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Power Line based Data Communication (as a cost effective solution to traditional system) and Interleave Division Multiple Access.

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Abstract— **In this paper a novel approach for data communication is proposed in which Power Line is used as a transmission medium. It amalgamates the benefits of data transmission with interleave division multiple access (IDMA) scheme, which reduces the further use of wires and provides high speed networking capability for in house data communication. In the proposed Power line communication (PLC) system. For transmitting data through PLC, high frequency signal (1.6 to 30 Mhz) are superimposed at low energy level over the 50 Hz electrical signal and the newly received signal is transmitted via the power infrastructure and can be received and decoded remotely. More quantitatively, it is demonstrated that PLC system for IDMA scheme supports higher data rate communication and effective bandwidth utilization.**

Index Terms— **FSK, QPSK, Power Grid, Smart Grid, BER (Bit Error Rate), CDMA (Code Division Multiple Access), IDMA (Interleave Division Multiple Access) etc.**

I. Introduction

From last few decades the demand for video, voice and internet data within house and office increases rapidly though existing wireless communication is not available everywhere and it is very expensive as well as time consuming to install new wires for fulfilling the requirement over such a widely spread area. The one alternative to this problem is to use presently existing wire that is power line. We can utilize Power line as local area network (LAN)[4] to provide high-speed data connections between computers, peripherals and the various multimedia equipments. Power line communication[11] is a technology that can be used for communicating over the existing power line cable. The existing and widespread power distribution infrastructure can provide high speed networking capabilities for In house data communication. For transmitting data through PLC, high frequency signal (1.6 to 30 Mhz) are superimposed at low energy lever over the 50 Hz electrical signal and the newly received signal transmitted via the power infrastructure can be received and decoded reomotely. Data is typically transmitted through any medium by adopting various modulation techniques and multiple access schemes such as FSK (Frequency Shift Keying), QPSK (Quadrature Phase Shift Keying), BPSK (Binary Phase Shift Keying), DPSK (Differential Phase Shift Keying), DSSS (Direct Sequence Spread Spectrum) and OFDMA (Orthogonal Frequency Division Multiple Access) and CDMA (Code Division Multiple Access) etc. The existing multiple access techniques are basically suitable for small data rate communication only and unsuitable for high data rate transmission and burst data traffic. The CDMA is most eminent multiple access scheme which offers improved bandwidth efficiency than the time division multiple access and frequency division multiple access scheme. The performance of CDMA scheme is mainly limited by multiple access interference (MAI) and inter-symbol interference (ISI). In CDMA coding and spreading operation is accomplished separately. The fundamental study of information theory represents optimal multiple access channel capacity that can be obtained when the entire bandwidth expansion is dedicated to coding. It can be achieved only when coding and spreading operation is mixed together and this is known as low-rate coding. The separation of coding and spreading is not possible in CDMA frame work., so there is new approach known as IDMA[14], in which coding and spreading is combined together, and achieve bandwidth expansion by low rate coding. IDMA[14] inherits many advantages from CDMA, like diversity against fading and mitigation of the worst-case other-cell user interference problem[1, 10].This article is organized in 8 sections. Section 2 represents the Power Grid and Smart Grid and the basic Difference among them, section 3 represents the Power Line Communication Channel[11], section 4 represents the Power line Home Networking, section 5 represents Multipath channel model for Power Line Communication[11], section 6 represents The IDMA (Interleave Division Multiple Access) Framework, section 7 result discussion and last section deals with the conclusion of the paper.

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II. POWER GRID AND SMART GRID

The in general meaning of power grid is transmission system for electricity. Power grid and electric grid can be used interchangeably. An electrical grid is an interconnected

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network for transporting electricity from suppliers to consumers. It contains generating station, high-voltage transmission lines that carry power from power station to demand centers far from the source, and distribution line that connect the individual customers. Power grid comprises of transmission line, distribution line and end users or load line. The main operations of power Grid are as below is generation, transmission, distribution and power control Figure 1. Power grid system is also knows as one way communication.

