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Orthogonal Frequency Division Multiplexing based Power Line Communication in Smart Grids Using Least Square Channel Estimation

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ABSTRACT

Smart grids are gaining popularity these days due to their immense advantages. Communication plays important role in Smart Grids Systems to coordinate between generation, distribution and consumption of energy. Noise in power lines significantly distorts the original data signal. In this paper, a novel technique is proposed to prevent the original signal distortion and bring about the end to end communication efficiency. In broadband Power Line Communication (PLC) at higher frequencies, the unshielded power lines act as radiating antennas which increases the chances of Inter Symbol Interference in the original signal. A technique, Orthogonal Frequency Division Multiplexing (OFDM) is proposed which uses Least Square Channel Estimator (LSCE) over PLC channel in the presence of impulsive noise. In OFDM the most challenging technique, i.e. LSCE significantly enhances the equalization at the receiver by high resolution channel estimation which subsequently improves the communication performance. The throughput of data is analyzed by means of computer simulations.

Keywords: *OFDM; Cyclic Prefix; Impulsive noise; AWGN; Power Line Communication.*

1. INTRODUCTION

The smart grid systems have gained worldwide attention recently for their intelligent energy supervision. Power Line Communication (PLC) is thought to play an imperative role in the performance of smart grids due to the inherent accessibility of power lines as energy carriers and the consequential compensation in terms of installation expenses [1]. PLC allows bidirectional communication [2]. The PLC device connected to the load loop is enabled to transmit data that propagates in the same fashion from the RX to the TX coil as a low power broadband signal [3]. Frequencies around 0 f should be masked at the physical layer in the PLC protocols which can be easily accomplished in the Home Plug AV devices that use the OFDM protocol. Smart grid is a reorganized electrical network that utilizes communications technology to assemble and proceed on information which might contain the responses of energy providers and consumers. This is accomplished in a programmed manner to develop the reliability, economics, sustainability and efficiency of the production and allocation of electrical energy. It was found that almost 50% to 70% of the electricity of any country is used by offices and homes. Present system of electricity distribution greatly lowers the efficiency and maintenance as it does not acknowledge the potential delivered from homes, factories or the offices [4]. To bring about this efficiency and maintenance, system of smart grids cooperating with smart houses is needed. In this smart architecture, smart homes, buildings, offices and other consumer places will communicate and contribute within the smart network and with external environment. Work is being carried out in different areas to make the future grids efficient and smarter. Some of innovations are as; (a). Management of in house energy that uses user feedback, real-time tariffs, allocation of services to energy providers & grid operators, and intelligent use of energy by appliances. (b). Collection Software architecture that uses agent technology for service delivery by groups of smart houses to wholesale markets & grid operators. (c). Managing of real-time tariff metering data and system-level management goals by consumption of services oriented architecture & powerful bidirectional coupling with the enterprise system. Orthogonal Frequency Division Multiplexing (OFDM) is becoming a prominent technique in wired networks and PLC. In the proposed algorithm, we have designed a LSCE for OFDM system which significantly improves the quality of OFDM system and communication efficiency.

The rest of the paper is organized as follows: Section II presents technology overview. Results and discussion is presented in Section III and finally Section IV concludes the paper.

2. TECHNOLOGY OVERVIEW

A. OFDM SYSTEM BASED POWER LINE COMMUNICATION

PLC uses power lines as a medium which, along with electricity flow, can accommodate the efficient bidirectional communication [6]. The theory of communicating through PLC is quite primitive, however, it wasn't brought into use for commercial purposes on immense scale because Power Companies kept this restricted to them only. The primary reason of this restriction is the fact that power line conveys power from generation terminal to the end users through three dissimilar levels, i.e. High Voltage (HV), Medium Voltage (MV) and Low Voltage (LV) levels. At the bottom of these stages, sustaining signal is very intricate and expensive wherein quality of the data signal can be kept well above the minimum threshold on same voltage level. Secondary issues include the irregular infrastructure of Power Line system, i.e. power lines are followed by the transformers and data signal cannot pass through the transformer. This could be fixed by using bypass devices across the transformers and data signal can be separated from the transformer and added again to the power line instead of going through the transformer. However, this adds overall cost to the system with increased complexity. Tertiary reason that makes PLC as an undivided option includes the transmission losses in power and distribution. Quaternary problem with PLC is that power lines are un-shielded act as antenna at higher frequencies and, therefore, frequencies of other power lines in the surrounding area can easily interfere. Finally, complication with Power Lines is that impulsive noise can easily be added to the signal which can completely destroy data signal in the system. All of these problems have been investigated by the researchers wherein OFDM is suggested as the most appropriate approach

