The Analysis of the Indoor PLC Channel Characteristics Based on Information Nodes Channel Modeling Method

Wei Cai, Jian Le, and Kai-pei Liu

***Abstract*—In this paper, a novel channel modeling method of the power-line communication (PLC) channel based on the information nodes has been proposed firstly to deal with all kinds of network topologies that may emerge in indoor power networks. Based on this method, the influence laws of the length from transmitter to receiver, branched lengths, branch load impedances and number of branches to the channel transmission characteristics has been analyzed in detail. The paper emphatically analyzes the influence on fading frequency and fading depth induced by these factors. It is seen that the power-line input impedance is fixed at signal attenuation peak frequency point. The conclusions in this paper provide the necessary theoretical basis to power-line communication modulation method.**

***Index Terms*—Power-line communication, information nodes, channel model, channel characteristics, frequency fading.**

I. Introduction

Power-line carrier is a communication approach to transfer voice or data with high speed over the power line which has been loaded with power frequency signal. It aroused worldwide attention and research when it appeared [1]. Nowadays the researches are focus on channel modeling [2]-[4], noise characteristics analysis [5]-[6] and signal modulation [7]-[8].

Channel modeling methods can also be divided into time-domain [9]-[11] and frequency-domain types [12]-[14]. The time-domain methods treat the PLC channel as a multi-path environment and use the reflection model to represent the physical characteristics of the channel. The frequency-domain modeling method breaks down the entire network into several cascaded sub-network, and then calculates the transmission matrix or scattering matrix of each sub-network. All of these methods have difficult to deal with multiple rings and ever mesh topologies that may emerge in indoor power networks.

On the other hand, the topologies of distribution networks are diverse and the load conditions are complex, the transmission characteristics and input impedance will be influenced by many factors, such as the branch numbers, electrical equipment and line length, and these results in the complexity of the PLC transmission characteristics. Gao feng et al [15] gives the measurement result of the signal attenuation characteristics in an industrial building with different transmission distances, it can be seen that the transmission distance has a significant influence on the signal attenuation characteristics. The paper also points out that the load switching has a great influence on the power line communication systems. But the paper doesn't analysis the influence laws of transmission distance and load switching. Furthermore, the power network input impedance changes with signal frequency, which brings great difficulty to the design of electricity carrier equipment [16].

This paper firstly propose a power line channel modeling method based on information nodes that has the ability to deal with all kinds of topologies that may emerge in indoor power networks, and then analysis the influence laws of channel transmission characteristics when the line length, branch length, load impedance, the number of branches or the location of branches changes. It provides reference to the optimization design of power line communication system.

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II. Information Node-Based Channel Modeling Method

Fig. 1 gives a general complex network topology which contains signal source V_S and its impedance Z_S, loads $Z_{L1}\ldots Z_{Li}$ and Z_{Lj}, power lines Line 1…*Line i* and *Line j*. The purpose of power line channel modeling is to obtain the amplitude and phase transmission characteristics between the signal trans- mittter and any receiver.

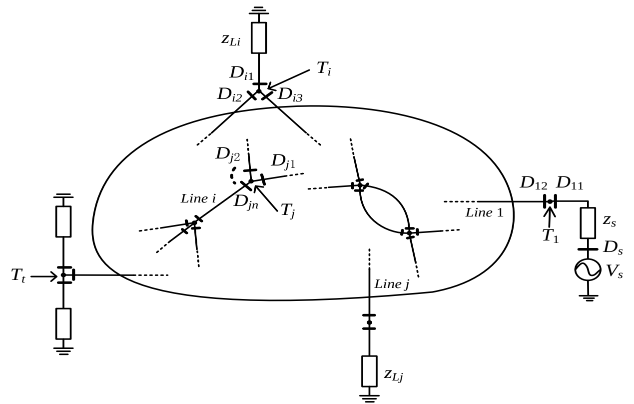

Fig. 1. Complex network topology

The main idea of the proposed power line channel modeling method is to set information nodes for the signal source, power lines and loads at the nearest points to the network node to which these component accesses, such as D_{i1} for load Z_{Li} to node T_i in Fig.1. In addition, an information node D_S must be set between signal source and its impedance. The information nodes settings for each kind of network components are shown in Fig. 2.