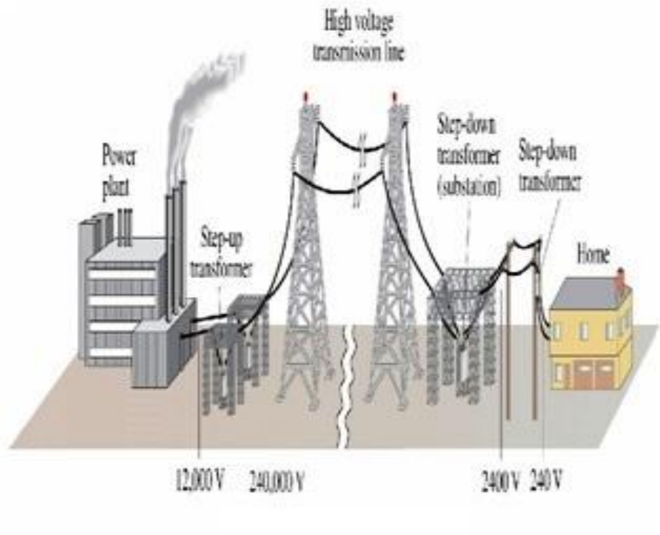

Figure1. Power Grid System

Smart grid is intelligent system which combines the two technologies namely Power grid and Data communication. Construction of smart grid implies the addition of computer and communications technology to the existing electricity grid. With an overlay of digital technology, the power grid is more efficient, secured and reliable. Smart grid provides two way communications between distribution unit and consumers. Before Smart Grid (as shown in figure 3), traditional systems (as shown in figure 2) were based on one-way power flow and simple interactions.

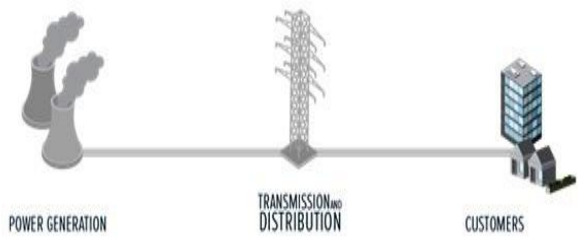

Figure 2. Traditional Power Grid Systems

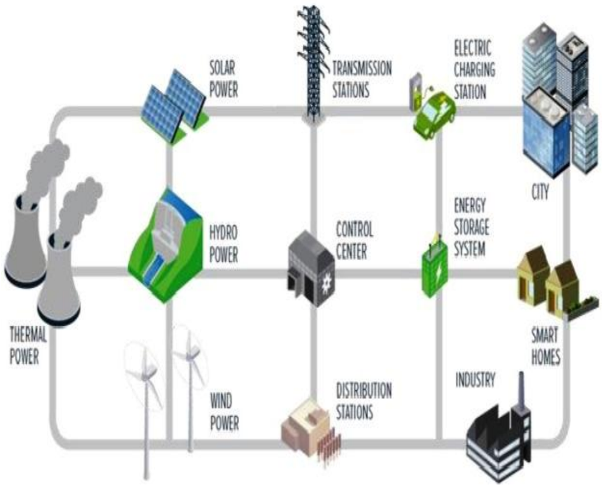

Figure 3. Smart Grid System Two way Communication.