B. POWER LINE COMMUNICATION ARCHITECTURE WITH OFDM MODEL

OFDM system based PLC shows great prospective in the future communication system for smart grid system. PLC is also known as Broadband over Power Line [7]. The Modeling of each part, i.e. PLC and OFDM system should be described to understand how these systems work together. For this purpose PLC model is divided into three parts: (a) PL (Power Line) Model (b) OFDM model based on LSCE (c) Noise Model that includes Additive White Gaussian Noise (AWGN) and Impulsive Noise.

- **Power Line Channel Model:** In every country, the power line transmits electricity of 50Hz. Power line has various types of noises such as the nodal topology mainly produces the multipath effects. Along the Power Line voltage changes to three different types of levels, i.e. LV, MV and HV levels. Figure.1 shows an example of advanced metering system architecture with PLC [8]. Different residences and commercial buildings are connected to the LV power line followed by the connection with the MV power line through the transformer. As different loads are connected to the power line and delivers variety of power, which along with the group of different cables creates impedance mismatch. This introduces multipath propagation of the data signal along the power line. Mainly two types of noises can be added to the signal, i.e. AWGN noise and impulsive noise. Power Line Communication Channel Model is given by [12]:

$$H(f)=\sum_{i=0}^{N} g_i.A(F.d_i).e^{-j2\pi F\tau_i} \qquad (1)$$

$H(f)$ is the transfer function representing PLC channel Model.

g_i is a weighing factor for the path i

$A(F.d_i)$ is attenuation part of the path i

$e^{-j2\pi F\tau_i}$ is Delay part of the path i

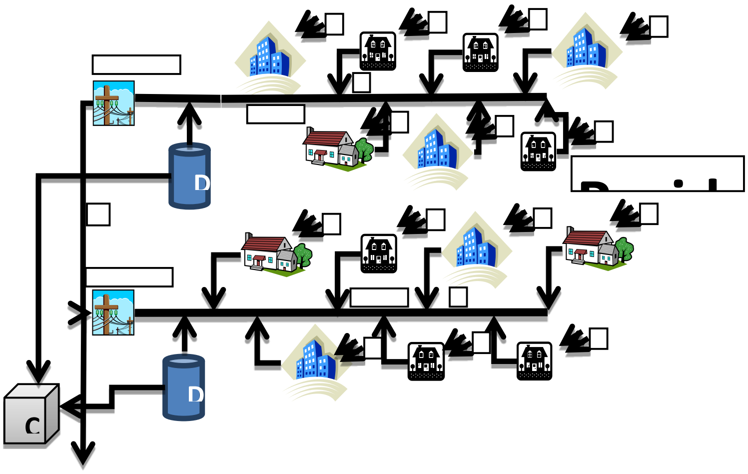

Fig. 1. PLC based Advanced Metering Infrastructure

- **OFDM Model:** OFDM, due to its great flexibility and computational productivity, is one of the top most processes existing. This technique includes both the modulation and process and multiplexing, where Modulation is actually the change in one of the signal parameters “frequency, phase or amplitude” and Multiplexing is the process of sending signals more than one using same channel with sustaining the veracity of these signals at the receiver end[9]. OFDM changes the given stream of bits of data into various parallel streams. With this conversion high bit rate also changes to lower bit rate. These parallel lower bit rate streams then pass through the modulator which modulates each of the streams onto separate carriers (also called subcarriers). FDM “Frequency Division Multiplexing” divides the given bandwidth into narrow channels to send multiple data streams at the same period of time. Here too the BW “Bandwidth” is divided into “n” number of channels. After Multiplexing Bandwidth of each channel where bit streams of lower bit rate is sent, is equal to the total bandwidth BW divided by the n number of channels.

$$f_2 - f_1 = BW/n \qquad (2)$$

In Frequency division multiplexing frequencies from other channels in the vicinity can interfere which can be fixed by introducing guard bands, this will decrease the bandwidth of the individual channel so the Bandwidth of the n^{th} channel is given by:

BW of n^{th} channel = $f_2 - f_1$ - Guard bandwidth

OFDM commences the theory of orthogonality of sub carriers, so the two signals should be mutually exclusive over symbol interval time.

