



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Special Issue 1, December 2013

Load Modeling of Broadband Power Line Communication (BPLC) Network

Mini S. Thomas¹, Senior Member, IEEE, Vinay Kumar Chandna², Senior Member, IEEE and Seema Arora³,
Student Member, IEEE

Professor, Department of Electrical Engineering, Jamia Millia Islamia, New Delhi, India¹

Professor, Department of Electrical Engineering, JSS College of Engineering, Noida, India²

Research Scholar, Department of Electrical Engineering, Jamia Millia Islamia, New Delhi, India³

Abstract: Power line communication technology uses power lines for its data communication. This technology takes profits from the advantage of not requiring any additional wiring and thus offers an inexpensive medium for data transmission. For data communication, it is necessary to determine the characteristics of the Powerline channel which has been considered as a medium not only for low-rate, control purpose communication, but also for high-speed data communication. However, the power line channel is extremely difficult to model as it is a very noisy transmission medium. For creating a complete PLC communication system, there is necessity to create model of channels. The simulations and analysis carried out in this work will help in characterization of broadband power line communication (BPLC) network. The paper also provides insight into the laboratory facilities for research in performance analysis of BPLC network at Jamia Millia Islamia.

Keywords: Channel modeling, broadband power line communication communications, Multipath, BER.

I. INTRODUCTION

BROADBAND OVER POWER LINE COMMUNICATIONS (BPLC) is a term used to identify technologies, set of equipments, applications and software and management services that allow users to communicate over already existing power lines. The advantage of using this technology is that the power-line network is the most pervasive and accessible network. It reaches every power socket in every home. Since the power-line network is already installed, there is no need to lay new cables. The technology operates in the 1-30 MHz and can deliver data rates up to 200Mbps. The logic behind providing high bit-rate data services exploiting the power grid rests in the fact that vast infrastructure already exists in place for power distribution, and hence the penetration of the service could be much higher than any other wire line alternative [1].

To analyze the performance and to access the possibilities of optimization of transmission systems, a reasonably accurate channel model is needed [2]. With this aim, various models of a power-line network for broadband data transmission have been derived in the recent past. Some of those models can be found in Phillips [3], Zimmermann and Dostert [4], and Gali and Banwell [5], etc. However, a widely accepted channel model has not yet been presented, since models based on either experimental results or obtained from specific network topologies or boundary conditions are not general and incomplete, for predicting the behavior of power-line networks. The powerline medium is an unstable transmission channel owing to the variance of impedance caused by variety of appliances that could be connected to the power outlets, and these impedance fluctuations lead to multipath of BPLC channel [4, 6]. The noise present in the BPLC environment makes the communication over power lines further more difficult.

For the communication engineers, BPLC represents the formidable challenge of transmitting data along a communication media that was originally designed for the electrical energy delivery and not for communication purpose. Since home networking transcends the simply data communication between computers or Internet access,

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Special Issue 1, December 2013

BPLC technology appears as a potential way to become the smart home concept, and the indoor multimedia data interchange, in a reality. Although the performance of BPLC technology supporting multimedia applications with quality service at bit rates of up to 200 Mbps has been proved, it is reasonable to consider BPLC as a complementary technology and not as a competitor for the other home-networking technologies; both wired and wireless [7].

II. BPLC CHANNEL MODELING

BPLC channel modeling work can be categorized as BPL communication model, Models of power lines and Source of Interference (Noise) model [2, 8 and 9]. The focus of our work presented in this paper is on the load modeling of indoor BPLC, and in particular, calculation of effects of load on the BER rate. The most representative indoor BPL modeling approaches have been proposed based on the recent literature. Fig 1 shows the block diagram of BPLC channel model.

