHOD

The main objective of this study is to minimize the effects of unwanted signal (noise) in Power Line Communication System (PLC). The performance of PLC was analyzed to obtain the system conditions before the introduction of noise. The impulsive noise was introduced to PLC and its characteristics were analyzed to detect the noise in the PLC system and maximum values of the signals were calculated. Adaptive notch filter was implemented as discrete filtered to suppress the periodic impulsive noise in the system and to enhance the network's performance in the presence of impulsive noise using the Bit Error Rate (BER). The Adaptive notch filter using Least Mean Squares (LMS) algorithm was modelled for a PLC using MATLAB and the system was simulated with 26 nodes network by varying the distance between the node ranging from 10 to 100 meters. The process was carried out using mathematical modelling and then, the performance evaluation of PLC with adaptive LMS filtering was analyzed without and with impulsive noise.

A. Mathematical Modelling of PLC System Filters

The basic function of filters in PLC network is to restrain the undesirable frequencies that may occur in the control signal. The details of discrete model of power line noise are required in design the filters that can de-noising the noise in PLC system. This model was derived from adaptive noise cancellation system shown in Figure 3.

The impulsive noise sources with duration ranging from hundreds of microseconds to a few milliseconds are calculated using equation (2):

$$i_{cs}(t) = A_{cs}V(t)\sum_{k-1}^{n} \exp\left(\frac{-i + \dfrac{k}{2f_{AC}}}{\tau_{cs}}\right)\theta\left(t - \frac{k}{2f_{AC}}\right) \tag{2}$$

The spectral density of this noise is shaped as a result of measured spectrum of impulsivity in practice Power Spectrum Density (PSD) decayed at an approximate rate of 30 dB per 1 MHz. The impulsive noise output signal envelope in time domain is given as:

$$S(t) = \frac{1}{\sqrt{N}}\sum_{k=0}^{n-1} S_k \exp\left(j\frac{2\pi kt}{T}\right)\cdot P(t)\ 0 < t < T \tag{3}$$

It is assumed that the number of subcarriers is large enough so that the real and imaginary parts of the OFDM signal $S(t)$ can be modeled as Gaussian random variables. The received signal of additive noise channel is given as in equation (4). The receiver structure was modified in order to deal with impulsive noise $i(t)$.

$$R(t) = S(t) + \omega(t) + i(t) \tag{4}$$

In addition, the nodal network distance between numbers of bit is calculated as:

$$d(v_1, v_2) = \sum_{k=0}^{n-1} XOR(v_1(t), v_2(t)) \tag{5}$$

Hence the minimum distance between the numbers of bit is given as:

$$d_{\min} \geq 2t_c + 1 \tag{6}$$

$$d_{\min} = \min_{i \neq j} d(v_i, v_j) \tag{7}$$

According to Varma *et al.,* (2019), a typical power line could span across 5 km to 50 km. In a PLC network, data signal can travel long distance due to attenuation, noise and distortion. As the distance increased, the signal attenuation increased and the effect of noise in the power line channel increased. In order to overcome these limitations, adaptive filter was implemented.

For the adaptive filter model, the desired signal was the signal with the presence of impulsive noise. When the impulsive noise signal passed through the adaptive filter, the filtration process took place and the noise was filtered. The uncorrupted output $y(t)$ is given as:

$$y(t) = \omega(t) * x(t) \tag{8}$$

The input signal for a new weight is given as:

$$\omega(t) = \omega(t-1) + \mu * e(t) * x(t) \tag{9}$$

The error signal is calculated by subtracting the filter output from the desired signal as:

$$e(t) = d(t) - y(t) \tag{10}$$

where; A_{cs} is a constant, τ_{cs} is decaying time parameter, $V(t)$ is complex white Gaussian noise process with zero mean and variance one, and $\theta(t)$ is Heaviside step function, N is the number of subcarriers, T is duration of one OFDM symbol, $P(t)$ denotes the root-raised-cosine pulse shape with roll-off factor 0.25, $S(t)$ denotes the desired signal, $\omega(t)$ is complex Gaussian noise, and $i(t)$ represents the impulsive noise which is not Gaussian, $x(t)$ is the reference input signal where the impulsive noise signal was given, $y(t)$ is the product of the new weight, $\omega(t)$ is the summation of old weight function and the product of the step size, $d_{\min}$ is the minimum distance, t_c is the bit error positive integer and v_i and v_2 are code words.

B. Simulation of Mathematical Modelling of PLC System Filters

Simulation of the Least Mean Squares (LMS) adaptive notch filter was done in MATLAB environment. MATLAB scripts were written to assess the behavior of the PLC channel without and with impulsive noise and with adaptive LMS filtering. The input bit stream was generated randomly using convolution coding at the end of the transmitted. The performance of the PLC system was analyzed in the presence of impulsive noise in terms of BER.

The parameters used for adaptive notch filter and the simulation parameters are shown in Table 1 and Table 2 respectively.