$$\int_0^T S_1(t)\bullet S_2 \bullet dt = 0 \qquad (3)$$

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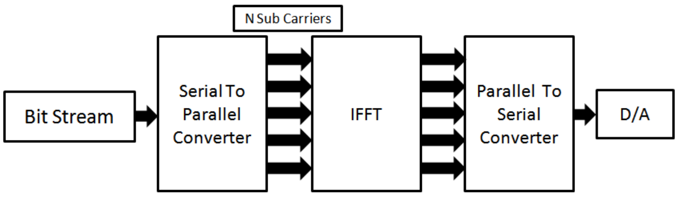

Fig. 2. Block Diagram of OFDM at Transmission side

In Figure.2 Serial bit stream of transmitted data equally distribute along the parallel subcarriers. This increases the symbol time and decreases the bit rate per channel which is helpful in reducing the ISI "Inter Symbol Interference" to the minimum possible level. The parallel streams passes through the modulation generating frequency components. IFFT "Inverse Fast Fourier transform" converts these frequency components into time samples. After IFFT, OFDM symbol is generated, as:

$$X[n] = \frac{1}{\sqrt{N}} \bullet \sum_{t=0}^{N-1} X[i] \cdot e^{2\pi ni/N}, 0 \le n \le N-1 \quad (4)$$

X[n] shows a sum of symbols that have been modulated with frequency modulated by $e^{2\pi ni/N}$ factor [10]

i. CP "Cyclic Prefix": Multipath environment encounters destructive and constructive addition of signals this can reduces the quality of baseband signal. This can also be called ISI. In OFDM system this problem is dealt with the introduction of CP "Cyclic Prefix" to the symbol. After modulation, at the end of each symbol is added with a CP. The job of CP is same as the guard bands in frequency division multiplexing. ISI is reduced on addition of CP, as the introduction of CP increases the symbol duration across the channel, in due course reduces symbol rate.

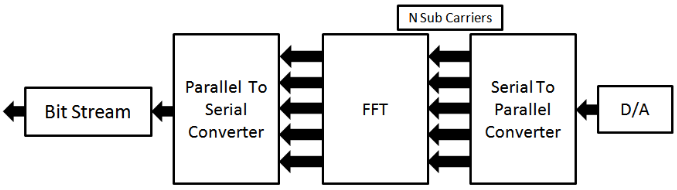

Fig. 3. Block Diagram of OFDM at Receiver side

Length of CP depends upon the channel delay. After introducing CP the symbols are sent to the parallel to serial conversion block. OFDM symbol earlier than CP makes convolution between channel and OFDM symbol, round in nature. OFDM based PLC is formed by block diagrams of transmitter, PLC channel, and receiver. On the whole PLC with OFDM model is shown in Figure.4 [11]. Transmitted signal is transformed in coding series, i.e. a multilevel symbol in mapping block for all subcarriers. For each of

Fig. 4. Model of OFDM based PLC System

subcarrier, the estimation is important for phase and amplitude determination. After the estimation of transfer channel the data is converted to the parallel streams while passing through S/P "Serial to Parallel" Conversion Block. Then with IFFT frequency components are converted into time region. CP block inserts cyclic prefixes to prevent ISI and protect the OFDM symbols. Receiver side uses the same model but in reverse manner. At the end of the process in OFDM a bit error probability is calculated and received data is compared with the transmitted data [12].

The attraction of OFDM is primarily due to its property to tackle ISI due to constructive or destructive interference of multipath signals [13].

ii. LSCE" Least Square Channel Estimation: Least Square Channel Estimation is adopted by OFDM technique to achieve a good trade-off between complexity and accuracy [14]. Pilots are inserted in this estimation in time & frequency direction, at random phasors. This preserves signal information and channel response through convolution and down-sampling processes. It minimizes the squared distance between the received and original signal. It can be shown as follows:

$$Min_{H^t}\, j(H) = Min_{H^t}\left(\left|Y - XH\right|^2\right) \quad (5)$$

$$Min_{H^t}\, j(H) = Min_{H^t}\left\{\left(\left|Y - XH\right|^t\right)\left(\left|Y - XH\right|\right)\right\} \quad (6)$$

Where $(.)^t$ is the conjugate transpose of the operator H (channel parameter).

