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Power line communication channel modeling with Orthogonal Frequency Division Multiplexing signal modulation in LabView

The aim of this work is development of algorithm for evaluation of transfer function in power line communication (PLC) channel with narrowband orthogonal frequency division multiplexing (OFDM) signal modulation using convenient user interface. This algorithm can be used while planning PLC system. There were explored long line and parametric model of power line. Assuming similarity of wireless and power line communication the influence of multipath on line impedance was investigated. It was shown that signal amplitude is Ricean distributed. The coefficients for this variance distribution were derived from the attenuation parametric modeling. For simulation LabView program interface was chosen. The developed algorithm permits evaluation of maximal distance between receiver and transmitter that doesn't require repeater installation.

Keywords: PLC, OFDM, parametric model of power line communication channel, Ricean distribution.

Introduction

Investigation of propagation power losses takes important part in PLC systems development [2, 6]. While planning communication grid three characteristics are generally taken into consideration: reliability, resilience, cost, datarate and delay. In terms of PLC cost can be reduced by minimizing of modems' and repeaters' quantity. The restrictions for this optimization task are reliability and datarate as far as these characteristics decrease with the distance between modems due to the signal attenuation. So it becomes necessary to create a tool for evaluating of maximal distance between a pair of modems in power line communication network as function of required datarate and available frequency range. Evaluation should be performed basing on existing power line network architecture.

In this work there was described an algorithm for transfer function investigation with OFDM signal modulation [8] with not fixed power line topology in frequency range from 10 kHz to 450 kHz that is ARIB (Association of Radio Industries and Businesses) standard. Transfer function is an important part of physical layer structure of Open System Interconnection (OSI) communication protocol model. The investigations are based on parametric power line model described in [1, 3] and probabilistic power

line model (Ricean distribution, generally used for wireless technologies) described in [4, 5, 6] that are combined further. Also power line communication channel characteristics were used [2] to define additional effects on probabilistic parameters values.

To verify described algorithm there were done simulations in program interface Labview_[8].

1. Channel model

a. Parametric model

Parametric model is the main apparatus for PLC channel modeling with no significant capillarity [1], [3]. It does not require calculation of primary parameters and thus allows relatively easy evaluating of the PLC channel performance.

According to [1] the frequency response (the transfer function $H(f)$ of a transmission line length l) can be expressed as following ($U(x)$ is the voltage at the distance x):

$$H(f) = \frac{U(x)_{x=l}}{U(x)_{x=0}} \cdot \left[e^{-\gamma(f)l} + r(f) \cdot e^{\gamma(f)l} \right] \quad (1)$$

$$\text{where} \quad e^{\pm\gamma(f)l} = e^{\pm\alpha(f)l} + e^{\pm j\beta(f)l} \quad (2)$$

f – operation frequency, Hz;

$\gamma(f)$ – propagation constant;

l – distance between observed points, m;

$\alpha(f)$ – attenuation factor;

$\beta(f)$ – phase factor.

Here is used a demonstrational variant of the simulation of real network using model parameters presented in [3]. According to this source the propagation constant can be found as follows:

$$a(f) = a_0 + a_1 f^k = 8 \cdot 10^{-6} \cdot \sqrt{f}, \quad (3)$$

where a_0 , a_1 and k – approximation coefficients.

I.e. according to the theory of long lines [1] only primary resistance is considered to be non-zero. These parameters are cable depended and can be derived only from the measurements with certain cable.

Frequency response for i -th pair of nodes:

$$H_i(f) = a(l_i, f) \cdot e^{-j2\pi f \tau_i} \quad (4)$$

where $a(l_i, f)$ is the signal attenuation proportioned with the length and the frequency:

$$a(l_i, f) = e^{-(a_0 + a_1 f^k) l_i} \quad (5)$$

and τ_i - propagation delay that can be expressed by using the dielectric constant ε of insulating materials, the light speed c and the line length l_i as follows:

$$\tau_i = \frac{l_i \sqrt{\varepsilon}}{c} \quad (6)$$

b. Ricean channel

Parametric model does not allow modeling of multipath. In [3] was a proposition to use weighting coefficients for each path and sum up frequency response (4) of all channels. But such solution is feasible in case of considerable capillarity of power line network of frequent change of applications' impedances. It is possible to observe a special similarity between PLC and radio channels as illustrated in Tab. 1 [1].

In wireless communications the multipath is modeled by Ricean fading [9]. In contrast to the solution in [3] this model does not require fixed network architecture. The disadvantage of the approach is that frequency response is evaluated using probability distribution.