Table 1: Adaptive Filter Parameters

Inputs		Outputs	
x	Input signal	Y	Output of the filter
d	Desired signal	E	Error signal
M	Filter length		
μ	Step size factor		
ω	Weight function		

Table 2: Simulation Parameters

Parameters	Value
Number of nodes	26
Distance between the nodes	10 to 100 meters
Noise scheme	15 e^{-10}
Step size	0.2
Order of filter	5

The simulation procedure for Adaptive filter using LMS algorithm for minimizing the noise which is interfered with PLC signal is as follows:

Step 1: Input system data and adaptive filter parameters
Step 2: Initialize the algorithm by setting all filter coefficients to zero (0).
Step 3: Calculate the estimation error by subtracting the desired signal from the filtered signal as shown in equation (10).
Step 4: Updated the estimate error by the summation of old estimate and product of adaptation, constant estimation error and tap input using equation (9).
Step 5: Constitute the filtration process using equation (8).
Step 6: If the periodic impulsive noise is detected, the notch filter filtered the frequencies above threshold value, otherwise increase the iteration number by one and then go to step 2 and repeat the computation.
Step 7: Calculate the nodes network distance between number of bit and stop.

Figure 4 shows the flowchart of adaptive filter using LMS algorithm for this study.

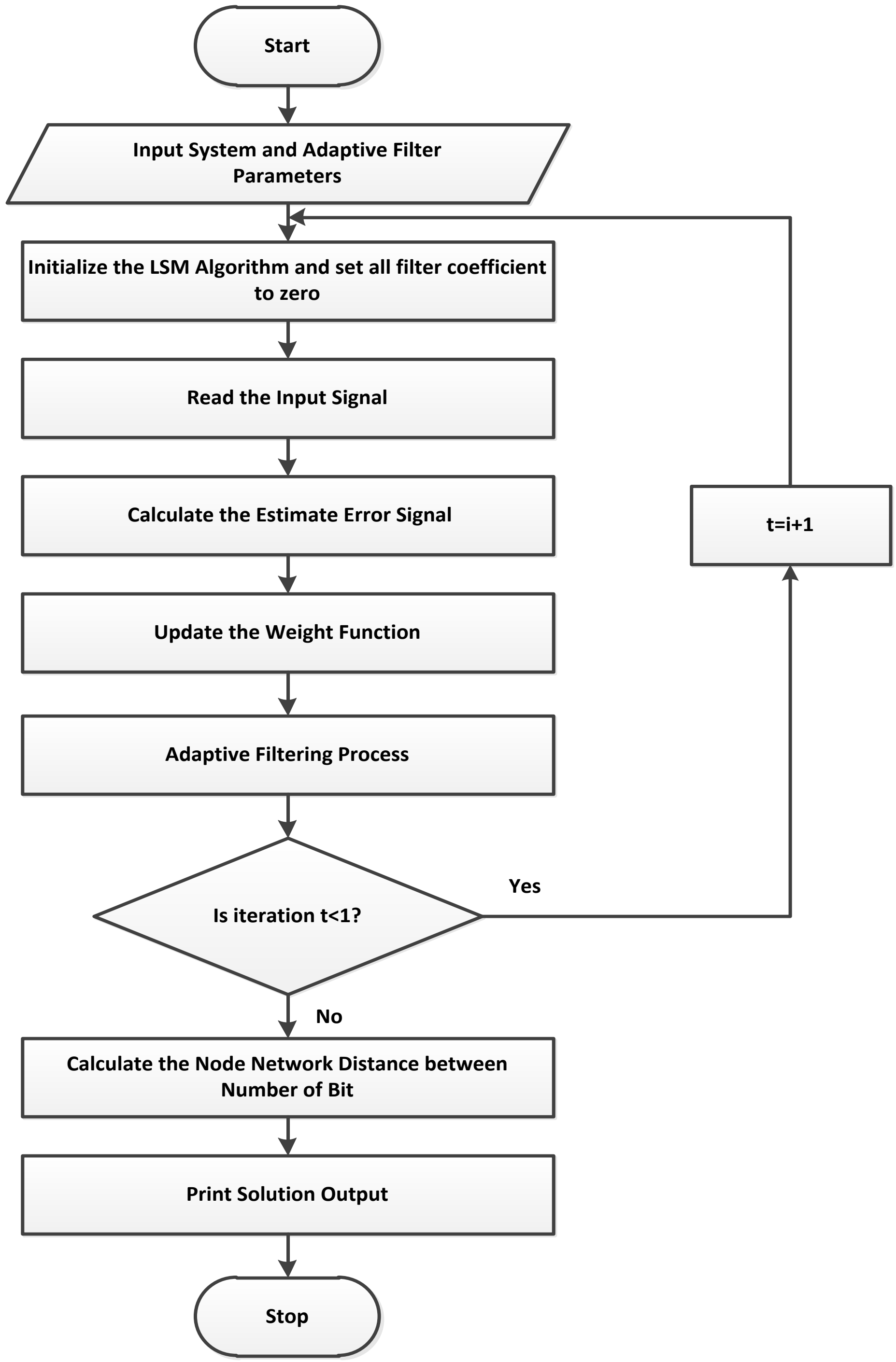

Figure 4: The Adaptive Notch Filter Flowchart

3. RESULTS AND DISCUSSION

The simulation results of the mathematical modelling of adaptive notch filter using Least Mean Squares (LMS) to reduce the effects of unwanted signal (noise) in Power Line Communication System (PLC) is presented in Figure 5 to Figure 12. The results were presented without and with impulsive noise, and with adaptive LMS filtering with the help of Bit Error Rate (BER) and node distance. The simulation was done with 26 nodes network and distance between the nodes was varied from 10 to 100 meters to analyze the behavior of the network.