By finding minima of the channel parameters and differentiating equation (6) with respect to H^t LSCE is founded. LSCE is very simple and less costly.

iii. Noise Model: Power Line Communication encounters various types of noises, such as multipath attenuation, impulsive noise, ISI etc. This is because various types of loads are connected to the power line with bus topology and this along with the various types of wirings creates impedance mismatch and add errors to the system.

OFDM based PLC is shown by block diagrams of transmitter containing OFDM model, PLC channel with the insertion of noise a, and receiver with OFDM model in reversed manner. This collectively can be called OFDM based PLC and is shown in Figure. 4

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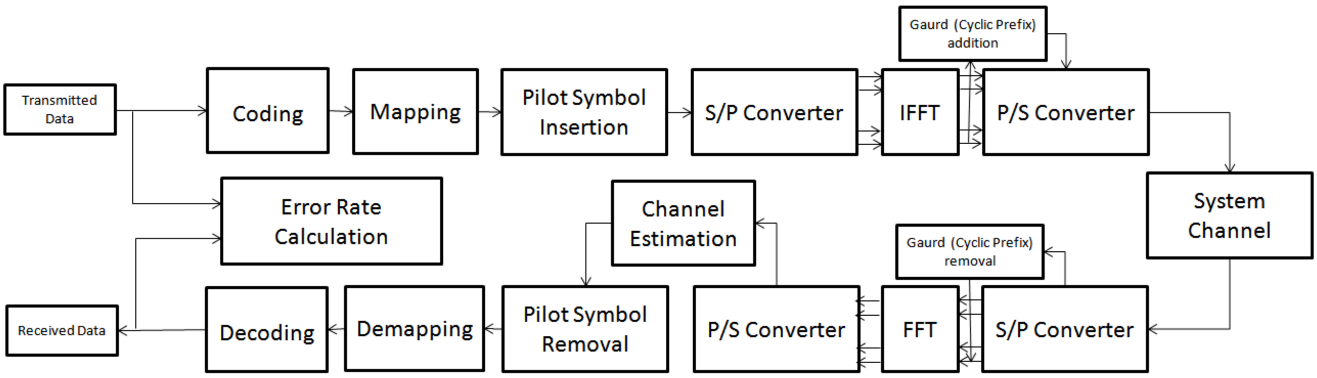


Along the path from transmitter to the receiver various noises that get added up to the system is illustrated in following model

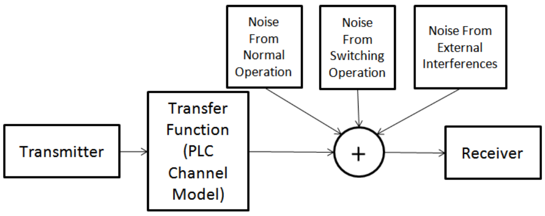


Fig. 5 Noise Model

Figure.5 shows noise model, there are three categories of noise (a) Normal Operations Noise. (b) Switching Operations Noise and (c) Noise due to Interference with external channels. System can never be perfect and noise from normal operations is always there. Noise due to switching has relatively high amplitude and causes impulsive noise which is for a very short period of time but creates a meaningful distortion in data symbol [15]. The switching system and external interference adds AWGN noise into the data transmission. Impulsive noise is given by;

$$i_k = g_k * b_k \qquad (7)$$

Where b_k is the Poisson Process and g_k is the White Gaussian process with variance 2 and zero mean [16]. The total noise n_k is as:

$$n_k = w_k + i_k$$

(8)

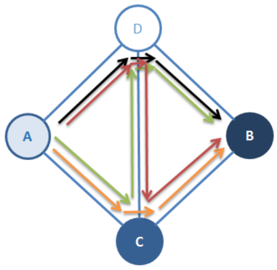
$$n_k = w_k + g_k * b_k$$

(9)

iv. Multipath Channel Model: In power line communication system signals do not follow single path for propagation, but similar pattern as wireless signals is followed. Thus this makes a similarity between power line transmission and cellular transmission and there are multiple paths for propagation of signal from power grid to end user. Following model is illustrated to understand this behavior.

Fig. 6. Possible paths for the signal

Let A be the power grid or the transmitter and B be the



point of receiving signal. Transmitted signal could follow four possible routes. BER and signal strength of a received signal depends upon the distance covered and path followed by that signal. Power Line Communication Channel Model is given by:

$$H(f) = \sum_{i=0}^{N} g_i . A(F.d_i).e^{-j2\pi F \tau_i}$$

Delay τ_i can be encounter by multipath propagation in power line communication. τ_i is the delayed time and is equal to[17]:

$$\tau_i = \frac{d_i \sqrt{\varepsilon_r}}{c_\circ} = \frac{d_i}{v_p}$$

Where

d_i is indicating followed path

$\sqrt{\varepsilon_r}$ is insulating material's dielectric constant.