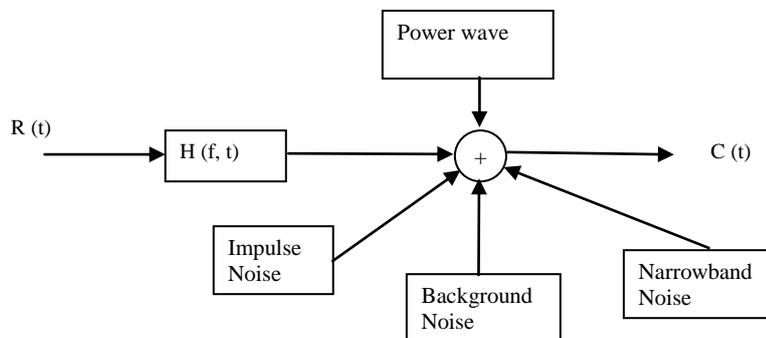


Fig 1. PLC Channel Model

The model can be created by using transmission line theory, which applies chain parameter matrices or scattering parameters to describe the relation between input and output voltage and current by two-port network [2,10,11and 12]. Power line model can also be created by using the concept of environment of multipath signal propagation [4 and 6]. The parameters of this line are obtained from a distribution network topology or based on metering and measurements.

III. MODELING THE INDOOR POWERLINE BASED ON TRANSMISSION LINE THEORY

The indoor power cables (fig.2) are approximated to be a two-wire transmission line with solid core conductor for software simulation. The line voltage $V(x)$ and the current $I(x)$ with x as displacement can be expressed in the frequency domain.

$$\frac{\partial V(x)}{\partial x} = -(R + j\omega L)I(x) \quad (1)$$

$$\frac{\partial I(x)}{\partial x} = -(G + j\omega C)V(x) \quad (2)$$

Differentiating both equations (1) and (2), we get:

$$\frac{\partial^2 V(x)}{\partial x^2} = \gamma^2 V(x) \quad (3)$$



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Special Issue 1, December 2013

$$\frac{\partial^2 \mathbf{I}(x)}{\partial x^2} = \gamma^2 \mathbf{I}(x) \quad (4)$$

The propagation of signals over power lines introduces an attenuation, which increases with the length of the line and the frequency. The line attenuation is caused by the heat loss and radiation on the power line and is a function of characteristic impedance Z_0 and transmission line complex valued propagation constant γ . These two intrinsic line parameters dominate the wave behavior along the power line.

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \quad (5)$$

$$Z_0 = \sqrt{(R + j\omega L)/(G + j\omega C)} \quad (6)$$

R, L, G and C are the resistance, inductance, conductance and capacitance per unit length of the power line conductor respectively. In order to derive γ and Z_0 , the four primary line constants have to be derived first.

$$R = 1 / \pi (\sqrt{\pi f \mu_0 / \sigma_c}) \quad (7)$$

$$G = \pi \sigma / (\cosh^{-1}(D/2a)) \quad (8)$$

$$L = \mu / \pi \cosh^{-1}(D/2a) \quad (9)$$

$$C = \pi \epsilon / \cosh^{-1}(D/2a) \quad (10)$$

A solution for V (x) and I (x) is:

$$\mathbf{V}_x = \mathbf{V}_f e^{\gamma x} + \mathbf{V}_r e^{-\gamma x} \quad (11)$$

$$\mathbf{I}_x = \mathbf{I}_f e^{\gamma x} - \mathbf{I}_r e^{-\gamma x} \quad (12)$$

where x is the displacement from the load, negative towards the source, and V_f , V_r , I_f and I_r are forward and reflected voltages and currents respectively at the load end of the line. The above expressions can be rewritten as:

$$\mathbf{V}_x = \mathbf{V}_f (e^{\gamma x} + \Gamma e^{-\gamma x}) \quad (13)$$

$$\mathbf{I}_x = \mathbf{I}_f (e^{\gamma x} - \Gamma e^{-\gamma x}) \quad (14)$$

where Γ is the complex reflection coefficient at the load. Transmission line behavior is described by these equations and the boundary conditions imposed by the load with load impedance given by $Z_L = V/I$.

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (15)$$

$$\Gamma(x) = \Gamma \frac{e^{\gamma x}}{e^{-\gamma x}} \quad (16)$$

The equations (1) to (16) fully describe the behavior of a transmission line with a given load impedance. Input impedance Z_{in} of line of length l can be calculated from the load impedance :

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Special Issue 1, December 2013

$$Z = Z_o \frac{Z_L + Z_o \tanh(\gamma l)}{Z_o + Z_L \tanh(\gamma l)} \quad (17)$$

If V_1 and I_1 are the voltage and current at the input port, and V_2 and I_2 are the voltage and current at the output port ; the relationships exist (equations 18 and 19) for the two port network equivalent of a transmission line:

$$V_1 = V_2 \cosh(\gamma l) + I_2 Z_o \sinh(\gamma l) \quad (18)$$

$$I_1 = \frac{V_2}{Z_o} \sinh(\gamma l) + I_2 \cosh(\gamma l) \quad (19)$$

The dielectric material, between the cable conductors, is inhomogeneous in both space (due to the round shape of the cable conductor) and contents (mixture of insulation and air). But since the cables are of close proximity to each other, the thickness ‘t’ of the insulation is comparable with that of the air space between the conductors. In this model, the dielectric is assumed to be just a mixed content material and the effects of the inhomogeneous in space are neglected to keep the model tractable.