Table 1. An analogy between PLC and radio channels

	The radio channel	The PLC channel
A multipath signal propagation	Reflections from barriers	Points with imperfect matching of impedance
A temporal variability of the transmission channel	User movement – Dopplers dispersion	Impedance is alternating with allocation

According to [4] if there are at least eight paths it's sufficient to consider that in-phase and quadrature components of signal at the receiver [10] are Gaussian distributed. It means that if talking about network that is comprised from 9 or more modems it's possible to simplify calculations using Ricean fading channel model. Such a network is considered in this paper.

According to [10] signal amplitude at the receiver is characterized by following distribution:

$$f_r(r) = \frac{r}{p} (1+K) \times \exp\left(-\frac{K(1+K)r^2}{2p}\right) I_0\left(r \sqrt{\frac{2K(1+K)}{p}}\right) \quad (7)$$

where r – signal amplitude at the receiver (amplitude at transmitter is 1);

K – Ricean coefficient, called K-factor;

p - local mean power (unitless);

$I_0(\cdot)$ - Bessel function.

K-factor is interpreted as the ratio of the power in the direct path component (from transmitter to receiver) to the local mean scattered power:

$$K = \frac{E_{0,0}^2}{2\sigma^2} \quad (8)$$

Here $E_{0,0}$ - signal amplitude of direct path component (unitless);

σ^2 - local mean scattered power (unitless).

Local mean power is defined as:

$$\bar{p} = \frac{E_{0,0}^2}{2} + \sigma^2 \quad (9)$$

Local mean scattered power is obtained as:

$$\sigma^2 = E\left[\sum_{i=1}^{N_T} \frac{E_{i,0}^2}{2} + \sum_{k=1}^{N_R} \frac{E_{0,k}^2}{2} + \sum_{k=1}^{N_R} \sum_{i=1}^{N_T} \frac{E_{i,k}^2}{2}\right] \quad (10)$$

Here N_T are the waves that experience reflections at the transmitter only, N_R are the waves that experience reflections at the receiver only and $N_T N_R$ are the waves that reflections at both transmitter receiver. We denote waves by an index 'i' indicating the path and reflection near the transmitter and an index 'k' denoting the path and reflections near the receiver. (i, k) th wave has a real amplitude given by $E_{i,k}$. $E[\cdot]$ means that every $E_{i,k}$ is not real measured value. However $E_{i,k}$ for every (i, k) th wave can be estimated from [4].

2. Simulation results

a. K-factor evaluation

Value of K-factor was calculated using (5), (8), (10) and Random Number generator for varying l_i – distance between nodes in range [100, 300] meters. There was assumed $N_R = N_T = 8$ (eight paths). Dominant path was taken 100m long. If taking amplitude of the transmitted signal to be $_1$:

$$E_{i,k} = g_{i,k} \cdot a(l_{i,k}, f_{\max}) \quad (11)$$

where $f_{\max} = 500\text{kHz}$; g_i - weighting coefficient that describes reflection coefficient from the end of the line [1] and is also randomly varied in range [-1,1].

The calculation of K-factor was repeated 100000 times and its average meaning was found. As simulation shows this iteration pointer leads to accuracy of K-factor in third digit. Varying length of dominant path from zero to max (300 m) we see decreasing of this parameter due to the propagation attenuation (Fig. 1).

b. Maximal signal attenuation factor evaluation

Upper layers of OSI model require bit error rate (BER) characteristic from physical layer. It characterizes physical layer on higher levels of used communication protocol and depends on channel model and error correction mechanism. For 802.16a wireless communication protocol physical

layer model is created in program interface Lab-view. Wireless and PLC modems usually use forward error correction and convolutional coding. Taking it and idea of subsection 1.b into consideration we can use observed program for PLC. It allows calculating BER basing on the current value of SNR ratio.

Here we assume maximal BER value to be 10^{-2} . The assumption is needed for testing of the developed in this work algorithm for transfer function investigation. With program interface in Lab-view we find that BER 10^{-2} corresponds to SNR = 30 dB. In [11] maximal signal to noise ratio (SNR) for system with OFDM (Orthogonal Frequency Division Multiplexing) modulation is said to be 60 dB. At this attenuation two OFDM PLC modems can communicate with speed just 3 kbps. SNR value of 30 dB allows higher buadrate. In order to use SNR in conjunction with the above formulas we need interpret SNR as a ratio of signal to noise amplitude. For this value we use definition of SNR:

$$SNR = -10 \lg \frac{E_b}{N_0} \quad (12)$$

we find $\frac{E_b}{N_0} = 10^{\frac{SNR}{10}} = 10^{\frac{30}{10}} = 10^{-3}$

here N_0 is the power of Gaussian noise.

