Modeling of Impulsive Noise in PLC Systems Using Middleton Class A Noise Model

Vesna M. Golubovic[1], Zoran R. Petrovic[2], Jasmina Mandic-Lukic[3]

Abstract – **Power line communications (PLC) represent technology for transmission of information along the existing electric utility infrastructure. This is technology with great potential to enable reliable high-speed data communications over low-voltage power distribution network or existing indoor power lines. In order to achieve high-speed data transmission using PLC, high carrier frequencies must be considered (within the range from 500kHz to 20MHz). One of the major disadvantages in this frequency range is influence of impulsive noise and narrowband interference. In this paper Middleton Class A noise model is implemented for modeling of this kind of disturbances. Simulation model is developed and compared with theoretic results. Theoretic expression for BER (Bit Error Rate) in case of BPSK (Binary Phase Shift Keying) signal transmission in presence of Class A noise is derived. Simulation model is also implemented for determining BER and results are compared with theoretic ones. Finally, concluding remarks are given with some suggestions for possible future work.**

Keywords –**PLC channel, impulsive noise, simulation model.**

I. INTRODUCTION

There is constantly growing demand for systems that would enable reliable high-speed data communications. Solutions that are easy for implementation and don't require too much of investments are of great interest [1]. PLC technology has natural potential to develop power distribution network into economic and convenient communication medium. Main advantage of PLC technology is that it uses highly developed and widely available infrastructure for data transmission. Furthermore, since many communication devices are normally plugged into an electric outlet, unification of these two networks is very attractive combination. There are two main applications for PLC systems. The first application is broadband Internet access. This kind of Internet access could help overcoming problems concerning covering of rural areas. Alternative access solution usually doesn't exist there and investment in new infrastructure is not feasible. PLC systems can also be used as alternative for local network, as power plugs are available in almost every room.

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Although PLC represents potentially "no new wire" solution, there are a number of technical issues that should be addressed. Power lines are not originally designed as data transmission medium. In fact, PLC channel suffers from a number of occurrences that are not desirable during the data transmitting. In order to design appropriate system that can cope with very hostile nature of power line channel it is necessary to develop channel model with sufficient accuracy. The problem of modeling PLC channel is very complex; as it is cited in [2] "there is no universally recognized power line channel model available". PLC channel is disturbed by various noise types, but in the frequency range of interest it is mostly dominated by impulsive noise [3], [4], [5].

In Section II PLC channel characteristics are given and importance of impulsive noise is emphasized. In Section III memoryless Class A Middleton noise model is described in details and proposed as model for impulsive noise, interference and background noise in PLC channel [6]. Simulation model is developed and implemented in case of determining Class A noise PDF (probability density function). In Section IV theoretic BER formula is derived for the case of transmitting BPSK signal in the presence of Class A noise. Simulation model is also used for determining BER. It is shown that simulation and theoretic results fit very well in both implementations. Finally, some concluding remarks are given with suggestions for possible future work.

II. PLC CHANNEL

In order to achieve high-speed communications over power line channel, higher carrier frequencies within the range of 500kHz to 20MHz should be considered. In frequency range of interest signals are mostly degraded due to effects of multipath propagation, various kinds of noise and frequency dependent cable attenuation [5]. PLC channel characteristics are also very time and frequency dependent.

Multipath effect in power line channel is consequence of signal propagation along more than one path. During transmission signal exhibits reflections and cancellations caused by impedance mismatches at joints and points where equipment is connected to the network. Multipath nature of PLC channel is described in [5] for frequency range from 500kHz to 20MHz. Transfer function of PLC channel given is given in [5], in the form of transversal filter with frequency dependent attenuation. As PLC channel is very dependent on location and network topology, variable number of propagation paths is implemented, depending on channel peculiarities.

On contrary to many other communication channels, noise in PLC channel cannot be described with AWGN (Additive White Gaussian Noise) noise type. There are various types of noise, colored background noise, asynchronous impulsive noise, and narrowband interferers. As noted in [3], in a frequency range from several hundred kilohertz up to 20 MHz PLC channel is mostly dominated by narrowband interference and asynchronous impulsive noise. Asynchronous impulsive noise is caused by unavoidable switching transients in the network [3].

Impulsive disturbances can cause bit or burst errors that can significantly degrade system performances. Thus, properly describing of impulsive noise for purpose of designing system that can efficiently combat this kind of noise is of great interest.

There are a number of papers that are dealing with problematic of impulsive noise in PLC channels. In [3] Gilbert–Elliot model is proposed as a simple PLC channel model. This channel model is not memoryless and therefore it is very suitable for modeling burst of errors [7]. For more accurate channel model, partitioned Markov chain approach with variable number of states is also proposed. Markov chain parameters are evaluated according to statistics obtained by real channel measurements. Disadvantage of this model is that Markov chain values have to be individually determined in each separate scenario and do not represent general channel model.