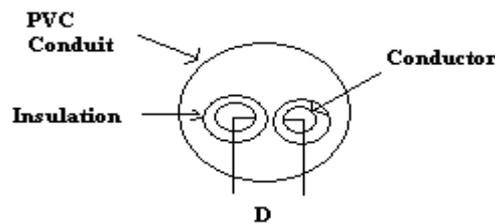
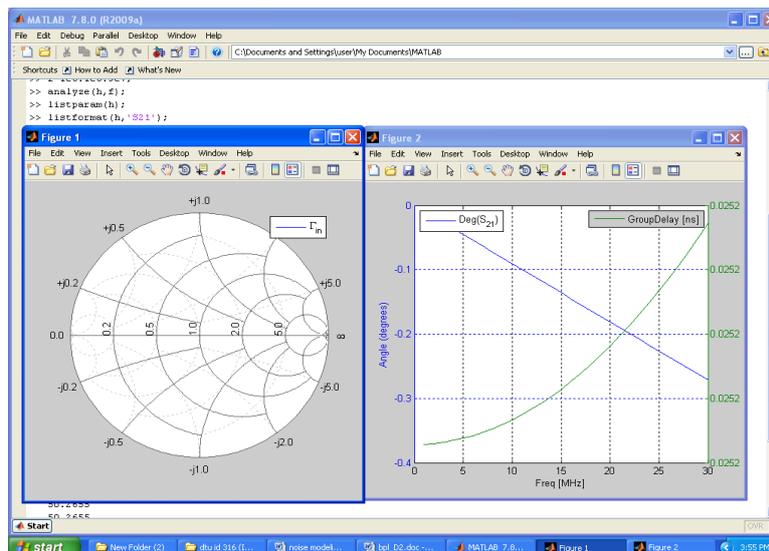


Fig. 2. Approximate model of the power line



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Special Issue 1, December 2013

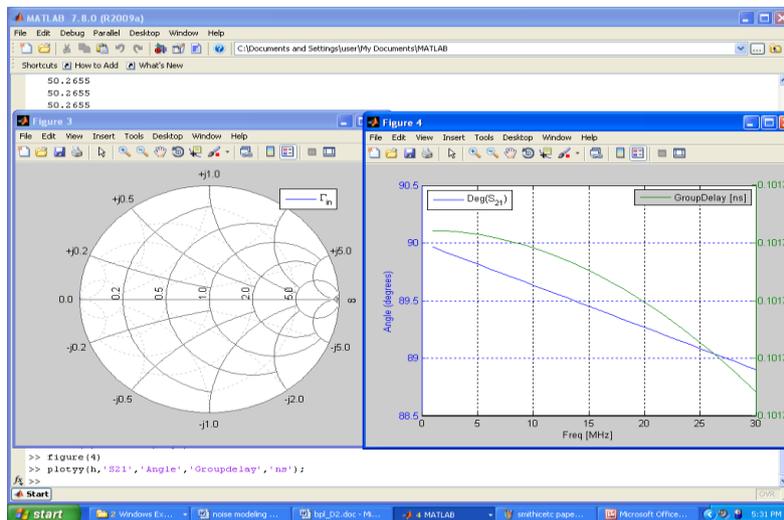


Fig. 3a and 3b .Shunt stub terminated in an open circuit and shunt stub terminated in a short circuit.

The simulations have initially been carried out in MATLAB with the small length of transmission line (taken to be 0.01m length) with shunt stub terminated in an open circuit as shown in fig.3a and shunt stub terminated in a short circuit as shown in fig.3b. The simulations have next been carried out in MATLAB with the length of transmission line taken to be 15 m with shunt stub terminated in an open circuit. The simulation results are revealed in fig.4. The length of transmission line is again taken to be 15 m with shunt stub terminated but short circuit. The simulation results are revealed in fig.5.