Figure 5 shows the relationship between BER and node distance without impulsive noise in the PLC system. The values of BER for distance values ranging from 10 m to 100 m were 0.02, 0.025, 0.03, 0.03, 0.03, 0.032, 0.037, 0.037, 0.038, 0.039, 0.04, 0.041, 0.043, 0.045, 0.05, 0.052, 0.058, 0.06 and 0.07 respectively. The result showed that as the node distance increased, the BER values also increased.

The relationship between BER and node distance with impulsive noise in the PLC system in Figure 6 showed that the values of BER for distance varied from 10 m to 100 m and 0.041, 0.044, 0.050, 0.052, 0.055, 0.057 0.058, 0.058, 0.059, 0.059, 0.06, 0.065, 0.078, 0.082, 0.085 0.087, 0.1, 0.12 and 0.12 respectively. The result showed that as the node distance increased, there was an exponential increase in signal attenuation of BER and the effect of noise in the power line channel increased. Therefore, the performance of the PLC network decreased gradually.

Figure 7 shoed the results of BER and node distance with adaptive LMS filtering. The values of BER for distance values ranging from 10 m to 100 m in the system are 0.029, 0.031, 0.035, 0.037, 0.039, 0.04, 0.042, 0.045, 0.048, 0.05, 0.055, 0.058, 0.062, 0.068, 0.072, 0.075, 0.082, 0.082 and 0.083 respectively. The result also showed that as the node distance increased, the BER values also increased. However, the BER value decreased with introduction of adaptive LMS filter compared to when the impulsive noise was introduced. Hence, the performance of the PLC network increased.

The performance of the PLC network without and in the presence of impulsive noise, and with adaptive LMS filtering noise reduction techniques was compared in terms of BER in Figure 8. There was an exponential increase in BER values when the distance between the nodes was increases. Also, the signal attenuation increases and the effect of noise in the power line channel increased. The results showed that BER values were high when the impulsive noise was introduced to the network and decreased with the introduction of noise reduction technique (adaptive LMS filter). It was shown that the introduction of adaptive LMS filter performed better by decreasing the BER value as well as increasing the performance of the PLC system with inclusion of impulsive noise.

Figure 9 indicated the relationship between BER and number of node without impulsive noise in the PLC system. The values of BER for number of node ranged from 1 to 26 and 0.0, 0.0, 0.05, 0.10, 0.14, 0.15, 0.17, 0.18, 0.18, 0.20, 0.21, 0.22, 0.22, 0.24, 0.24, 0.24, 0.24, 0.245, 0.24, 0.25, 0.27, 0.27, 0.28, 0.30, 0.32 and 0.33 respectively. The result showed that as the number of node increased, the BER values also increased. The BER obtained without the presence of impulsive noise was due to the presence of interference in the PLC channel.

The interaction between BER and number of node with impulsive noise in the PLC system were shown in Figure 10. The values of BER for BER for number of node ranging from 1 to 26 were 0.0, 0.0, 0.15, 0.17, 0.24, 0.25, 0.26, 0.27, 0.27, 0.29, 0.29, 0.29, 0.29, 0.29, 0.30, 0.31, 0.31, 0.32, 0.32, 0.32, 0.33, 0.34, 0.34, 0.34, 0.34 and 0.35 respectively. The result showed that as the number of node increased, there were significantly increase in signal attenuation and the effect of noise in the power line channel increased. Therefore, there was a decrease in the performance of the PLC network.