Without loss of generality, we assume that a power network shown as Fig. 1 consists of m power lines and n loads. The two terminations of each power line are connected to one network node, so the number of the information nodes that are related to power lines is 2m. Similarly, the number of the information nodes related to loads is n. Information nodes D_S and D_{11} are related to signal source V_S. So the total number S of information nodes of the whole network is:

$$S=2m+n+2 \tag{1}$$

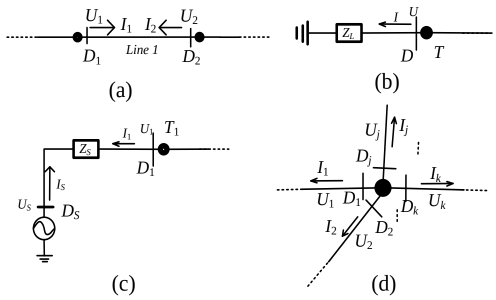

Fig. 2. Information nodes (a) power line (b) load (c) signal source (d) network node.

There are two unknown electrical quantities related to an information node, i.e. the voltage of this node and the current flowing out of this node. Thus there are 4m+2n+4 unknown quantities of the whole network. In this paper, the current reference direction is out of the network nodes (as indicated by the arrows in Fig. 2).

As shown in Fig. 2(a), D_1 and D_2 are the two information nodes of power line Line1. According to the transmission theory, the *V-I* relation between these two information nodes can be concluded as:

$$\left.\begin{aligned} U_2 &= U_1 ch\gamma x - I_1 Z_C sh\gamma x \\ -I_2 &= I_1 ch\gamma x - \frac{U_1}{Z_C} sh\gamma x \end{aligned}\right\} \tag{2}$$

where U_1 and U_2 are the voltages of information nodes D_1 and D_2, I_1 and I_2 are the currents flowing out of information nodes D_1 and D_2, respectively.

For each power line, we can list two equations similar to formula (2), so 2m equations can be obtained when there are m power lines.

As shown in Fig. 2(b), for each load, its voltage V and current I must satisfied Ohm's Law:

$$U = Z_L \times I \tag{3}$$

where Z_L is the load impedance. So n equations can be obtained when there are n loads.

As shown in Fig. 2(c), D_1 and D_S are the information nodes related to signal source, two equations can be deduced as following:

$$\left.\begin{aligned} U_S &= U_1 - I_1 \times Z_S \\ I_S &= -I_1 \end{aligned}\right\} \tag{4}$$

where Z_S is the internal impedance of the signal source.

Generally, supposing there are j information nodes related to the network node T_j(as shown in Fig. 2(d)), and based on the basic circuit theory, we can obtain j independence equations related to T_j as following:

$$\left.\begin{aligned} U_1 = U_2 = \cdots = U_k = \cdots = U_j \\ I_1 + I_2 + \cdots + I_k + \cdots + I_j = 0 \end{aligned}\right\} \tag{5}$$

For a network with m power lines, n loads and one signal source, there must be 2m+n+1 information nodes, so 2m+n+1 independence equations can be listed for all the network nodes.

Thus for a power network consists of m power lines and n loads, 2m+n+2m+n+1+2=4m+2n+3 independent equations can be obtained based on the above derivation.

As mentioned above, there are 4m+2n+4 unknown variables for the whole network, while there are 4m+2n+3 independent equations that make a homogeneous linear equations, thus the ratio relation of any two of the 4m+2n+4 unknown variables can be calculated easily. For an example, the voltage transmission characteristics between the signal transmitter and a receiver that is located at node Ti can be obtained as following:

$$H_i(f) = \frac{U_{Zi}}{U_S} \tag{6}$$

where U_{Zi} is the voltage of information node Di1 that is related to network node T_i.