One of suitable models for this type of noise is memoryless additive Class A noise channel model [2], [8], [9]. It is usually used as model for a man-made impulsive noise.

III. CLASS A MIDDLETON NOISE MODEL

Class A discrete model PDF is given by [6]

$$PDF(z)=\sum_{m=0}^{+\infty} P_m(A)\cdot\frac{1}{\sqrt{2\pi\sigma_m^2}}\cdot e^{-\frac{z^2}{2\sigma_m^2}} \quad (1)$$

where $P_m(A)$ are coefficients of Poisson distribution, given by

$$P_m(A)=e^{-A}\cdot\frac{A^m}{m!} \quad (2)$$

Thus, Class A PDF is given by infinite sum of weighted additive white Gaussian noise distributions with increasing variances. Variance of each distribution is given by

$$\sigma_m^2=\sigma^2\cdot\frac{m/A+\Gamma}{1+\Gamma} \quad (3)$$

where σ^2 is total noise power. Parameter Γ describes ratio of the Gaussian noise power σ_G^2 to the impulsive noise power σ_I^2, and is equal $\Gamma=\sigma_G^2/\sigma_I^2$ (total noise power is $\sigma^2=\sigma_G^2+\sigma_I^2$). So, Class A noise always includes background noise with power σ_G^2, and can additionally include a number of impulsive sources. Number of additional sources is distributed according to Poisson distribution (with mathematic expectation equal A). Probability of having one additional source is equal $P_1(A)$ and total noise power in that case is $\sigma_1^2=\sigma_G^2+\sigma_I^2/A$. Similarly, probability of having m additional impulsive sources is equal $P_m(A)$ and total noise power in that case is $\sigma_m^2=\sigma_G^2+m\sigma_I^2/A$ [6], [10].

The other parameter used in Eq. (1) is called Impulsive Index. Small A (say A=0.01) describes highly structured channel interference and therefore impulsive channel. Large A means large overlap with a corresponding approach to Gaussian PDF [6], [10].

Class A model is memoryless, so noise sample at the moment t_k is not dependent on previous channel states. States are taken independently for every noise sample. Noise model obtained in this way is the most critical for evaluating system performances, as it represents the most critical case because of its memoryless character.

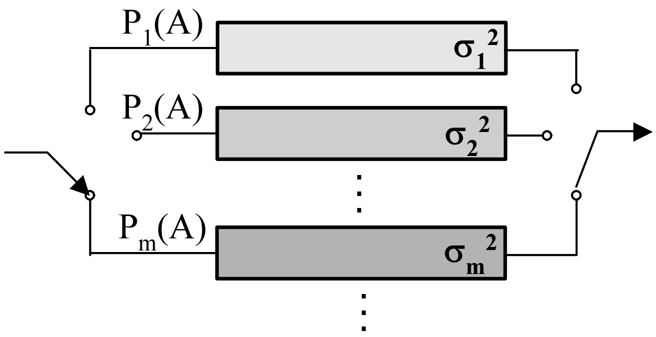

Fig. 1. Equivalent Middleton Class A channel model

This model can be graphically represented by equivalent model that comprises infinite number of parallel channels, as it is shown in Fig. 1. In each moment t_k only one channel is active. Probability of m^{th} channel being active is distributed according to Poisson distribution and is equal $P_m(A)$. Therefore, $P_m(A)$ is also probability that signal at the receiver is influenced by Gaussian noise with power σ_m^2.

TABLE I
POISSON COEFFICIENTS FOR DIFFERENT PARAMETER VALUES

	A=0.01	A=0.1	A=1	A=10
m=0	0.99	0.9048	0.3678	$4.54\cdot10^{-5}$
m=1	$9.9\cdot10^{-3}$	$9.05\cdot10^{-2}$	0.3678	$4.54\cdot10^{-4}$
m=2	$4.95\cdot10^{-5}$	$4.52\cdot10^{-3}$	0.1839	$2.27\cdot10^{-3}$
m=3	$1.65\cdot10^{-7}$	$1.51\cdot10^{-4}$	0.0613	$7.56\cdot10^{-3}$
m=4	$4.12\cdot10\text{-}^{10}$	$3.77\cdot10^{-6}$	$1.53\cdot10^{-2}$	$1.89\cdot10^{-2}$
m=5	$8.25\cdot10^{-13}$	$7.54\cdot10^{-8}$	$3.06\cdot10^{-3}$	$3.78\cdot10^{-2}$
m=6	$1.37\cdot10^{-15}$	$1.25\cdot10^{-9}$	$5.1\cdot10^{-4}$	$6.3\cdot10^{-2}$
m=7	$1.96\cdot10^{-18}$	$1.79\cdot10^{-11}$	$7.3\cdot10^{-5}$	$9\cdot10^{-2}$
m=8	$2.4\cdot10^{-21}$	$2.24\cdot10^{-13}$	$9.12\cdot10^{-6}$	0.1126
m=9	$2.7\cdot10^{-24}$	$2.5\cdot10^{-15}$	$1.01\cdot10^{-6}$	0.125