- The distance between the two conductors (Live and Neutral) ‘D’= 2t + 2t + 2a = 4.06 mm
- t = thickness of insulation = 0.7 mm
- a = radius of copper conductor = 0.63 mm
- Conductivity of copper $\sigma_c = 5.8 \times 10^7$ S/m
- Relative permittivity of dielectric $\epsilon_r = 0.8$
- Conductivity of dielectric $\sigma_d = 1 \times 10^{-5}$ S/m

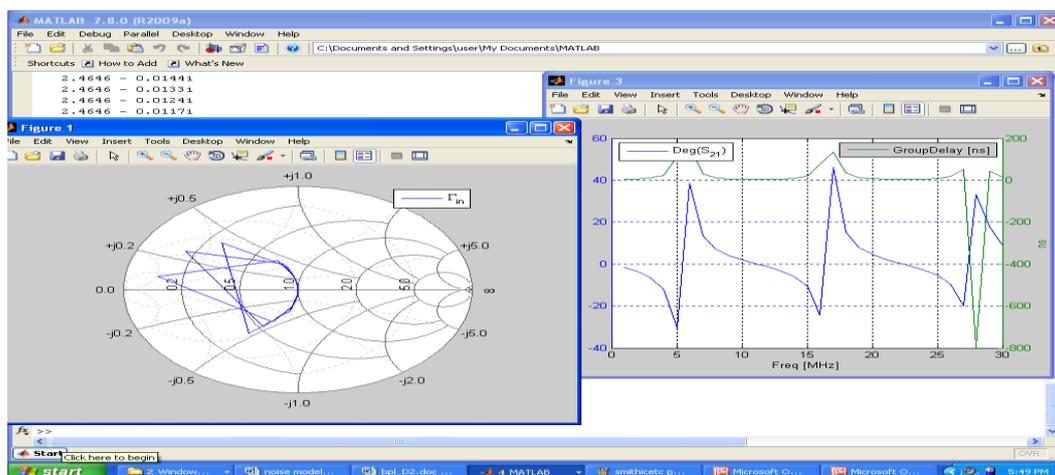


Fig 4. Simulation results for open termination

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Special Issue 1, December 2013

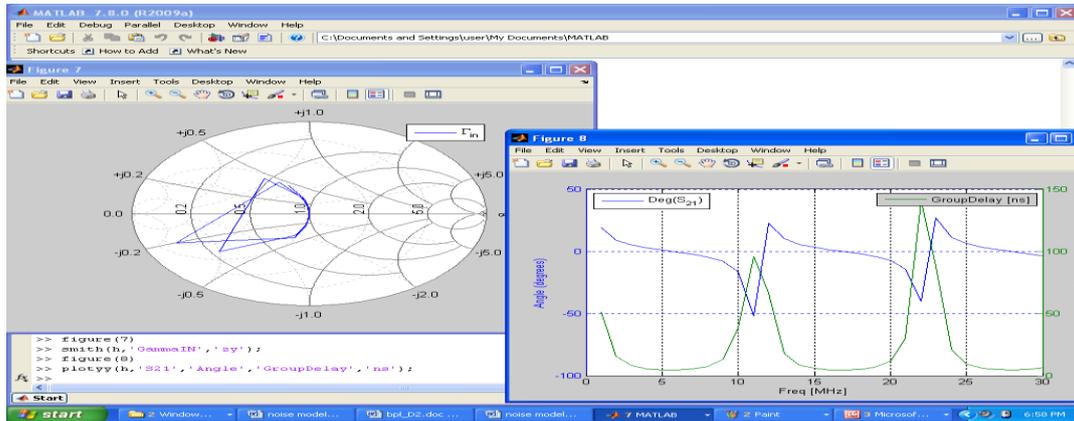


Fig 5. Simulation results for short termination

IV. EFFECT OF VARYING LOADS

Low-voltage power distribution networks (indoor) were designed only for supply of electrical signals at 50 Hz to households. The sockets, or terminal nodes, are considered the access points to the channel where transmitter or receiver equipment or loads can be located. Every device connected to the power network represents a load to the network, whose model includes, besides its impedance value, noise source associated with it. The frequency dependent and time variant values of the loads can be obtained directly from measurements of typical electrical loads. Some loads may have constant impedance value as long as their connection status does not change, but others exist that present a cyclic variation of their value according to the mains frequency.

