Modeling of indoor power line for home application using broadband

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Abstract: The objective of this paper is to study the feasibility of Broadband technologies for home application in an effective manner and to develop a simplified transfer characteristic model for the low voltage indoor power line for Broadband power line communication based on the transmission line theory using software simulation for generalization purpose as it is already known that there is no such thing as a standard "power line network". A bottom-up approach based on the frequency-domain modeling and using scattering matrix is implemented for channel modeling in this paper.

Keywords: Broadband, Home automation, Power line communications, Channel model, Transfer function.

I. INTRODUCTION

Power line communication (PLC) has been utilized for low bandwidth applications for many years. Recently, the technology has been enhanced to be capable of supporting high speed transmission of data, voice and video services .It is obvious that there are many advantages in using a power line network as a communication channel for broadband power line communication (BPLC). Firstly, the power network is the most pervasive network comparing to any other networks in the world and its availability reaches every sockets in our house [1]. And then, it is a "no new wire" technology. Using existing power line network for BPLC is economy. Moreover, access to the internet is becoming true by using low voltage power line network

An alternative to broadband technologies is broadband power line communications. The new technology operates in the 1-30 MHz and can deliver data rates up to several Mbps [1]. The rationale behind providing high bit-rate data services exploiting the power grid resides in the vast infrastructure in place for power distribution, and the penetration of the service could be much higher than any other wire line alternative. In spite of the renewed interest in Power line communications, this technology still faces several technical challenges and regulatory issues: the power line channel is extremely difficult to model; it is a very noisy transmission medium; Power line cables in the 240V secondary distribution systems are often unshielded, thus becoming both sources and targets of electromagnetic interference (EMI); transformers can introduce severe distortion in the absence of bypass couplers. Due to above reasons and since power line technology appears to be more mature for the indoor home-networking scenario than for the outside broadband access one, focus here is on the modeling of the indoor power line channel and, in particular, on the transfer function between outlets. A new software based approach to the characterization of the indoor power line channel has been investigated and is described here.

A bottom-up approach based on the frequency-domain modeling and using scattering matrix is implemented in this paper similarly as in [4], however a two-wire line model with no effect of third conductor is used since the conductor of concern are only on which the signal propagates i.e. the 'hot' and 'return' wire. Moreover what the above paper [4] and the previous papers lacks   is that the equations used for the determination of primary line parameters R, L, C and G are that which are used for low frequencies and when the distance between the conductors is very much greater than the radius of the conductor, whereas in an indoor power line network the cables are simply pulled through the conduit and lie in close proximity to each other and the technology operates at high radio frequency (MHz). This paper is organized as follows. An overview of broadband communications for home automation, taking an example of home application is discussed in Section II Also, how Broadband PLC can be integrated into the existing broadband backbone infrastructure is mentioned in this section. Section III deals with the transmission line analysis of power line. Modeling of power line is done in Section IV. Transfer function characterization using software simulation is discussed in Section V while concluding remarks are mentioned at the end in Section VI.

II.   HOME AUTOMATION USING BROADBAND

In the broadband scenario, home PLC (indoor) systems use internal electrical infrastructure as transmission medium and house meter (M) is connected with outdoor low-voltage network as shown in fig 1 .There are two basic network elements that is modem and base station (BS). A PLC modem connects standard communications equipment, used by the subscribers, to a power line transmission medium [3]. The user-side interface can provide various standard interfaces for different communications devices (e.g. Ethernet and Universal Serial Bus (USB) interfaces for realization of data transmission and S0 and a/b interfaces for telephony).
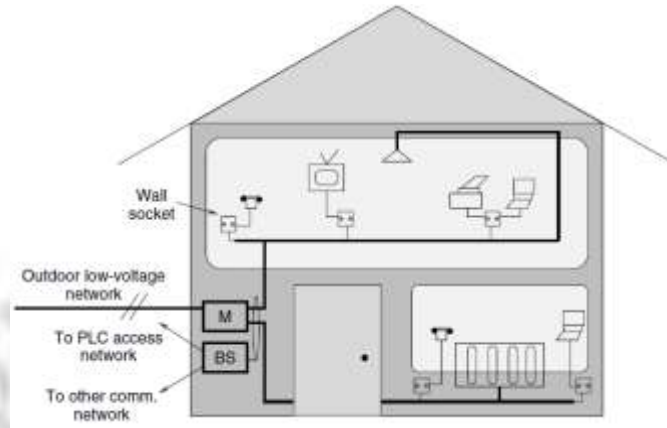.