I. POWER LINE COMMUNICATION SYSTEM

The role of power line initially begins from transmitting the electric power from source to various users or receivers in the range of frequency 50-60 Hz. The PLC (Power Line communication) acts as a communication medium in between the transmitter and the receiver and is known as power line channel5,7 or power line carrier modem3,5,6,7,11. As the PLC3,5,6,7,11 is used as a medium of communication the data rate can vary. PLC Carries data on conductor that is simultaneously used for AC electric power transmission or electric power distribution to consumers also. It is also called as power line carrier3. The PLC technology (Power Line Communication) uses a Power Line for data communication. PLC Technology does not require any additional wiring. It can be further classified as Narrowband PLC and Broadband PLC. Narrowband PLC works for lower range of frequencies (3-500 kHz), lower data rates (up to 100s of kbps), longer range (up to several kilometers), which can further be extended using repeaters. Broadband PLC works at higher range of frequencies (1.8-250 MHz), higher data rates (up to 100s of Mbps) and is commonly used in shorter-range of applications. So PLC technology promotes data communication of medium and low voltage power lines. It involves the delivery of Communication signal with maximum efficiency over PLC applications. Else it will result in loss of data when the transmission is carried at high data rates. Even it is cost effective solution for smart grid applications but PLC environments also suffers from challenges like attenuation (transmission or path loss / fading), reliability and communication systems performances11.

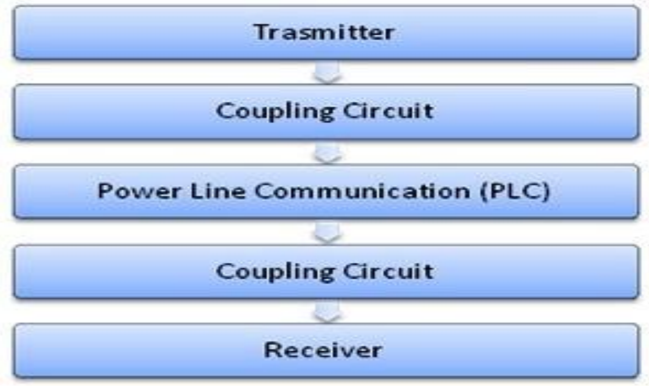

Figure 4 PLC System

The figure 4 represents the general architecture of the PLC system. Transmitter model represents a block diagram used for the generation of signal while, the Receiver model represents a block diagram for the reception of a signal. The coupling circuit is used as a circuit model with coupling transformers.

I. POWER LINE HOME NETWORKING

In the Power line carrier communication system, the power line is not only used for energy transmission but is also used as a medium for data communication. Power line networking is an efficient and emerging home networking technology that allows the end-users or consumers to use their already existing electrical wiring system in order to connect with home appliances and to reach other as well as to connect with Internet. Home networking utilizes the advantages of high speed power line networking technology to control anything which is plugged into the AC (Alternating Current) outlet. This includes the lights, televisions, thermostats and alarms among other. The Power line communication can be further classified into two different part, access5,6 and in-house5,6 PLC. Access power line technologies (APLC) are responsible for sending the data over the lower-voltage electric networks that connects the consumer's home to electric utility provider. It enables a "last mile" local loop solution which facilitates individual homes with the broadband connectivity to Internet. In-house power line technologies (IHPLC) communicate data exclusively within the consumer's permits and extends it to all of the electrical outlets within the home, The same electrical outlets which provide AC power are acting as Access point for various network devices. The access and In-house power line networking solutions as shown in figure 5 both are used for sending the data signals over the power line however the technologies difference varies at fundamental level.

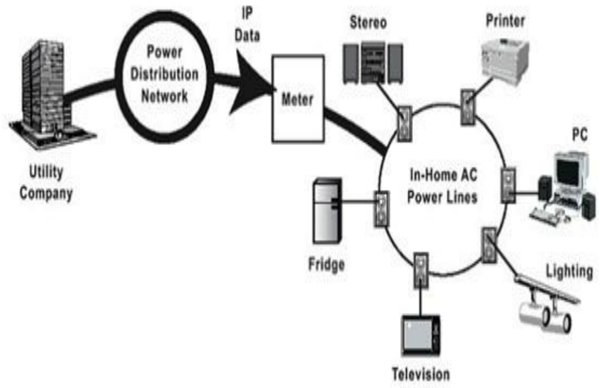

Figure 5 Power Line In-house Network.