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$c_{\circ}$ is speed of light.

3. EXPERIMENTAL RESULTS AND ANALYSIS

PLC channel model gain is modeled by using the equation (1) with meaningful data, i.e. by knowing all possible paths travelled by the signal. For example, in Figure 7, i.e. Simulation Model, "A" is the transmitter and "B" is the receiver, and four possible paths N, i.e.;

Path 1: A → D → B
Path 2: A → D → C → B
Path 3: A → C → D → B
Path 4: A → C → B

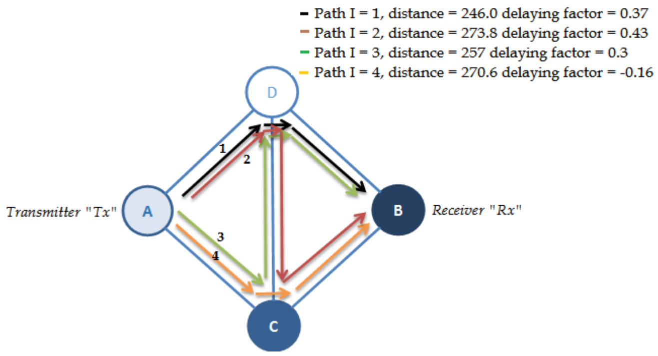


Figure. 7: Simulation Model

For all these four possible paths, distance covered by the signal can easily be calculated. The simulation model is designed for the total 4 paths (N=4). The calculated distances and weighing factors for paths 1, 2, 3, 4 are mentioned in Table.1 and for all paths attenuation parameters are mentioned in Table. 2.
m = 1:N.

Table. 1: Path parameters

I	g_1	d_i/m	I	g_1	d_i/m	I
1	0.37	246.0	3	0.3	257	1
2	0.43	273.8	4	-0.16	270.6	2

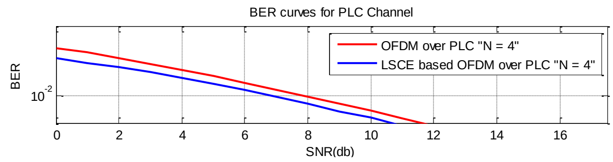
Table. 2: Attenuation parameters

K	a_0	a_1
1	0	7.8e10-10 s/m

- **Simulation Results:** By using MATLAB simulator, random bit stream has been generated which has been modulated to BPSK signal. Modulated signal has been allocated to 52 subcarriers out of 64, while vacant subcarriers have been filled out with zeros. In simple words, serial bit stream had been converted to parallel. Inverse Fast Fourier Transform (IFFT) is executed to generate OFDM. For reduction of inter symbol interference, CP has been added to the signal. Length of CP was kept comparable to delay factor of PLC channel. This OFDM signal has been convoluted bit by bit with the generated PLC channel. Figures. 8, (a), (b) and (c), show different results wherein channel model was varied from N = 4 to N = 14 and then to N = 20 in different scenarios. Increasing number of channels increases the chances of the better.Figure. 8 shows different results for the proposed algorithm of LSCE based OFDM over power line communication. For N = 4, there are only four possible paths and if all these paths are occupied by the attenuations then the results are not very impressing.

Table 3: Parameters used for Generating BER curve in Simulation Model

Simulation Tool	MATLAB
Number of Sub Carriers	64
FFT Block size	128
Number of occupied Sub Carriers	52
Length of CP	32
Number Of Bits	1.0e10
Number Of Channels	N1= 4, N2 = 14, N3 = 20



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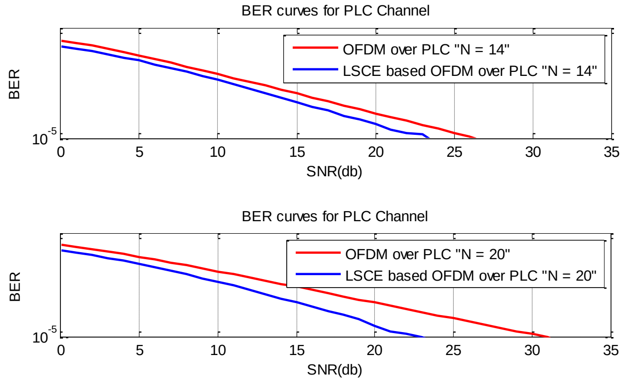