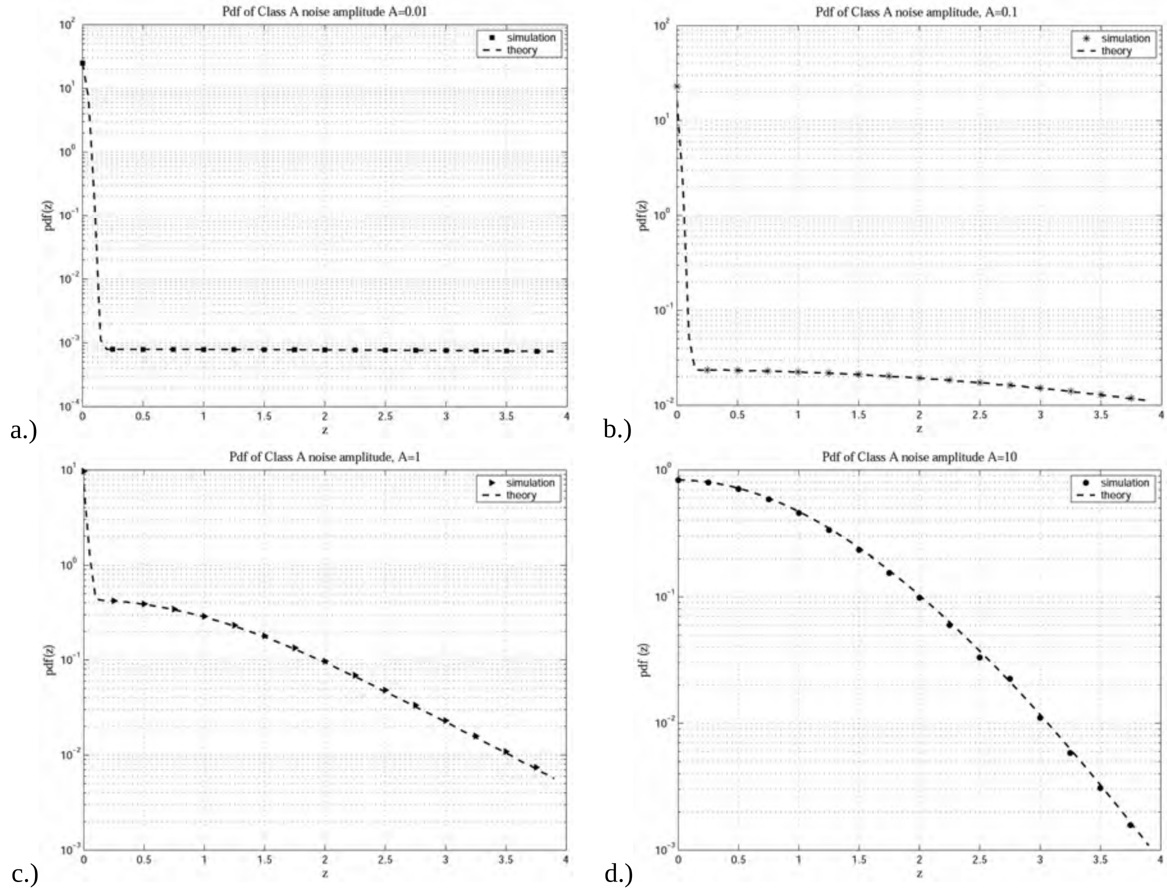

Fig. 2. Class A noise PDF for various A values (a. A=0.01, b. A=0.1, c. A=1, d. A=10)

Poisson coefficients are given in Table I for various A values. For values A≤1, Poisson coefficients decrease with m (on contrary to behaving of variance σ_m^2 with m) and channels with large variances σ_m^2 have small probabilities of realizations.

For very small A (A=0.01), $P_m(A)$ coefficient decrease very fast with m, while for A=10 coefficient values get their maximum for m=9 and m=10, and then decrease for m>10.

As Class A channel model consists of infinite series of Gaussian components, it's not convenient for computer simulations. Therefore, approximation that takes into account finite number of Gaussian distributions should be used. According to Table I, the number of component comprised by model should be smaller for small values of A. Similarly, the number of components should be larger for large A values.

