

Realization of Simulation Software for Power Line Communications

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Abstract

A simulation software is presented for estimating the performance of a low voltage power line communication system, where the parameters like modulation/coding techniques, bit rate, operating frequency and transmitter power are selectable. The simulation software estimates the BER performance in a over low-voltage power line channel, where the channel noise and the signal attenuation are predicted by using various models.

1. Introduction

PLC has been gaining a great interest for the applications such as AMR (automatic meter reading), SCADA (supervisory control and data acquisition), home automation and internet access, in spite of the fact that the power line channel is corrupted by high background noise, impulse noise and high signal attenuation [1]. Intense research is being devoted in order to overcome these difficulties and for better understanding and modelling the power line channel.

For communications over a LVL, a frequency band (3 kHz to 148.5 kHz) is allocated by a CENELEC Standard [2]. This standard specifies the frequency bands allocated to various applications, access protocols for different category of users, limits for the terminal output voltage in the operating band and limits for conducted and radiated disturbance. Similarly, an IEC standard [3] specifies the noise and signal attenuation characteristics in low- and medium voltage power lines. There are ongoing efforts for modelling the power line channel up to 30 MHz for high data rate communications as well.

The studies show that the power line channel is time-variant since the noise, attenuation and the phase shift caused by the channel vary depending on the geographical location, operating frequency and the time of the day. It is clear that it is not easy to establish a general model for the channel.

Noise in power lines is contributed by the background noise, impulse noise, narrowband noise and harmonic noise. Background noise is characterised by its power spectral density (PSD) that decreases with frequency, in the range of 9 kHz to 95 kHz [1]. Impulse noise in power lines is observed with impulse duration, generally less than 0.1 ms and with Poisson distributed interarrival times, varying between 0.1s to 1s [4].

The channel noise is characterized by the Middleton's class A noise model [5]; the class A noise is described by two parameters, the impulsive index, A , and Γ , which denotes the ratio of the power in Gaussian component to the power in Poisson component. Background noise and attenuation were modelled by using Hooijen's model [1] and the IEC model [3]. These models provide worst-case and best-case noise PSD and signal attenuation as a function of the frequency and range. By using these parameters, best and worst case E_b/N_0 ratios were determined as a function of both the range and the operating frequency.

2. Simulation Software

Simulation software presents the channel BER performance for non-coherent modulation techniques, such as m-ary FSK and m-ary DPSK. The effects of the forward error correction codes, such as (31,15) and (255, 239) RS codes, repetition code (n,1) for $n=1,2,7$ and (14,8) shortened cyclic code, were implemented in the software for improving the BER performance. The software allows the selection of any model (best- or worst-case of Hooijen's or IEC models) for noise and signal attenuation as well as any of the considered coding and modulation technique. The parameters, such as the carrier frequency (9 kHz to 95 kHz), bit rate, transmitter

power or voltage can be chosen. The BER performance can be observed graphically as a function of the range and the frequency of operation. The simulation results can be stored in a disk environment or can be printed.

2.1. Forward Error Correction Coding

Power line channel is characterised by high noise (background and impulsive) and strong signal attenuation. Therefore, the communication range is rather short and the bit error rate is potentially high. Thus, the use of forward error correction (FEC) codes is essential for reliable communication over this channel. In the simulation software, three coding methods; Reed-Solomon (RS) codes, repetition coding and (14,8) shortened cyclic code were implemented.

2.1.1 RS codes:

Impulse noise which occurs on power lines often strongly affects the data bits for its duration. RS codes appear very suitable for correction of the bit errors caused by the impulse noise.

2.1.2 Repetition code:

Repetition coding is a very simple technique. On the receiver side, decoding is performed by the Majority Decoding Rule. This coding technique is included in the S-FSK standard [6].

2.1.3 Block code:

In the simulation, (14,8) shortened cyclic code was considered, that was derived from the original (15,9) block code. This coding technique is proposed with CSMA (carrier sense multiple access) for home automation [7]. This code has the capability of correcting three consecutive bit errors [10].