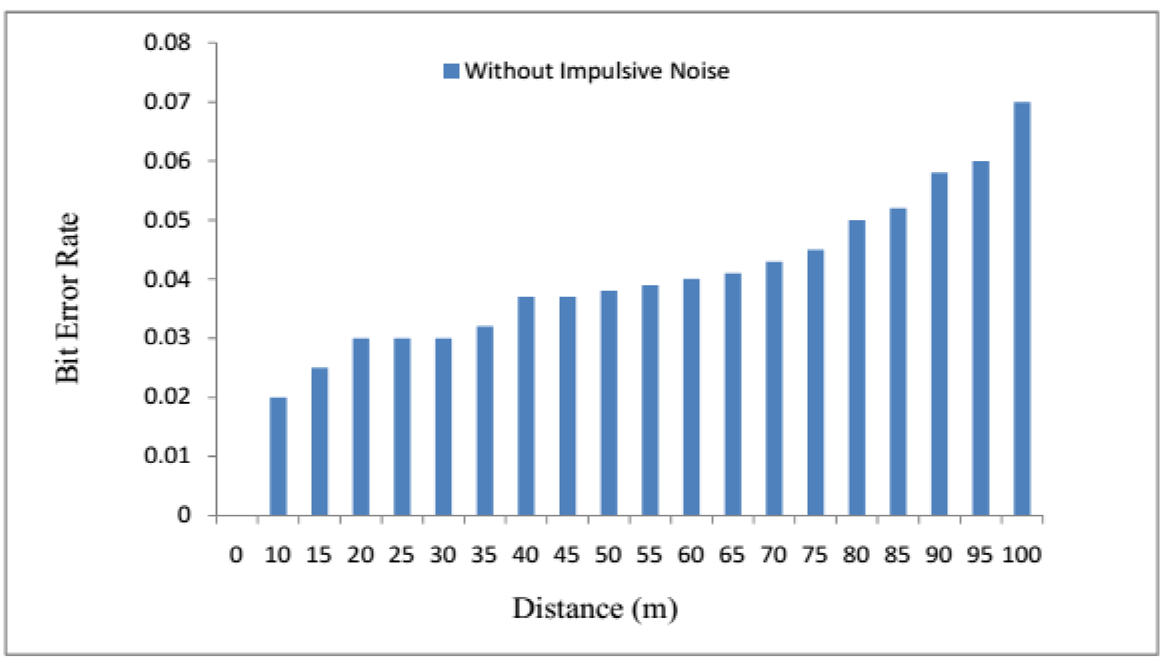

Figure 5: Bit Error Rate versus Node Distance without Impulsive Noise

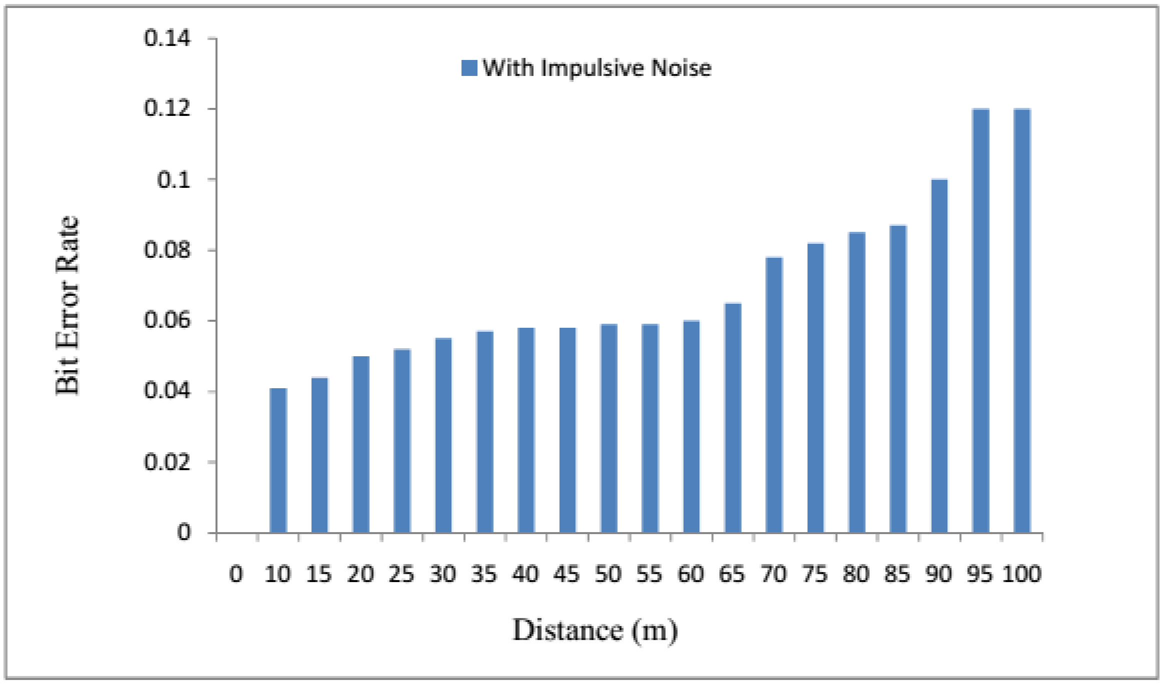

Figure 6: Bit Error Rate versus Node Distance with Impulsive Noise

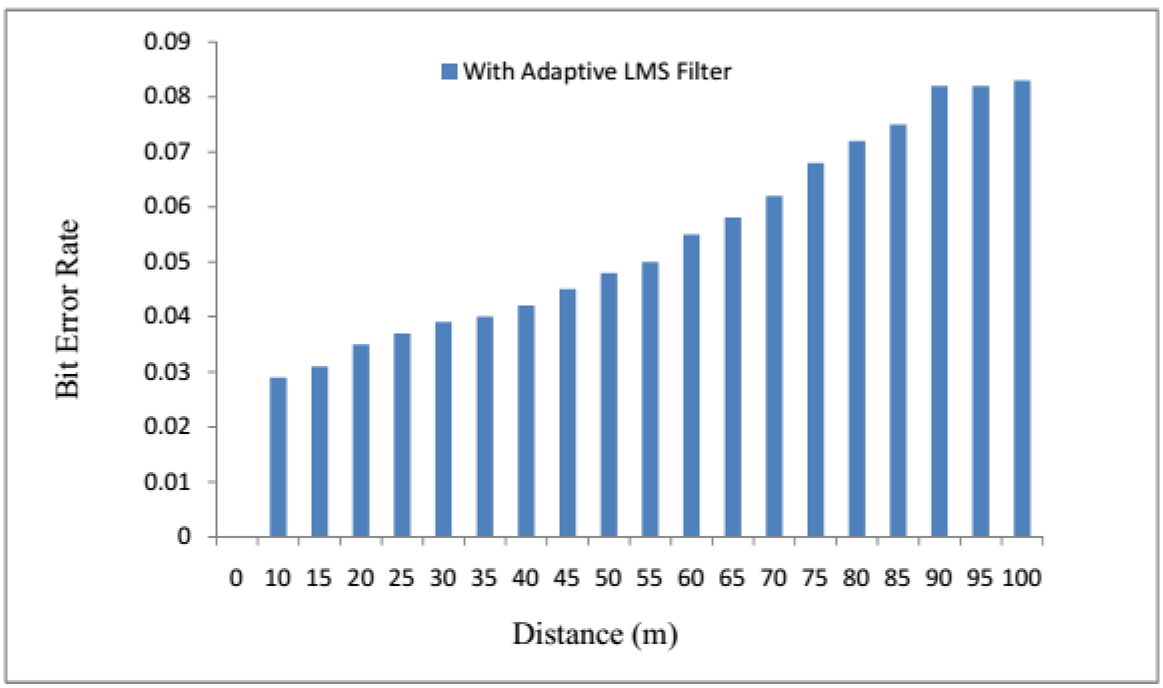

Figure 7: Bit Error Rate versus Node Distance with Adaptive LMS Filtering

The result of BER and number of node with adaptive LMS filtering is depicted in Figure 11. The values of BER for number of node ranging from 1 to 26 were 0.0, 0.0, 0.1, 0.13, 0.15, 0.19, 0.21, 0.22, 0.23, 0.25, 0.25, 0.26, 0.26, 0.27, 0.27, 0.28, 0.28, 0.29, 0.29, 0.29, 0.29, 0.30, 0.3, 0.3, 0.32 and 0.34 respectively. The result showed that as the node distance increased, the BER values also increased. In addition, with the introduction of adaptive LMS filter, the BER value decreased compared to when the impulsive noise was introduced and this improved the performance of the PLC network.