If a wide range of devices and appliances with variable electrical characteristics are either switched on or off at any location or node and at any time, their variation in the network will lead to strong fluctuations of the impedance. These impedance fluctuations and discontinuity lead to multipath behavior of the BPLC channel, making its utilization for the information transmission more delicate. Model of powerline channel can be expressed as linear combination of a time-varying filter with additive noise and an attenuating multipath channel. The multipath channel with additive noise can be described by an Echo Model [4]. In contrast to the known approaches, a top-down strategy [4] considers the communication channel as a black box and describing its transfer characteristics by a frequency response in the frequency range from 500 kHz up to 20 MHz by very few relevant parameters. The structure of the model is based on fundamental physical effects, which were analyzed during a great number of measurements. However, in contrast to previous approaches, the relevant parameters are not derived from component properties, but from channel measurements.

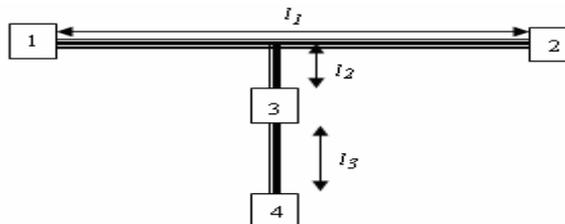


Fig 6. Section of Low voltage power distribution Network (Indoor)

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Special Issue 1, December 2013

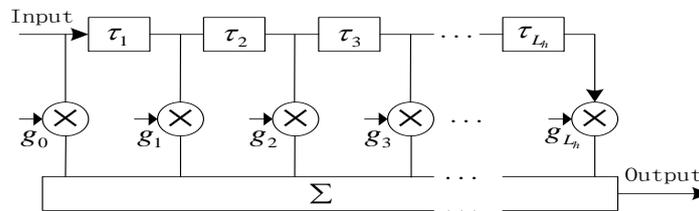


Fig 7. Echo model of power line

The echo model can be described by a discrete time impulse response $h(t)$.

$$h(t) = \sum g_i \delta(t - \tau_i) \quad (19)$$

Considering the effect of line attenuation due to heat loss and radiation and taking the Fast Fourier Transform, the channel response is given by equation (20).

$$H(f) = \sum g_i e^{-\alpha(f)d_i} e^{-2\pi f \tau_i} \quad (20)$$

g_i is the weighting factor and represents the product of the reflection and transmission factors along the path i
 d_i is the length of the path.

τ_i is the path delay introduced by path i and is the ratio of the path length (d_i) and phase velocity (v_p).

$$\tau_i = d_i / v_p \quad (21)$$

The simulation of the BPL system is carried out in MATLAB/SIMULINK with variable number of branches and increasing loads and the BER rate is compared graphically. As observed from fig.8 and fig.9, the effect of changing loads is more on networks with lesser number of branches. With increasing number of branches, the effect of load on the network goes on decreasing. With increase in the number of branches, the impedance of the network decreases because of a large number of impedances in parallel. More the number of branches, lesser is the network impedance.

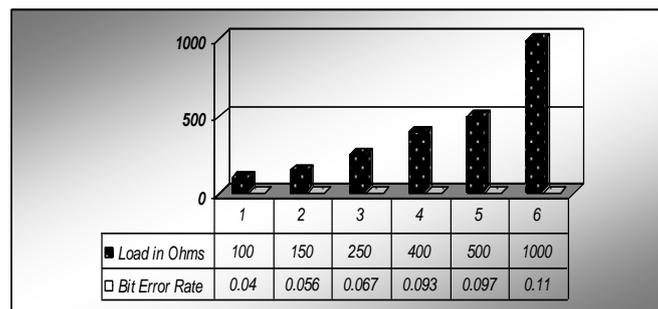


Fig.8 BER and load for one branch

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Special Issue 1, December 2013