Class A noise is simulated using Monte Carlo simulations. Depending on region that comprises value of uniformly distributed variable, Gaussian variable with appropriate variance is generated. Regions for decision are proportional to values of Poisson coefficients. In simulations, parameter Γ has value Γ=0.001. Results of simulations are given in Fig. 2 for four different A values (A=0.01, A=0.1, A=1 and A=10). In case of A=0.01 first 5 channels are taken into account, and for evaluating theoretic values m<100 in Eq. (1) are taken into account. Similarly, for large A, large m is needed for sufficiently precise results. For A=10, first 25 channels are considered for simulation model. Theoretic and simulated curves fit very well for all values of A.

IV. ERROR PROBABILITY FOR BPSK

Observe BPSK transmission in the presence of Class A noise type. If m^{th} channel is realized in moment t_k, probability of error is equal

$$P_{e,m} = \int_U^{+\infty} \frac{1}{\sqrt{2\pi\sigma_m^2}} \cdot e^{-\frac{z^2}{2\sigma_m^2}} dz = \frac{1}{2}\operatorname{erfc}\left(\frac{U^2}{2\sigma_m^2}\right) \qquad (4)$$

where U represents BPSK signal amplitude. BER in the presence of Class A noise can be found as mathematical expectation of probability of error given by Eq. (4), for all possible channel realizations. Therefore it is given by:

$$P_{e,tot} = \sum_{m=0}^{\infty} P_m(A) \cdot P_{e,m} = \frac{e^{-A}}{2} \sum_{m=0}^{\infty} \frac{A^m}{m!} \operatorname{erfc}\left(\frac{U^2}{2\sigma_m^2}\right) \qquad (5)$$

Simulation model described in Section III is implemented for determining BER. In Fig. 3. theoretic results obtained by Eq. (5) are compared with simulation results. Results are shown for different values of A (A=0.01, A=0.1, A=1 and A=10). Theoretic BER curves determined by Eq. (5) are given for upper bound of m equal 100. As there is almost no difference between theoretic and approximate values, it can be concluded that the use of simulation model is approved. Thus, this model can be used as a base model for computer evaluation of system performances when influence of Class A impulsive noise exists.

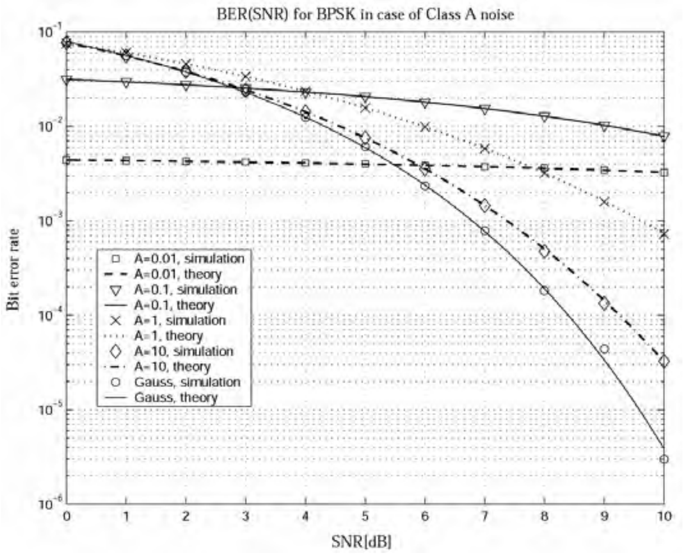

Fig. 3. Theoretic and simulation BER curves for case of BPSK transmission in the presence of Class A noise

V. CONCLUDING REMARKS

Class A discrete model given by [6] is suitable for modeling impulsive noise and narrowband interference in PLC systems [2], [4], [8], [9]. One of main advantages is that it represents the most critical case for system performance evaluation because of memoryless character of Class A channel model. Furthermore, because of its generality it's applicable in theoretic evaluations and simulations of systems performances.

Contribution of this paper is in developing efficient simulation model for Class A impulsive noise. This model is implemented for determining Class A impulsive noise PDF. Simulation results are compared with results obtained using theoretic PDF formula. Simulation model is also implemented for determining BER in BPSK system influenced by Class A noise. Theoretic expression for BER is derived. Theoretic and simulated results are compared for several different specific values of channel model parameter A. According to results obtained in this paper, it is clear that use of simulation method is approved and can be easily implemented in more complex systems.

Subject of future work will be channel model that comprises multipath nature of PLC channel and frequency selective attenuation, as well as its impulsive nature. Different modulation and coding schemes can be implemented [2], [4]. As various types of DSL (Digital Subscriber Line) systems suffer from similar disturbances [1], [4], solution can be found in modulation and coding schemes similar to those used in this systems, but adapted to specific characteristic of PLC channel.

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