Figure 12 showed the comparison of performance of the PLC network without and with the impulsive noise and with adaptive LMS filtering noise reduction techniques in terms of BER and number of nodes. There was a significant deterioration in BER performance due to the influence of impulsive noise. Furthermore, there was a gradual increase in BER while increasing the number of nodes. However, as the number of node reached its saturation point, there was no significant change in BER value. The results showed that the introduction of adaptive LMS filter performed better by decreasing the BER value as well as increasing the performance of the PLC system with inclusion of impulsive noise.

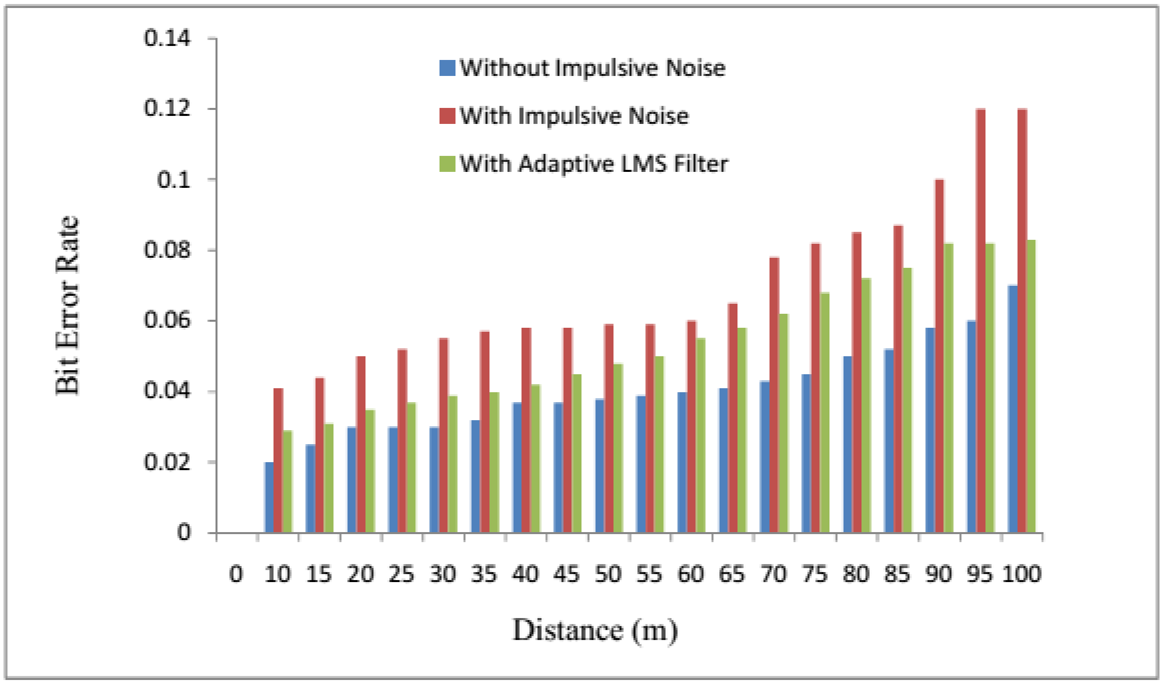

Figure 8: Comparison of Bit Error Rate versus Node Distance without and with Impulsive Noise, and with Adaptive LMS Filtering