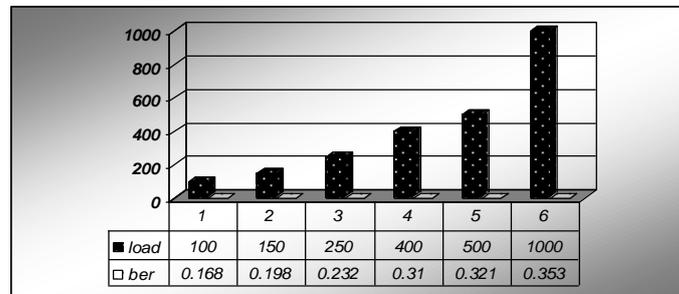


Fig.9 BER and load for three branches

V. BROADBAND PLC EQUIPMENTS FOR INDOOR POWER LINE NETWORK

Network performance analysis of CORINEX Communication, Inc. Broadband PLC equipments (fig10 and fig 11) for indoor power line network using measurements of different network characteristics parameters such as throughput and latency is conducted for the network in Jamia Millia Islamia.



Fig 10. Corinex AV200 Enterprise Powerline Adapters in Jamia Millia Islamia BPL and SCADA Lab.

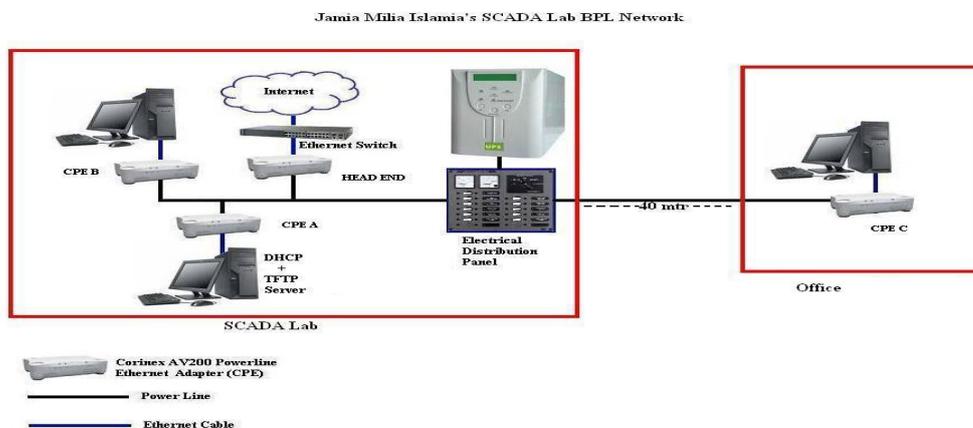


Fig 11. A Typical Layout of BPL Network in Jamia Millia Islamia BPL and SCADA Lab.

The Corinex AV200 Enterprise Power line Adapters [6, 8 and10] installed enable the users to connect individual PCs or other devices with Ethernet communications links into a local area network through existing electric power lines



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Special Issue 1, December 2013

(Power line), also enable PC file and application sharing, allow peripheral and printer sharing through the Power line network, enables shared broadband Internet access, enables sharing of bandwidth for multimedia payloads, including voice, data, audio and video, eliminates the need for long network cables running throughout.

VI. CONCLUSION

The simulation results reveal that in a realistic PLC scenario, the transient variations of the nature of termination, value of loads (i.e. transient impulsive noise) and the different network conditions (i.e. different access point with different mismatch), make the PLC transmission channel time-frequency dependent. In principle, channel attenuation depends on the characteristics such as length, per-unit-length parameters, frequency dependence etc. of the cables and of the loads. While the frequency dependence can be mathematically modeled, the load variation cannot be analytically calculated as the loads are applied or disconnected several times a day randomly. The load variations are quite significant. Models of the transfer characteristics of the mains network prove to be significant for design of such future networks.