2.2. Attenuation Models

The attenuation of signals in a power line channel changes randomly as a function of the time of the day, the geographic location and the frequency of operation. Two attenuation models were implemented into the simulation software:

2.2.1 Hooijen's model [1]:

The signal attenuation in this model depends only on the distance between receiver and transmitter and varies between 40 dB/km to 100 dB/km.

2.2.2 IEC-1334-1-4 Standard [3]:

The signal attenuation was given for overhead power lines as a function of the range between 100 and 500 metres for the frequencies from 60 to 90 kHz. Based on this standard, the attenuation can be approximated by 55 dB/km for 60 kHz to 90 kHz as a function of range and 0.25 dB/kHz for changes in the frequency:

$$A = 12.6 + 0.055(d - 100) + 0.25(f - 60) \quad (dB) \quad (1)$$

where f denotes the frequency in kHz above 60 kHz and d is the distance in meters.

2.3. Noise Models

Noise observed on power lines have two main components, namely, the background noise and the impulse noise. These two main noise components are modelled for the best and the worst cases and are implemented into the simulation software.

2.3.1 Background noise

Background noise is observed on the power line permanently. Background noise is modelled by two models and these two models are classified for the best and the worst cases. These two noise models are obtained from [1] and the IEC Standard [3]. In [1], the PSD of the background noise is approximated by

$$N(f) = -96.4 - 0.395 f_{kHz} \quad \text{dB W/Hz for the best case} \quad (2)$$

$$N(f) = -76.4 - 0.395 f_{\text{kHz}} \text{ dB W/Hz for the worst case} \quad (3)$$

Note that the noise PSD for the worst case is 20 dB above the best case irrespective of the frequency. According to the IEC noise model [3], which was implemented into the simulation software, the best- and worst-case noise voltage levels are given by

$$V_n = 0.001 f_{\text{kHz}}^2 - 0.25 f_{\text{kHz}} - 52 \text{ dBV for the best case} \quad (4)$$

$$V_n = 0.001 f_{\text{kHz}}^2 - 0.25 f_{\text{kHz}} - 40 \text{ dBV for the worst case} \quad (5)$$

2.3.2 Impulse noise

Impulse noise is modelled by its duration, amplitude and inter-arrival time. In the software, two impulse noise models were implemented; the Tranter model [8] and the Middleton model. Tranter model represents the worst-case scenario and is simply a special case of the Middleton model.

- **Tranter model**

The probability of bit error can be expressed as the sum of two parts due to impulse noise and the background noise:

$$P_e = \lambda \tau P_e(\epsilon | \text{impulse}) + (1 - \lambda \tau) P_e(\epsilon | \text{Gaussian}) \quad (6)$$

Tranter model is based on the assumption that, when an impulse noise occurs, all affected symbols will be in error, with a BER close to 0.5. This leads to an error floor which cannot be recovered by increasing the SNR. In case of BPSK, the BER is given by

$$p_e = \frac{1}{2} \lambda \tau + (1 - \lambda \tau) Q \left(\sqrt{\frac{2E_b}{N_0}} \right) \quad (7)$$

where E_b denotes energy per bit, λ denotes interarrival rate of the impulse noise and τ denotes impulse duration, which are in general random. Thus, $\lambda \tau$ denotes the probability that the system is hit by the impulse noise and $(1 - \lambda \tau)$ shows the probability that the system is affected by only the background noise.

- **Middleton model**

Non-Gaussian interference is classified into three categories by Middleton [5, 9], and are called as class A, class B and class C. For class A noise, interference arising from sources whose spectra are comparable to or narrower than the bandwidth of the receiver. In simulation software, class A noise model was used to model the channel noise (background noise and impulse noise). The pdf of class A noise amplitude is defined by

$$f_z(z) = \sum_{m=0}^{\infty} e^{-A} \frac{A^m}{m!} \frac{1}{\sqrt{2\pi S \sigma_m^2}} \exp \left(\frac{-z^2}{2S \sigma_m^2} \right) \quad (8)$$

where Poisson pdf, $e^{-A} A^m/m!$, denotes the probability of m interfering sources being activated. If $m=0$, then no interfering source is activated and the channel is disturbed only by the background noise. Here, σ_m^2 is defined by

$$\sigma_m^2 = \frac{m/A + \Gamma}{1 + \Gamma} \quad (9)$$

In (9), A is equal to $\lambda \tau$ and Γ is equal to σ_G^2 / σ_I^2 . S denotes the total noise power and is equal to $\sigma_G^2 + \sigma_I^2$.