Taking into account that power ratio is amplitude ratio squared we obtain amplitude ratio:

$$\left(\frac{A_{E_b}}{A_{N_0}} \right)_{\min} = \sqrt{10^{-3}} = 0.03162 \quad (13)$$

Now if we set nominal value of $A_{E_b} = 1$ we can use (13) in complex with above formulas to find maximal distance between two modems with no retransmitters required. This is done in next subsection.

c. Calculation sequence

Using (12), (13) and 802.16a physical layer model we found maximum allowable signal attenuation. Signal amplitude can be found with some probability from (7) as plotted on Fig. 2. Amplitude is in relative units.

The value of probability that is most preferable must be chosen practically. Here we assume to restrict length with 0.78 probability.

Combining (3) – (13) we evaluate maximal distance between transmitter and receiver versus frequency of the channel. This graph is plotted on Fig. 3.

As it could be seen from this plot on highest frequencies the highest attenuation is obtained. So to calculate maximal allowable distance between transmitter and receiver with no retransmitters all calculations must be performed on lowest frequency band of OFDM range. This was assumed as true on the beginning of simulations (all plots are done for $F = 500$ kHz) and was submitted in this section.

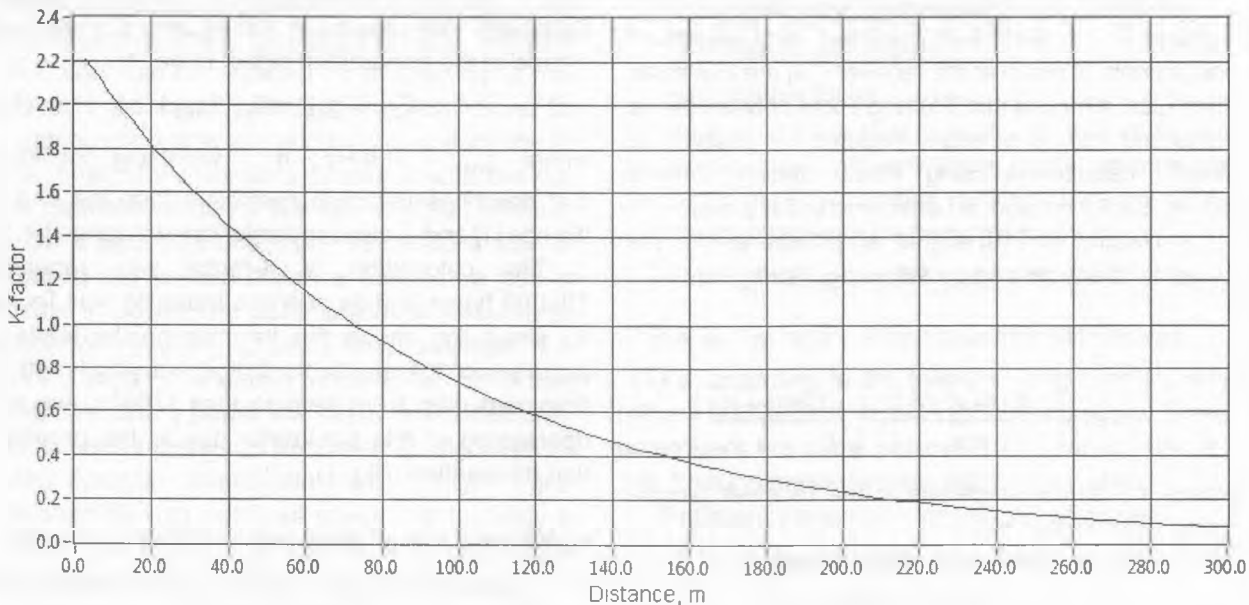


Fig. 1. Plot of K-factor versus distance

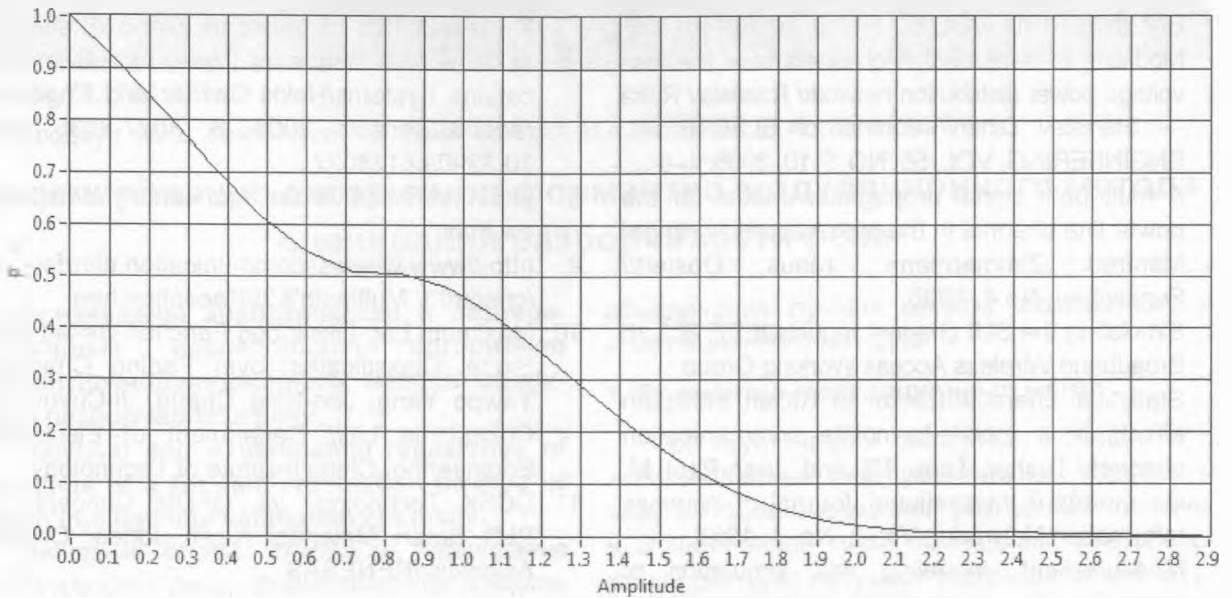


Fig. 2. Probability versus signal amplitude

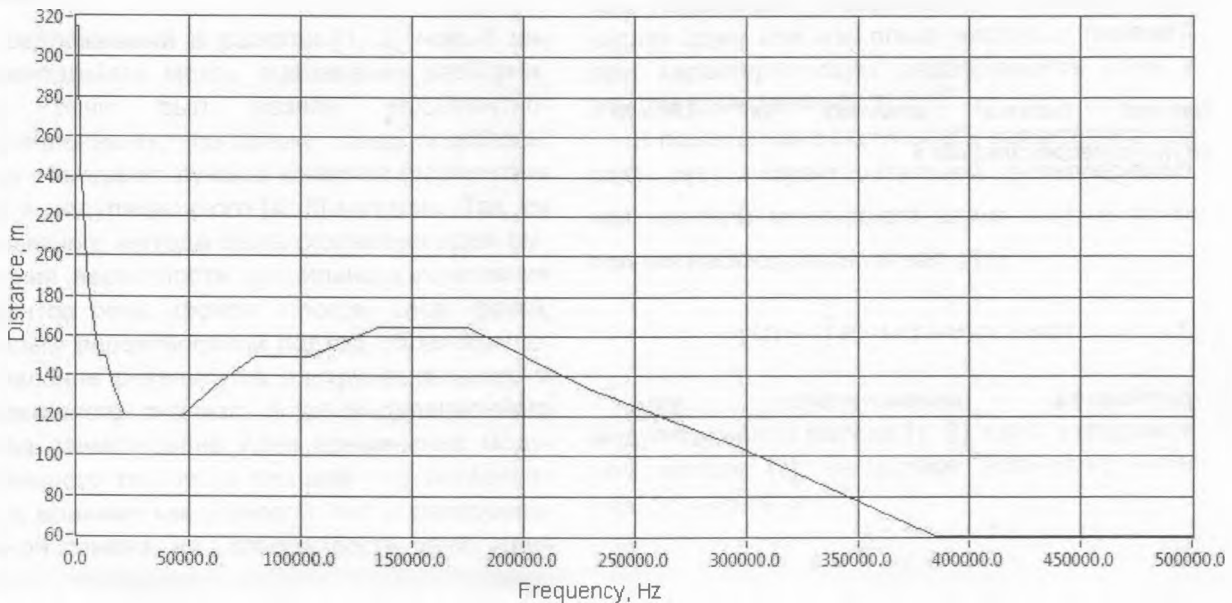


Fig. 3. Distance from transmitter to receiver vs frequency

Conclusion

The usage of the parametric model for transfer function computing is easier on practice than the ones that demand the measurement of primary line parameters. Instead signal amplitude and delay are measured only. But this model does not include multipath fading influence that considerably deteriorates communication protocol performance in PLC. In this paper the approach of the multipath modeling from wireless communication is used in

complex with parametric model to take into account the multipath in PLC.

As it could be seen from the simulations the minimal distance between two modems can be found as the function of preset parameters of the simplified PLC channel model and minimal probability values.

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