Similarly, the input impedance of the power line communication network can be obtained as following:

$$Z_{in}(f) = \frac{U_1}{-I_1} \tag{7}$$

where U_1 and I_1 are the voltage and current flowing out of information node D_{11} (as shown in Fig. 1), respectively.

As we can see that the theoretical expression of the voltage transmission characteristics from the transmitter to receiver and the input impedance of network can be calculated easily by general software such as MATLAB. And this method is applicable to a network with arbitrary topologies.

III. Effects of Line Length

A. Truck Length

A tree topology with a branch is taken to analysis the effects of line length, shown as Fig. 3. The signal source is located at node A, while the receiver is located at node C. Point B is always the midpoint of truck line AC. And BD is a branch line with the length l_3 is 10m. Power line *Line*1, *Line*2 and *Line*3 have the same parameters, the per unit length values of the resistance R_0, inductance L_0, line-to-line capacitance C_0 are 1mΩ/m, 276nH/m and 96pF/m respect-tively. The per unit length values of the conductance is ignored. The source internal impedance Z_S and receiver impedance Z_L are both 50Ω, and the branch load impedance is 5Ω.

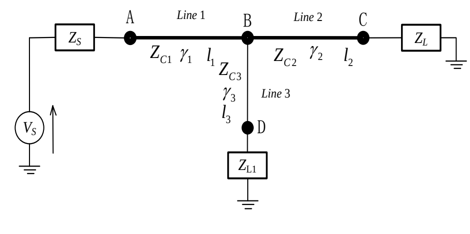

Fig. 3. Tree topology with a branch.

The length from transmitter to receiver is varied as 20m, 30m, 40m and 50m. Fig. 4 shows the amplitude frequency characteristic from transmitter to receiver. The signal frequency ranges from 1MHz to 30MHz. It is observed that the length from transmitter to receiver has less influence to amplitude frequency characteristic and the frequency of attenuation peaks are maintained at the 5MHz, 15MHz and 25MHz. Fig. 5 shows the network input impedance charateristics. It is observed that changes of the input impedance are complex, but the input impedance is nearly the same 50Ω at all the attenuation peaks.

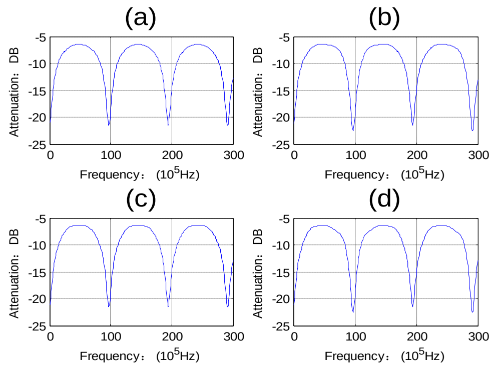

Fig. 4. Voltage transmission amplitude-frequency characteristics when the truck length changed.

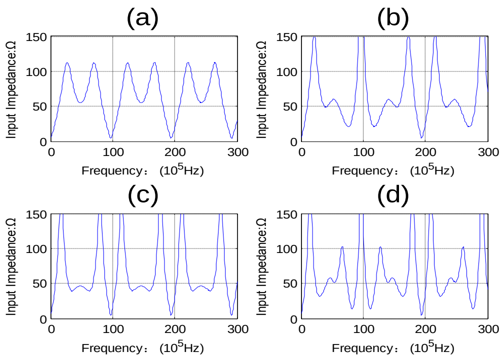

Fig. 5. Input impedance characteristics when the truck length changed.

B. Branch Length

Now the truck line length AC of the network shown as Fig. 3 is 20m but the branch length is varied as 5m, 10m, 15m and 20m. The source internal impedance Z_S and receiver impedance Z_L are both 50Ω. Fig. 6 shows the amplitude frequency characteristic from transmitter to receiver. It is observed that as the branch length increases, the number of attenuation peaks increases.