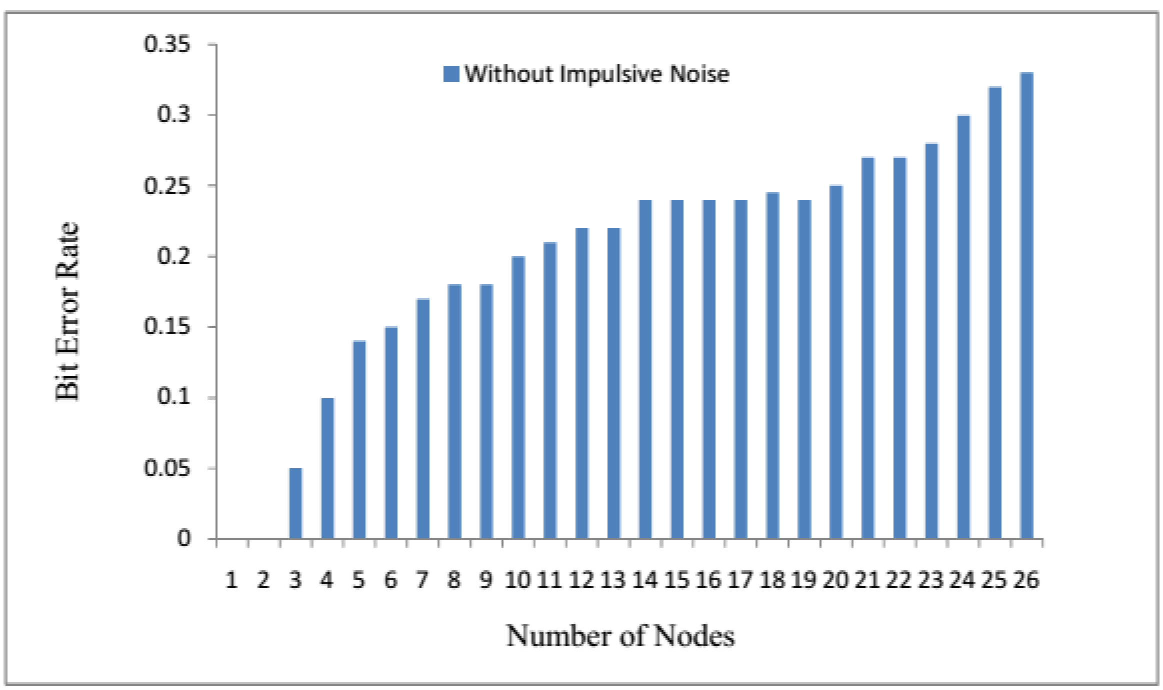

Figure 9: Bit Error Rate versus Number of Nodes without Impulsive Noise

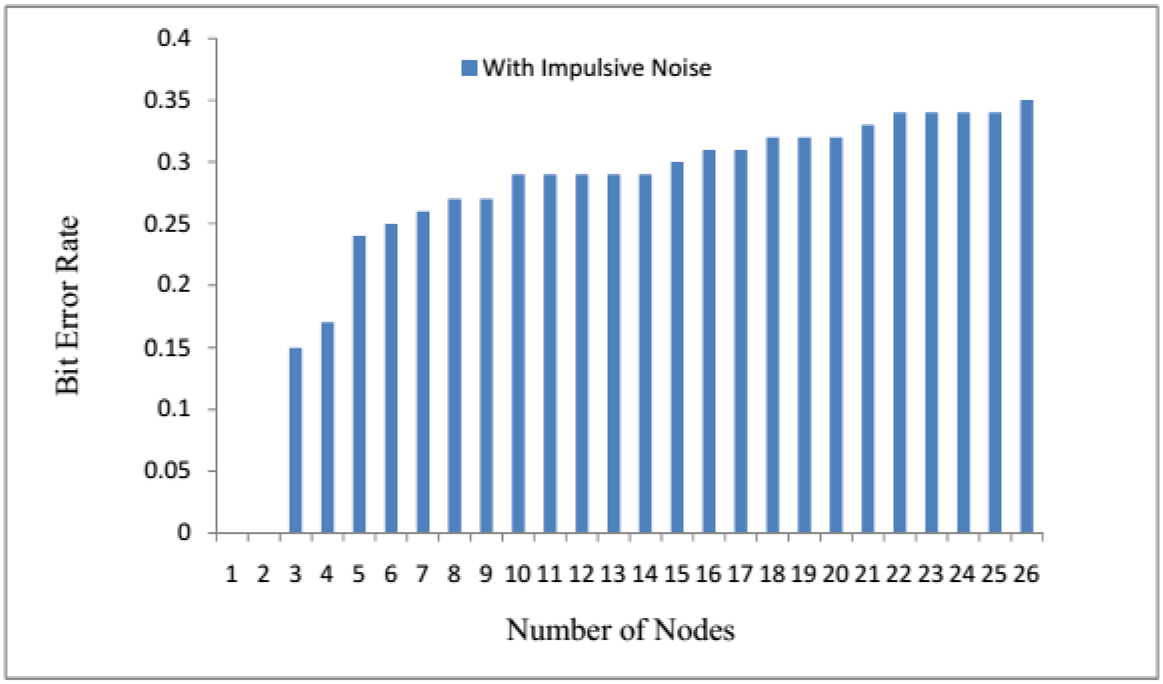

Figure 10: Bit Error Rate versus Number of Nodes with Impulsive Noise

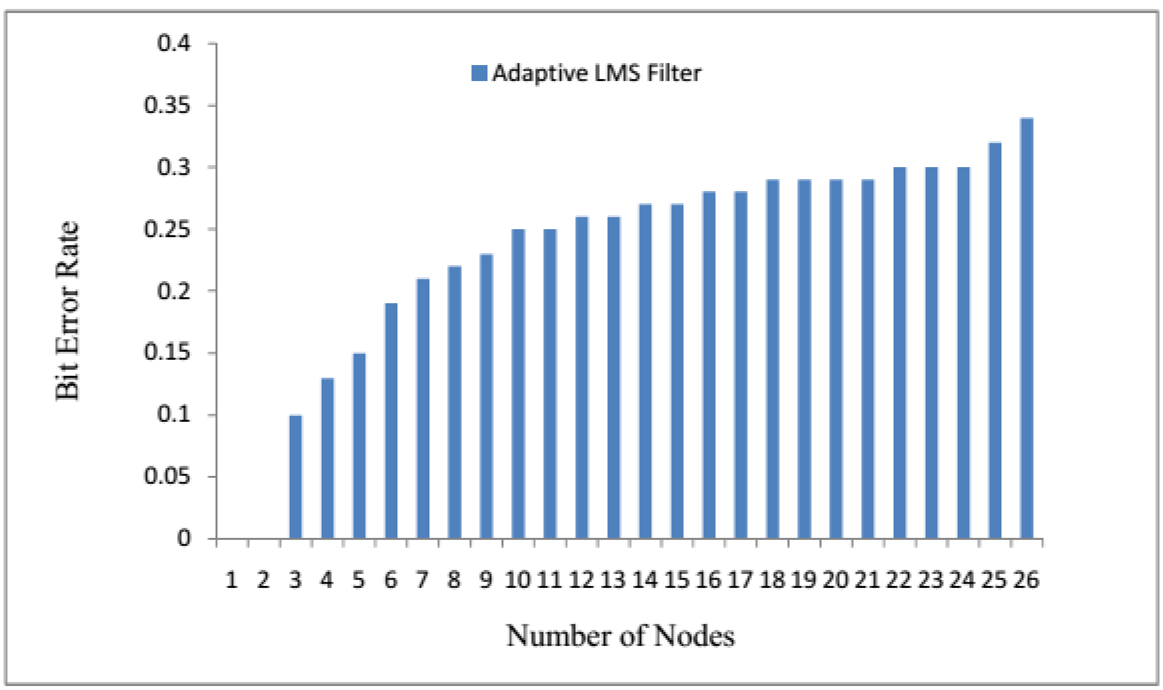

Figure 11: Bit Error Rate versus Number of Nodes with Adaptive LMS Filtering

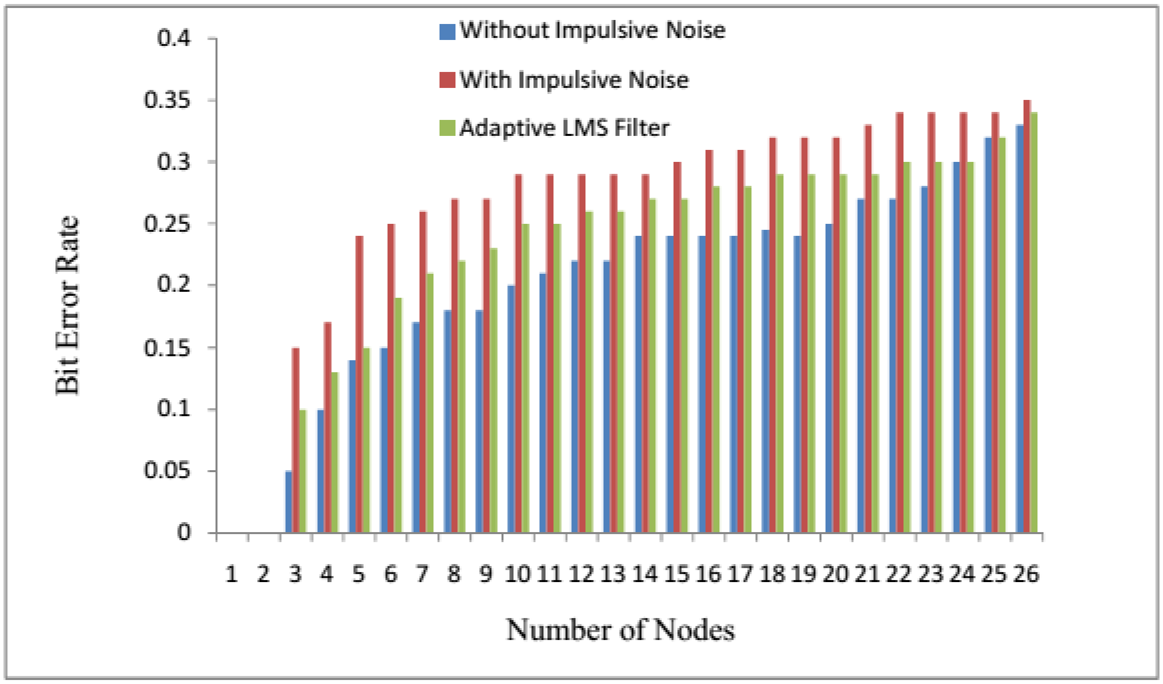

Figure 12: Comparison of Bit Error Rate versus Number of Nodes without and with Impulsive Noise, and with Adaptive LMS Filtering

4. CONCLUSION

This study has successfully developed an adaptive LMS filter mathematical model for periodic impulsive noise reduction in Power Line Communication (PLC) system. The Adaptive notch filter was modeled for a PLC using MATLAB to evaluate the behavior of the PLC channel. The model provided a benchmark for the design and evaluation of communication systems under the power line noise environment. In this study, the presence of impulsive noise was detected and then an adaptive notch filter was designed mathematically to mitigate and suppressed the impulsive noise. Simulation results showed that the adaptive LMS filter gave a better performance when compared to conventional PLC system. Simulation results showed that the value of BER of PLC system with adaptive LMS filtering decreased compared to the value of BER