II. MULTIPATH CHANNEL MODEL FOR PLC

In Power line transmission system the propagation of data signals do not follow single path or uni-path, but they follow a multipath transmission in order to fulfill the subscribers requirement12. The signal transmission in PLC is very similar to wireless signal transmission as involved in cellular communication. The PLC model is based completely on the physical signal propagation effects in main network including various branches and effect of impedance mismatching. PLC transmission is also affected by multipath propagation like wireless transmission accompanied by frequency selective fading. The signal attenuation of typical power cables increases with length and frequency in PLC transmission. Signal power and BER (Bit Error Rate) of Received signal in PLC transmission depends upon the path followed and the length of the path. Multipath propagation results in delay (τi) in PLC, which is given by:

$$\tau_i = \frac{d_i\sqrt{\epsilon r}}{c_o} = \frac{d_i}{v_p} \qquad (5.1)$$

di is the length of path, C0 is speed of light in vacuum and ϵr is dielectric constant of insulating material

$$H(f) = \sum_{i=1}^{N} g_i \,.\, A(f, d_i) .\, e^{-j2\pi\tau i} \qquad (5.2)$$

H(f) is Channel frequency response between two points. When the grid network becomes bigger and complex it could be partitioned into sub-channels for the individual performance study. A(f,di) is the cable loss which can be in the form of heat or signal leakage etc. where f is the frequency of operation, gi is weight factor which is directly proportional to number of reflections and path followed:

$$|gi| \leq 1 \qquad (5.3)$$

The values of H(f) and A(f,di) are determined experimentally. Based upon above given factors a mathematical model of multipath PLC transmission is:

$$H(f) = \sum_{i=1}^{N} g_i \, . \, A(f, d_i) . e^{-j2\pi\tau i} \qquad (5.4)$$

Based upon the extensive investigation12 on experimental data A(f,di) can be approximated by the mathematical formula for attenuation factor (α)

$$(f) = a0 + a1 .f^{k} \qquad (5.5)$$

where a0 and a1 are attenuation parameters leading to:

$$A(f, d) = e^{-\alpha(f).d} = e^{-(a0 + a1 .f^{k}).d} \qquad (5.6)$$

Using A(f,di) in □(f) gives the channel model for PLC transmission line:

$$H(f) = e^{-\alpha(f).d} = e^{-(a0 + a1 .f^{k}).d} . e^{-j2\pi f \left(\frac{di}{vp}\right)} \qquad (5.7)$$

gi = weighing factor

and the attenuation portion is given as

$$e^{-(a0 + a1 .f^{k}).d} \qquad (5.8)$$

While the Delay portion is given as

$$e^{-j2\pi f \left(\frac{di}{vp}\right)} = \qquad (5.9)$$

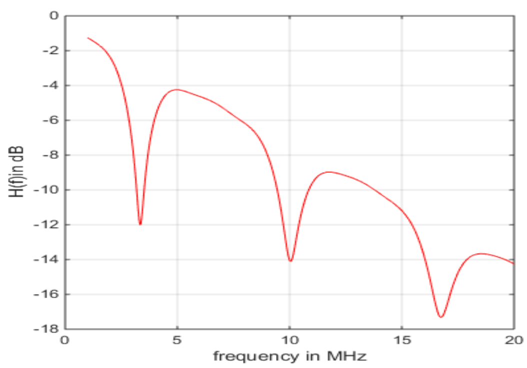

Figure 6. PLC channel model for gain (N=4)

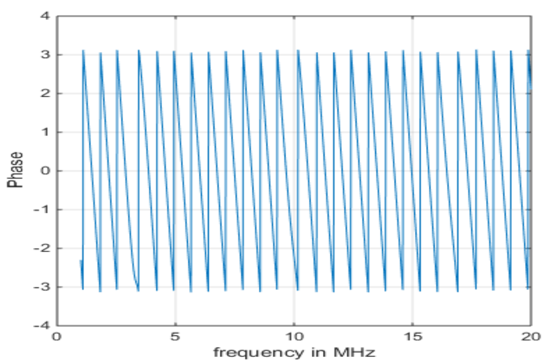

Figure 7. PLC channel model for phase (N=4)