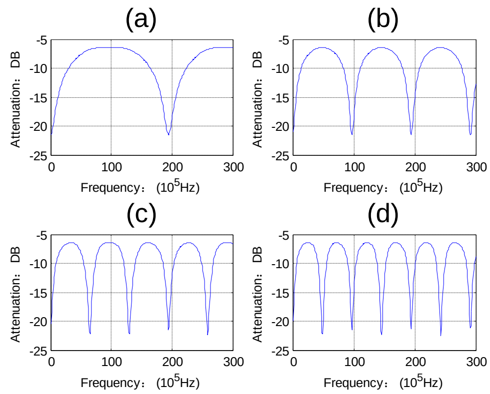

Fig. 6. Voltage transmission amplitude-frequency characteristics when the branch length changed.

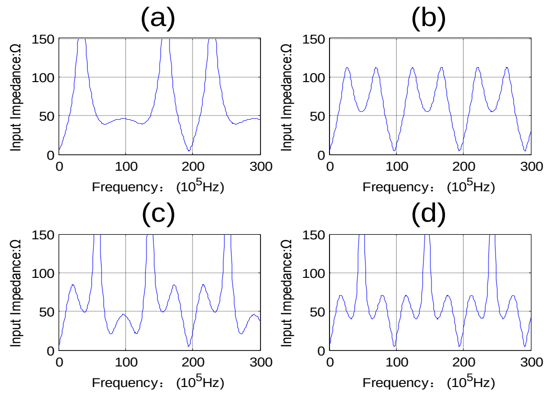

Fig. 7. Input impedance characteristics when the branch length changed.

Fig. 7 shows the network input impedance characteristics. It is observed that the changes of the input impedance are also the same complex, and the input impedance is also nearly 50Ω at all the attenuation peaks as well.

IV. Effects of Branch Load

Some of the electrical devices used in power network are with pure resistance characteristic, such as incandescent lamps, electric water heater and electric heater; while others are with the inductance characteristic, such as air-conditioning, refrigerator, and transformer et al. The power line communication channel environment is very complex due to the different impedance characteristic of these devices. In this section we will analysis the influence of pure resistance loads and inductance loads to transmission characteristic.

Firstly the pure resistance loads is considered, the length from transmitter to receiver is 20m and the branch length is 10m. The source internal impedance Z_S and receiver impedance Z_L are both 50Ω, the branch load varies as 5Ω, 20Ω, 53Ω, 100Ω, 200Ω and 500Ω. Fig. 8 shows the amplitude frequency characteristic from transmitter to receiver. It is observed that when the branch load varies from 5Ω to approach the power line character characteristic impedance, the location and amplitude of attenuation peaks have no obvious change, but the amplitude of attenuation notches reduces with the loads increases; when the branch load varies from approach the power line character characteristic impedance to infinite, the frequency and amplitude of attenuation peaks have no obvious change, the amplitude of attenuation notches increases with the loads increases. As the branch load impedance is basic equal to the characteristic impedance of the power line, the peak-valley of amplitude frequency characteristic becomes the least. (Fig. 8(c)).

Fig. 9 shows the network input impedance characteristics. It is observed that changes of the input impedance are also complex, and the input impedance is nearly 50Ω at all the attenuation peaks as well. But when the branch load equals to power line character characteristic, the input impedance characteristic is similar to sine. The period of the sine is 10MHz, the average value is 60Ω and the peak-valley is 80Ω.

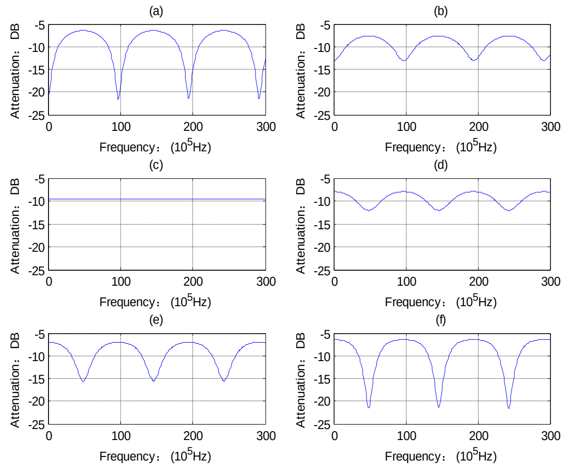

Fig. 8. Voltage transmission amplitude-frequency characteristics when the branch load impedance changed.