Figure. 8: Performance Analysis of proposed algorithm with conventional scheme for BER reduction

In N = 14, there are many paths for the same signal comparatively and chances of getting better signal is more, hence showing lesser bit error rate similarly by increasing channels more results are better. Signal to Noise Ratio (SNR) vs BER rate is greatly improved by introducing LSCE. By observing Figure 8 and comparing all these results at SNR = 20 db, BER of the proposed algorithm is much lowered as compared to the others results. This can be more clearly observed in Figure. 9, where only conventional OFDM over PLC is compared with LSCE based OFDM over PLC.

In simulation model for generating BER curves against SNR for PLC channel, Table. 3 is followed for (a) N=4, (b) N=14 and then (c) N=20. Figure 8 outcomes have been enhanced by adding improved LSCE to the OFDM similarly as in Figure. 9. Simulations assessed the collective effect of features like multipath, power loss and delaying factor. This is because the PLC channel characteristics are known as improved LSCE and is an efficient and simple method to estimate PLC channel conditions. Comparison of these results shows that by addition of improved LSCE, the system gets smarter as the smart grid system gets a decision capability and thus lesser BER against SNR is achieved as compared to conventional OFDM over PLC. Following figure is showing the results of simulations based on the data given in Table.3.

In Figure 9, ordinary OFDM over PLC is compared with LSCE based OFDM over PLC. Better SNR VS BER is observed by bringing together LSCE and OFDM. These results have been obtained by MATLAB simulations where 10^6 symbols are modulated with BPSK signal to observe SNR VS BER.

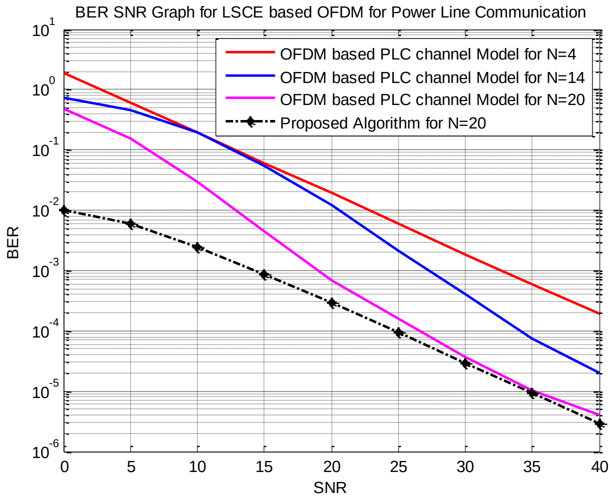

Figure 9: BER curves for PLC Channel

Table.3 contains all the information where data random bit stream is generated in the simulator and this bit stream being serial stream is converted into the parallel streams. This is done by modulating the signal to BPSK signal first and then modulated signal is multiplexed by allocating this signal to 52 subcarriers out of 64 whereas empty subcarriers have been occupied by the zeros. After Serial to parallel conversion, these streams are followed by IFFT execution. This generated OFDM data. CP has been added to the signal for the reduction of the ISI. Lengths of delay factor of PLC channel and CP are kept comparable. After PLC channel gain generation, OFDM is convoluted bit by bit with PLC channel gain. Impulsive noise added with AWGN, Gaussian noise and thermal noise are generated. All these noises and attenuations are added to the convoluted bits of OFDM over PLC. Streams of bit in parallel form are remodeled into serial bit streams. Time samples were converted back to frequency domain and CP has been removed the data in same fashion as at the input side. Data received is remodeled and are observed for BPSK signals

4. CONCLUSION

This paper provides the review of the smart grids and the communication system used therein using power lines. Communication is based upon OFDM which uses LSCE. Model for LSCE based OFDM over PLC is designed. The performance of BER vs SNR of OFDM over PLC are analyzed with and without LSCE. Practical conditions for PLC channel and different kinds of noises were considered and the results are found. Conventional OFDM over PLC was compared with the LSCE based having pilot insertion. Various noise circumstances based on real-world measurements and various channel conditions have been used in the simulations. The achieved outcomes shows that in the presence of all the noises such as AWGN added with impulsive noise, system noises and thermal noises, LSCE provides the best performance to OFDM-based PLC systems meaningfully. OFDM itself reduces impulsive noise with addition of smart LSCE in PLC, it greatly eliminates noise and attenuations and prominent improvements in Results are seen.