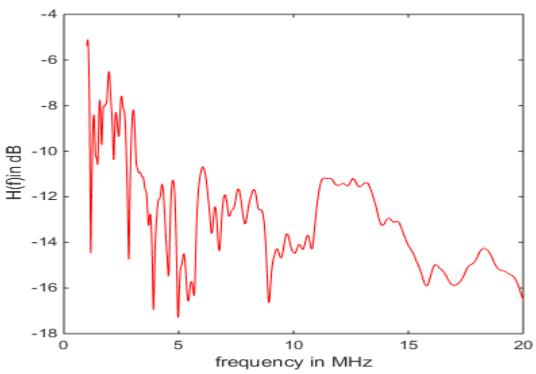

Figure 8. PLC channel model for gain (N=15)

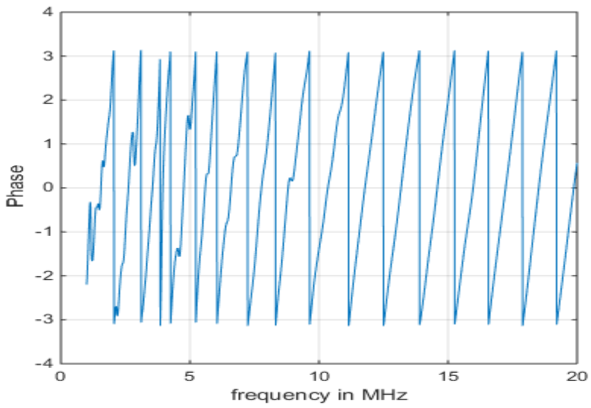

Figure 9. PLC channel model for phase (N=15)

III. IDMA FRAMEWOEK AND PERFORMANCE FOR POWER LINE

IDMA1,2 stands for Interleave division multiple access this is special version of CDMA in which the users are separated by user specific interleavers in place of different chip code or signature sequences like CDMA. In IDMA coding and spreading2,13 is perform in only one step and it offers low rate encoding with high coding gain8,15.

In Power Line Communication, the attenuation is directly proportional to frequency; which results in increase in attenuation when frequency increases. Power line transmission is also crucially affected by Multipath fading and Inter symbol Interference. CDMA suffers from degradation in the operational performance with increase in the number of users15. CDMA also suffers from multipath fading and inter symbol interference effects.

Recently, IDMA has been introduced as a new multiple access spread spectrum technique, that is very similar to CDMA, In IDMA scheme, the user-specific interleaver1,2 replaces the user specific codes as is used in CDMA scheme. Performance comparison of IDMA and CDMA has shown that the BER performance using IDMA is far better than the CDMA8,9. This new technique also remove the main

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problem and obstacles with CDMA like multipath fading and inter symbol interference.

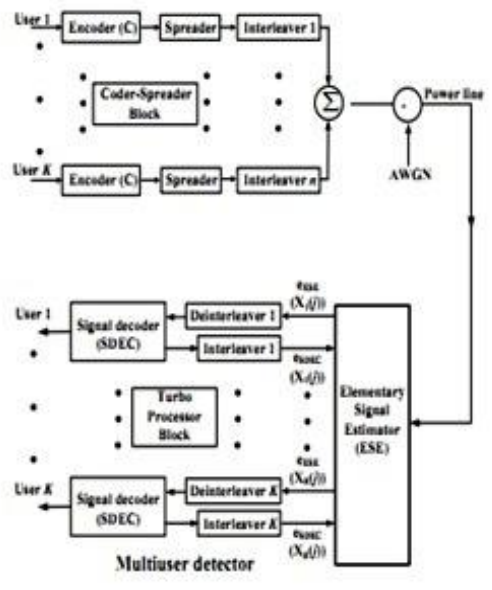

Figure 10. IDMA Transmitter and receiver structure with k simultaneous users for Power Line.