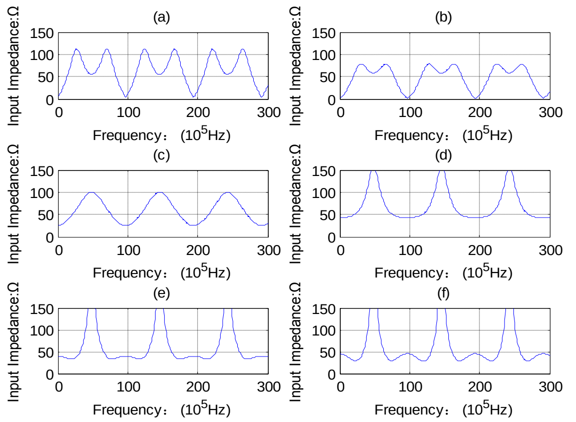

Fig. 9. Input impedance characteristics when the branch load impedance changed.

As to the inductance loads, they can be seen as open circuit because of the high frequency. The amplitude frequency characteristic and the input impedance are similar with Fig. 8 (f) and Fig. 9(f), respectively.

V. Effects of Number of Branches

A. Multiple Branches at Single Node

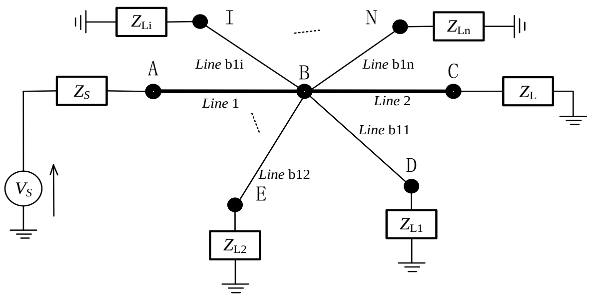

Fig. 10. Tree topology with multiple branches at single node.

For this study, the network configuration is shown as Fig. 10. The length from transmitter to receiver is 20m; B is the midpoint of AC. Branches number varies as 1, 2, 3 and 4. All of the branch length is 10m and terminated in 5Ω. The source internal impedance Z_S and receiver impedance Z_L are both 50Ω.

Fig. 11 shows the amplitude frequency characteristic from transmitter to receiver. It is observed that the location and amplitude of attenuation peaks, the location of attenuation notches have little change as the branch number increases, but the amplitude of attenuation notches increases as the branch number increases.

Fig. 12 shows the network input impedance characteristics. It is observed that the overall trends are the same. The input impedance is near to 0Ω at the point of attenuation notches, and the input impedance at the point of attenuation peaks have a slight increase as the branch number increases.

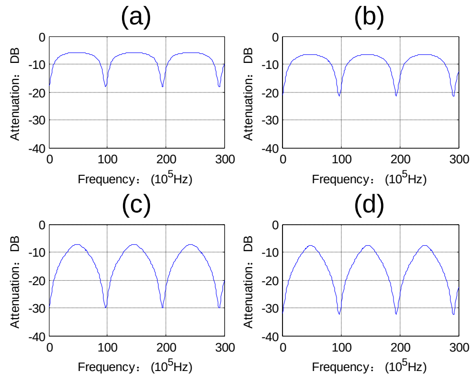

Fig. 11. Voltage transmission amplitude-frequency characteristics when the branches number changed.

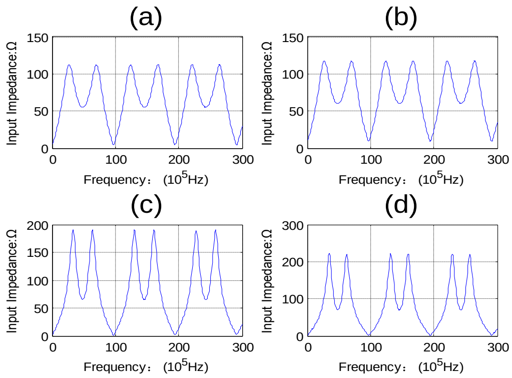

Fig. 12. Input impedance characteristics when the branches number changed.