REFERENCES

- [1] T. S. Pang, P. L. So, K. Y. See, and A. Kamarul, "Modeling and Analysis of Common-Mode Current Propagation in Broadband Power-Line Communication Networks," IEEE Transactions on Power Delivery, Vol. 23, No. 1, January 2008, pp.171-179.
- [2] P. Mlynek, M. Koutny, and J. Misurec, "Power line Modelling for creating PLC communication system," International Journal of Communications, Issue1, Volume 4, 2010, pp.13-21.
- [3] Holger Philipps, "Performance Measurements Of Powerline Channels At High Frequencies," International Conference on PLC, 1 998, pp. 229-237.
- [4] Manfred Zimmermann and Klaus Dostert, "A Multipath Model for the Powerline Channel," IEEE Transactions on Communications, Vol. 50, NO. 4, APRIL 2002, pp. 553-559.
- [5] Stefano Galli and Thomas Banwell, "A Novel Approach To The Modeling of the Indoor Power Line Channel—Part II: Transfer Function And Its Properties," IEEE Transactions On Power Delivery, Vol. 20, NO. 3, July 2005 pp. 1869-1878.
- [6] Vinay Kumar Chandna, and Mir Zahida, "Effect of Varying Topologies on the Performance of Broadband over Power Line," IEEE Transactions On Power Delivery, Vol. 25, No. 4, October 2010, pp. 2371-2375.
- [7] Gerardo Laguna and Ricardo Barr'on, "Survey on Indoor Power Line Communication Channel Modeling," IEEE Electronics, Robotics and Automotive Mechanics Conference 2008, pp.163-168
- [8] Seema Arora, Vinay Kumar Chandna and Mini S. Thomas, "Modeling of Broadband Indoor Power Line Channel for Various Network Topologies", IEEE PES Innovative Smart Grid Technologies, ISGT 2011, pp. 229-235.
- [9] Sami Barmada, Member, IEEE, Antonino Musolino, and Marco Raugi, "Innovative Model for Time-Varying Power Line Communication Channel Response Evaluation", IEEE Journal On Selected Areas In Communications, Vol. 24, No. 7, July 2006 pp.1317-1326
- [10] Shabana Mehruz, Abhishek Sinha and Mini S. Thomas, "Modeling of Indoor power line for Substation monitoring using Broadband Power line Communications", TENCON, Hyderabad, 2008, pp.1-4.
- [11] Er Liu, Yangpo Gao, Osama Bilal and Timo Korhonen, "Broadband Characterization Of Indoor Power line Channel". IEEE International Conference on Communications 2005, VOL 2, pp. 901-905.
- [12] Andrea M. Tonello and Tao Zheng, "Bottom-Up Transfer Function Generator for Broadband PLC Statistical Channel Modeling," IEEE Conference 2009, pp.7-12.

BIOGRAPHY

Mini S. Thomas (M-88, SM-99), graduated from University of Kerala in 1984, completed her M.Tech from IIT Madras in 1986 (both with gold medals) & PhD from IIT Delhi in 1991, all in Electrical Engineering. Her employment experiences include Regional Engineering College, Calicut, Kerala, and Delhi College of Engineering, New Delhi and presently as Professor in the Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi. Mini S. Thomas received the prestigious 'Career Award' for young teacher, instituted by AICTE, Govt. of India, for the year 1999. She has published over 70 papers in International/National Journals & Conferences. Her current research interests are in SCADA/EMS System and Substation and Distribution Automation.

V. K. Chandna (M-08, SM-11) graduated from Nagpur University in 1994 in electronics & power, completed his M.E. in Power System from Walchand college of Engg. Sangli, Maharashtra and Ph.D. in Electrical engineering, from Delhi College of Engineering. His employment experience includes ITS College of Engineering, Greater Noida, Jamia Millia Islamia, New Delhi, Walchand college of Engg., Nagpur, Raj Kumar Goel institute of technology, Ghaziabad (UP), Maharaja Agarsen Institute of Technology, Delhi, Jamia Millia Islamia (Central University), Delhi. He is presently working as Prof. and Head in Electrical Engg. Department, JSS College of Engineering, Noida. He has more than 20 papers in International Journal / Conferences of repute. His area of interest is Distributed Generation, Smart/ Microgrid, application of soft computing techniques to power system, SCADA, operation, design and control.

Seema Arora (S-10) received her B.Tech (with Honors) in Electrical from PEC, Panjab University, Chandigarh, in 1995, completed her M.E. in Power Electronics, Electrical Machines and Drives in 2006 from M.D. University, Rohtak. She worked in a consultancy of Thermal power plants as a Design and Protection Engineer. She is currently working as an Assistant Professor in the Department of Electrical and Electronics Engineering at GCET, Greater Noida. She is also doing PhD from Jamia Millia Islamia, New Delhi and her research area is Broadband over Power Lines. She has published various research papers in International /National Journals & Conferences of repute. Her research interests include Distributed Generation, Smart Grids, Micro grids, and Communication over Power Lines.