of PLC system without adaptive LMS filtering. The results also showed that the adaptive LMS filter gave a better performance than conventional PLC system. Therefore, adaptive LMS filtering could be effectively used for removing the periodic impulsive noise in PLS system.

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REFERENCE

1. Barazideh, R., Natarajan, B., Nikitin, A. V. and Davidchack, R. L. (2017): “Performance of analog nonlinear filtering for impulsive noise mitigation in OFDM-based PLC systems”, IEEE, 978-1-5386-2098-4/17, Pp. 1-6.
2. Bernacki, K., Wybra´nczyk, D., Zygmanowski, M., Latko, A., Michalak, J. and Rymarski, Z. (2019): “Disturbance and signal filter for power line communication”, Electronics, doi:10.3390/electronics8040378,Vo;. 8, No, 378, Pp. 1-17.
3. Hashiesh, F. and Soukal, P. (2009): “A proposed broadband power line communication system for smart grid applications in a typical Egyptian network”, 17th Telecommunications forum TELFOR 2009, Pp. 433-437.
4. Hashmat, R. (2012): “Characterization and modeling of the channel and noise for indoor MIMO PLC networks”, Signal and Image processing. Télécom Bretagne, Université de Rennes 1,Pp. 1-165.
5. Katayama, M., Yamazato, T. and and Okada, H. (2006): “A mathematical model of noise in narrowband power line communication systems”, IEEE Journal on Selected Areas in Communications, Vol. 24, No. 7, Pp. 1267-1276.