The performance of any digital communication system is given in terms of Bit error Rate also known as Quality of Service (QOS) and probability of error.
In theoretical probability of error is calculated by using the equation as below:

$$P_e(M) = \frac{1}{M} erfc\left(\sqrt{\frac{Eb}{N0}} \sin\left(\frac{\pi}{M}\right)\right) \quad (6.1)$$

The mathematical analysis and simulation using SIMULINK shows that BER performance for all the M-ary PSK (Phase Shift Keying) based digital modulation schemes decreases monotonically with increasing values of Eb/N0. To calculate probability of error in M-QAM (Quadrature Amplitude Modulation) (theoretical) the below equation is used :

$$P_e(M) = \frac{2}{M}\left(1 - \frac{1}{\sqrt{M}}\right) erfc\left(\sqrt{\frac{3mEb}{2(M-1)N0}}\right) \quad (6.2)$$

The power line channel7 modeling is tougher task because of unpredictable variation with frequency, time, day, geographic location etc. Impedance, attenuation and noise are the main parameters, taken into account. The power distribution system (up to 30 MHz) Absolute impedance has been carefully studied in several countries. A component model can be expressed by the following F matrix as shown in equation.

$$\begin{bmatrix} V1 \\ I1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V2 \\ I2 \end{bmatrix} \quad (6.3)$$

Where A, B, C, D are the coefficient of F matrix. V1, I1 are input Voltage and input current. V2, I2 are output voltage and output current. From an equivalent circuit model the coefficients are uniquely defined and it can also be termed as the model parameters of the component model. The two port model is used for the calculation of all the parameters[16].

$$A = Cosh(\gamma l) \quad (6.4)$$

$$B = Z.Sinh(\gamma l) \quad (6.5)$$

$$C = \frac{Sinh(\gamma l)}{Z} \quad (6.6)$$

$$D = Cosh(\gamma l) \quad (6.7)$$

And the transfer function H can be given as,

$$H = \frac{R1}{A.R1 + B + C.R1Rs + D.Rs} \quad (6.8)$$

Where γ is the propagation constant of the power line. Rs, R1 are source and load Impedance of the power line and l is the concentrating node total number in the transmission or reception side.

IV. RESULT AND DISCUSSION

Power Line model Simulated Result for 4 and 15 number of channels shown in the Figure 6, 7, 8 and 9 which clearly shows and concludes the relation between the parameters frequency, magnitude and phase. It shows the attenuation (frequency-dependent) and the frequency selective fading in Power Line Channel[7].

Single carrier modulation, frequency-shift keying (FSK), Quadrature phase-shift keying (QPSK), or other modulation methods are used as the modulation technique for narrowband applications on power lines. However, these modulation techniques are inadequate for providing high-speed communications in broadband applications on power line channels[7]. Frequency-selective fading is the major problem which places deep notches in the frequency response, and these corresponding locations may vary from cable to cable, time to time, and location to location. So for multiplexing the signals for large number of users and providing long distance communication IDMA can be used as the best possible alternative which is simply the improved version of CDMA.

IDMA supports asynchronous transmission and can perform better for large number of users. In IDMA networks, there is no any sophisticated synchronization requirement for data transmission. In IDMA the MAI (Multiple Access Interference), ISI (Inter Symbol interference) and interferences among users can be reduced up to maximum extent for providing high data rate Quality of Services.

V. CONCLUSION

Now days, the long distance data transmission with fast speed is our primary concern and requirement. Currently the speed achieved for data transmission is upto about 14 Mbps and we can expect further speed enhancement in the coming years, So Power Line (carrier) Communication system can be preferred choice over wireless or other Home Networking technology because of its easy installation and availability. By using IDMA[16] with PLC (as shown in figure 10), we can achieve a communication system which inherits the advantages of both schemes IDMA[16] as well as power line channel[7]. Wide variation in the Data rates can be achieved using power line communication. PLC major advantage is that its uses an existing infrastructure, so the cost of communication will get reduced.

With PLC which can work over the various frequencies, communication becomes easier and maximum bandwidth can be utilized.

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