Fig.1: Home power line communication

Method that allows the feeding of communications signals to the power line medium and its reception as shown in fig.2. The coupling has to ensure a safe galvanic separation and act as a high pass filter dividing the communications signal (1-30MHz) from the electrical power (50 or 60 Hz).All devices of an in-home PLC network are connected via PLC modems, such as the subscribers of a PLC access network[3] .
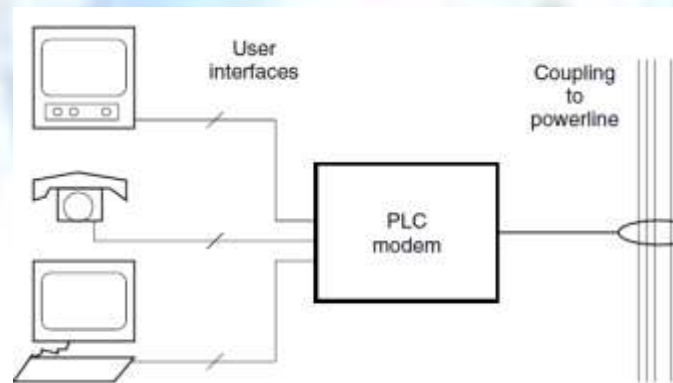

Fig- 2: Functions of Broadband PLC modem

The modems are connected directly to the wall power supply sockets (outlets), which are available in the whole house/flat. Thus, different communications devices can be connected to the in-home PLC network wherever wall sockets are available. There can also a base station that controls an in-home PLC network, and probably connects it to the outdoor area as shown in fig-3. The base station can be placed with the meter unit, or in any other suitable place in the in-home PLC network.
A PLC base station (master station) connects a home PLC system to its backbone network It realizes the connection between the backbone communications network and the power line transmission medium [3]. However, the base station does not connect individual subscriber devices, but it may provide multiple network communications interfaces, such as xDSL, Synchronous Digital Mierarch (SDH) for connection with a high-speed network, WLL for wireless interconnection, and so on.
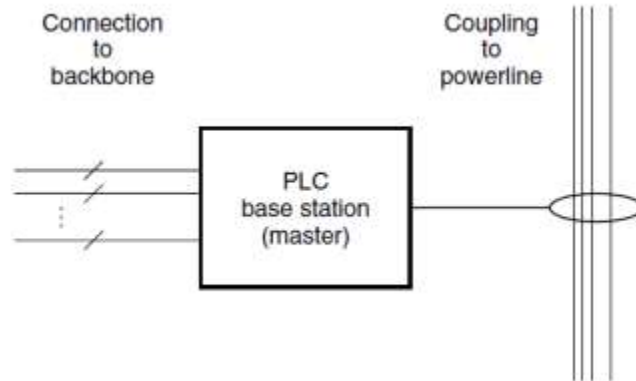
Fig-3 Function of Broadband PLC base station

In this way, a PLC base station can be used to realize connection with backbone networks using various communication technologies.