6. Mathew, S. and Murukan, P. (2014): “Periodic impulsive noise reduction in OFDM based power line communication”, International Journal of Research in Engineering and Technology, Vol. 03 Issue 05, Pp. 517-522.

7. Okafor, C.S. and Mbachu, C. B. (2018): "Enhanancing voice signal processing using blackman-haris windowed filtering technique", American Journal of Engineering Research, Vol. 7, Issue 11 , Pp, 27-32.
8. Reaz, M. B. I., Hussain, M. S. and Mohd-Yasin, F. (2006): "Techniques of EMG signal analysis: detection, processing, classification and applications", Biology Procedure, Vol. 8, No. 1, Pp. 11-35.
9. Tayel, M. B. and Hasanien, F. M. (2017): "Denoising method for power line communication", IOSR Journal of Electrical and Electronics Engineering, Vol. 12, Issue 2, Pp. 124-131.
10. Tonello, A.M, Pittolo, A. and Girotto, M. (2014): "Power line communications: understanding the channel for physical layer evolution based on filter bank modulation", The Institute of Electronics, Information and Communication Engineers, Pp. 1-10.
11. Varma, M. K., Jaffery, Z. A. and Ibraheem, J. (2019): Broadband power line communication: the channel and noise analysis for a power line network", International Journal of Computer Networks and Communications (IJCNC) Vol.11, No.1, Pp. 81-92.