B. Multiple Branches at Multiple Nodes

The network configuration is shown as Fig. 13. The length from transmitter to receiver is (10n+10)m, where n is the number of branch nodes. Each branch connects to one but only one node. All the branch lengths are the same 10m and are terminated with 5Ω. The source internal impedance Z_S and receiver impedance Z_L are both 50Ω. Branches number varies as 1, 3, 5 and 7.

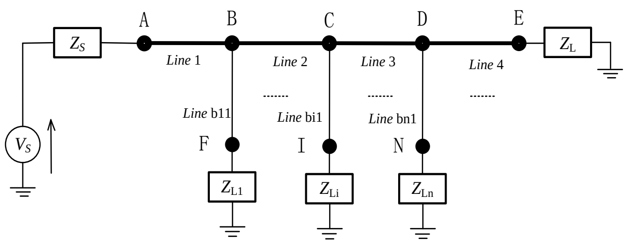

Fig. 13. Tree topology with multiple branches at multiple nodes

Fig. 14 shows the amplitude frequency characteristic from transmitter to receiver. Fig.15 shows the network input impedance characteristics. It is observed the amplitude of attenuation notches increases as the branch number increases. The overall trend are nearly the same, the input impedance is nearly 100Ω at all the attenuation peaks.

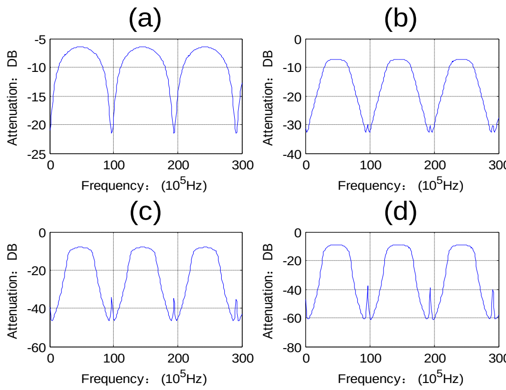

Fig. 14. Voltage transmission amplitude-frequency characteristics when the branches number changed.

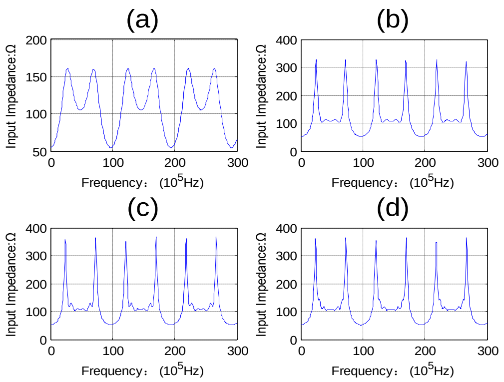

Fig. 15 Input impedance characteristics when the branches number changed.

VI. Conclusions

This paper analyzes the influence factors and its influence laws on the transmission characteristics and input impedance of network. It is shown that: 1) the length from transmitter to receiver has less influence to amplitude frequency characteristic, but the number of attenuation peaks increases with the branch length increases. 2) If the load is pure resistance, amplitude of attenuation peaks has no obvious change as the loads increases, but amplitude of attenuation peaks has the trendy of anti-parabolic as the loads increases. And when the branch load equals to power line character characteristic, the peak-valley of amplitude frequency characteristic becomes the least. If branch connects to inductance loads, the branch can be seen as open circuit because of the highly frequency. 3) When multiple branches connect to a single node, the location and amplitude of attenuation peaks have little change as the branch number increases; while multiple branches connect to multiple nodes, the amplitude of attenuation notches increases as the branch number increases. 4) The input impedance characteristics changes in different power topologies, but input impedance is nearly the same at all the attenuation peaks.

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