III. TRANSMISSION LINE ANALYSIS OF POWER LINE

When power lines are used to transmit high frequency communication signals, they can be regarded as transmission lines, which guide the transverse electromagnetic (TEM) waves along them. According to Electromagnetic theory, the two-wire transmission line must be a pair of parallel conducting wires separated by a uniform distance. In the actual installation, the power cables are simply pulled through the conduit and the separation between them is not uniform at all. However, the conduit normally has small cross-sectional area and this limits the variation of the separation between the cables. Hence, the assumption of uniform separation is reasonable in this case. Based on the above consideration, the paired power cables are regarded as a distributed parameter network, where voltages and currents can vary in magnitude and phase over its length. Hence, it can be described by circuit parameters that are distributed over its length as shown in fig.4 below. The quantities v (z, t) and v (z + Δ z, t) denote the instantaneous voltages at location z and z + Δ z, respectively. Similarly, i (z, t) and i (z + Δ z, t) denote the instantaneous currents at z and z + Δ z, respectively. R defines the resistance per unit length for both conductors (in Ω / m), L defines the inductance per unit length for both conductors (in H/m), G is the conductance per unit length (in S/m), and C is the capacitance per unit length (F/m). Based on the lumped-element circuit of a two wire transmission line as shown above, model parameters per unit length (m) at high radio frequencies when distance 'D' between conductors is comparable to the radius 'a' of the conductor the equations for the transmission line parameters are described as below [6]:
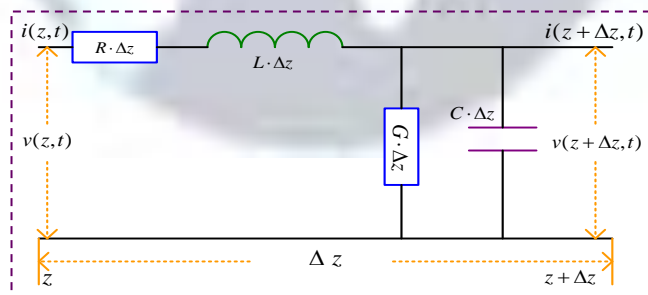

Fig.4 Equivalent circuit of two-wire transmission line

Resistance 'R' = $1/\pi a \delta \sigma_c$ (1)

Where 'δ' = skin depth = $\sqrt{1/\pi f \mu_c \sigma_c}$ and is a function of frequency 'f'. This effect causes an increase in the resistance of the cable and it worsens as the current frequency increases. Also,

Inductance $L = \dfrac{\mu_c}{\pi} a \cosh(D/2a)$ (2)

$$G = \dfrac{\pi \sigma_d}{a \cosh(D/2a)}$$

Conductance   (3)

Capacitance   (4)

Here, μ_c = permeability of copper conductor, σ_d = conductivity of the dielectric material, and ε_d = permittivity of the dielectric material.

IV.   MODELING THE INDOOR POWERLINE

Typically, the 'hot' and 'return' cables are used as the PLC transmission channel, which can be approximated as a close form of the "two-wire transmission line". The cables are made up of stranded copper conductors with PVC insulation laid inside PVC conduits that are embedded inside the wall in an Indian residential scenario. However, here the indoor power cables are approximated to be a two-wire transmission line with solid core conductor for generalization and ease of implementation using software simulation as shown in Fig. 5. 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 of the insulation 't' 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.
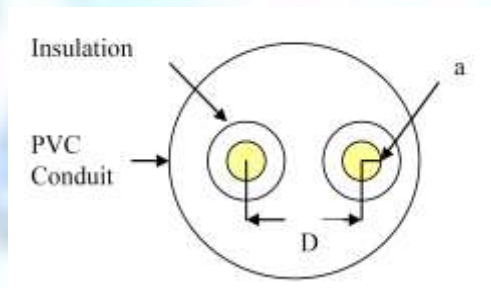

Fig.5: Approximate model of the indoor power line

Here, a is radius of conductor and distance between the two conductors (Live and Neutral) 'D'= 2t + 2t + 2a. Now, the length of transmission line is taken to be 'S'=8 m with shunt stub terminated in an open circuit as shown in fig.6 for simulation considering the fact that, indoor power lines are radial N-branched network as shown in fig 6 below.
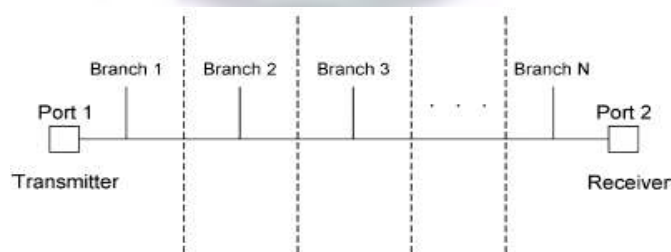