REFERENCES

[1] Yigit, M., Gungor, V.C., Tuna, G., Rangoussi, M. and Fadel, E., Power line communication technologies for smart grid applications: a review of advances and challenges. Computer Networks, Vol. 70, 2014, pp.366-383.

[2] Della Giustina, D., Ferrari, P., Flammini, A., Rinaldi, S. and Sisinni, E., Automation of distribution grids with IEC 61850: A first approach using broadband power line communication., IEEE Transactions on Instrumentation and Measurement, Vol. 62, Issue. 9, 2013, pp.2372-2383.

[3] Rahman, M.A., Al-Shaer, E. and Bera, P., A noninvasive threat analyzer for advanced metering infrastructure in smart grid, IEEE Transactions on Smart Grids, Vol. *4*, Issue. 1, 2013, pp.273-287.

[4] McBee, K.D. and Simões, M.G., Utilizing a smart grid monitoring system to improve voltage quality of customers, IEEE Transactions on Smart Grids, Vol. 3, Issue. 2, 2012, pp.738-743.

[5] Güngör, V.C., Sahin, D., Kocak, T., Ergüt, S., Buccella, C., Cecati, C. and Hancke, G.P., Smart grid technologies: communication technologies and standards, IEEE transactions on, Industrial informatics, Vol. 7, Issue. 4, 2011, pp.529-539.

[6] Ritter, S., Ruttinger, H., Bretschneider, P. and Westermann, D., New approaches for smart grid requirements: Grid protection and optimization of distribution grid operation, IEEE Power and Energy Society General Meeting, 2011, pp. 1-7.

[7] Zhang, P., Li, F. and Bhatt, N., Next-generation monitoring, analysis, and control for the future smart control center, IEEE Transactions on Smart Grid,, Vol. 1, Issue. 2, 2010, pp.186-192.

[8] Parikh, P.P., Kanabar, M.G. and Sidhu, T.S., Opportunities and challenges of wireless communication technologies for smart grid applications, IEEE Power and Energy Society General Meeting, 2010, pp. 1-7.

[9] Ferreira, H. C., Lampe, L., Newbury, J., and T. G. S. (Editors), Power Line Communications: Theory and Applications for Narrowband and Broadband Communications over Power Lines. John Wiley & Sons, June 2010.

[10] Fadlullah, Z.M., Fouda, M.M., Kato, N., Takeuchi, A., Iwasaki, N. and Nozaki, Y., Toward intelligent machine-to-machine communications in smart grid. *Communications Magazine, IEEE*, *49*(4), 2011, pp.60-65. W. M. Afifi and H. M. Elkamchouchi, “A new adaptive channel estimation for frequency selective time varying fading OFDM channels,” in Proc. Int. Conf. Comput. Eng. Syst., Cairo, Egypt, Dec. 2009.

[11] Yamamoto, Y., Pricing electricity from residential photovoltaic systems: A comparison of feed-in tariffs, net metering, and net purchase and sale. Solar Energy, 86(9), 2012, pp.2678-2685.

[12] Nanping, L., Yuan, Y., Kewen, X. and Zhiwei, Z., Study on channel estimation technology in OFDM system, IEEE International Joint Conference on Artificial Intelligence, 2009, pp. 773-776.

[13] Ma, Y.H., So, P.L. and Gunawan, E., Performance analysis of OFDM systems for broadband power line communications under impulsive noise and multipath effects, IEEE Transactions on Power Delivery, Vol. 20, Issue. 2, 2005, pp.674-682.

[14] Tlili, F., Rouissi, F. and Ghazel, A., 2003, May. Precoded OFDM for power line broadband communication. *Proceedings of the 2003 International Symposium on Circuits and Systems*, Vol. 2, *2003*, pp. II-109.

[15] Edfors, O., Sandell, M., Van de Beek, J.-J., Landström, D., and Sjöberg, F., An Introduction to Orthogonal Frequency Division Multiplexing, Luleå, Sweden: Luleå Tekniska Universitet, 1996, pp. 1–58.

[16] Van de Beek, J.-J., Edfors, O. S., Sandell, M., Wilson, S. K., and Börjesson, O. P., “On channel estimation in OFDM systems,” 45th IEEE Vehicular Technology Conference, Chicago, Il., vol. 2, pp. 815-819, July 1995.

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