Fig.6: a simplified indoor power line channel

In fig.6, port 1 is the transmitter from where the signal is sent, and port 2 is the receiver where the signal strength is measured.

V. TRANSFER FUNCTION MODELING

The main causes of attenuation in a power line network is due to the heat loss and radiations along the power line, reflections arising from the points of impedance discontinuities on the propagation channel causing destructive interference and due to the forward propagating wave falling out of phase with the main incident forward wave. Frequency-domain modeling approach using scattering matrix technique accounts for all these reflected and delayed paths in the power network. S-parameter matrix gives relationship between reflected (b) and incident (a) power waves as described below for a two port network.

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{5}$$

Here, S_{21} gives the Network Transfer Function.

Software simulation using MATLAB is done to obtain the transfer function whose magnitude (dB) versus frequency plot gives the attenuation in the signal strength and angle (radian) versus frequency plot gives the phase distortion or delay as shown in fig.7 and fig.8 respectively.
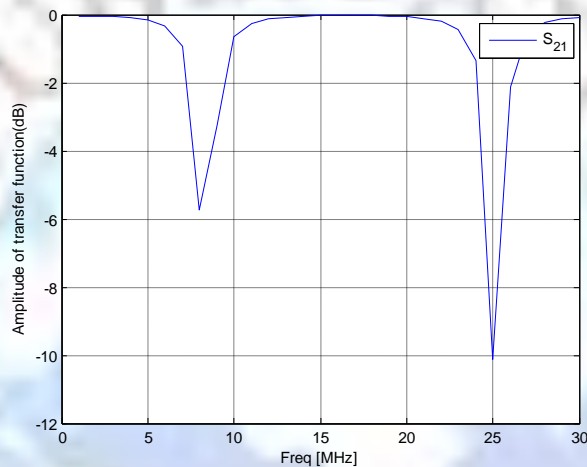

Fig. 7: Amplitude of Transfer function

Fig.7 shows the presence of deep notches at certain frequencies in the transfer function. For communication to establish between two access points, the carrier frequency chosen must not fall at deep notches.
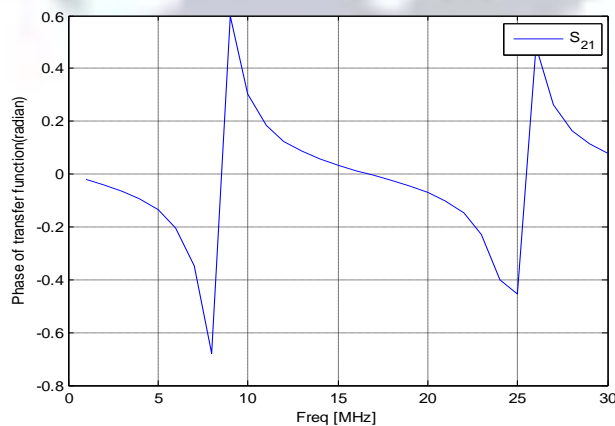

Fig. 8 Phase of Transfer function

Also, Fig.8 shows that when there is deep notch at certain frequency in the transfer function, there is a discontinuity in the phase characteristics leading to phase distortion or delay.

CONCLUSION

It is seen that Broadband PLC offers an exciting opportunity for applications like home automation using low voltage indoor power line. The low voltage single-phase power line is modeled as a two wire transmission line and the channel transfer function is determined using scattering matrix. Model can predict the channel transfer function of the PLC medium including the position of attenuation notches and the accompanying phase distortion or delay.

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