When the noncoherent FSK is used, the probability of error can be expressed by

$$P_{M_I} = \sum_{m=0}^{\infty} e^{-A} \frac{A^m}{m!} P_M \quad (10)$$

where

$$P_M = \sum_{n=1}^{M-1} \binom{M-1}{n} \frac{(-1)^{n+1}}{1+n} \exp \left[-\frac{n}{1+n} \frac{E_s}{2 S \sigma_m^2} \right] \quad (11)$$

In (11), $E_s = E_b \log_2 M$ denotes the symbol energy and M shows the alphabet size.

The pdf, in (8), consists of the summation of Gaussian noise pdf's with increasing variances. Note that (8) can also be expressed as the product of the probability of occurrence, with Poisson pdf, $e^{-A} A^m/m!$, of m interfering sources and the conditional probability of Gaussian noise with variance σ_m^2 . This implies that the class A noise can be produced by Gaussian noise sources, of which the occurrence in time is described by the Poisson pdf.

2.4. Modulation Schemes

To increase the robustness of the system against fluctuations in phase shift caused by the power line channel, non-coherent modulation techniques, such as non-coherent m -ary noncoherent FSK and m -ary DPSK, are considered. For noncoherent FSK, the alphabet size varies between 2 to 8 and the alphabet size of m -ary DPSK varies between 2 to 16.

2.5. Other Parameters

The other parameters considered are operating frequency, bit rate, transmitter power or voltage, transmitter impedance, line input impedance and the distance. In simulation software, operating frequency can be selected in the frequency range of 9 kHz to 95 kHz and selectable bit rates are higher than 200 bps. Transmitter power is bounded to 10 W for power and voltage inputs[2]. If one selects transmitter voltage, transmitter impedance and the line input impedance are needed to calculate the transmitted power from transmitter to receiver. Distance between the transmitter and the receiver is also selectable.

3. Results

Figures 4 and 5 show the probability of bit error by Middleton and Tranter models, respectively. The modulation scheme is 4-NCFSK and the bit rate is 4800 bps. Attenuation is taken as 100 dB/km and the noise model is considered as the worst-case according to [1]. Transmitter power is selected as 10 Watt; the operating frequency is 90 kHz and (5,1) repetition is used as coding.

In the Middleton's model, Γ plays an important role in the characterization of the channel. As Γ decreases, channel becomes progressively impulsive. Then, Middleton's and Tranter's model yield nearly the same results. In Tranter's model, the received bits hit by the impulse are all assumed to be in error, and thus the BER has a floor depending on the value of $\lambda\tau$, representing the probability of occurrence of the impulse noise.

Coded and uncoded BER performance is compared in Figure 4 as a function of the distance for the parameters given in the figure. For distances up to 200 m, the E_b/N_0 ratio is sufficiently high so that the effect of the impulse noise becomes progressively important and the BER increases with increasing distance. Between 200 m and 700 m, the impulse noise causes an error floor, of which the level is proportional to $\lambda\tau$. Beyond 700 m, the combined effects of the impulse noise and background noise, manifested by the low E_b/N_0 values, were observed. The main difference between coded and uncoded performances was that coding reduces the BER level but does not increase the range. The main difference between Figures 4 and 5 was observed for ranges shorter than 200 m, where, according to Tranter's model, the bits corrupted by the impulse noise are always destroyed irrespective of the level of E_b/N_0 .

4. Conclusions

In view of the constraints on the maximum allowed transmitter power level, imposed by CENELEC [2], communications at high data rate do not seem to be feasible due to strong noise power and high signal attenuation for ranges beyond 1 km or so, even if forward error correction coding is used.

For data communications over power lines, the best performance is obtained for Reed-Solomon coding and DPSK modulation technique. The DPSK performance worsens for increasing alphabet sizes. Although the coding is not effective for increasing the communication range, it significantly decreases the probability of error within the communication range.

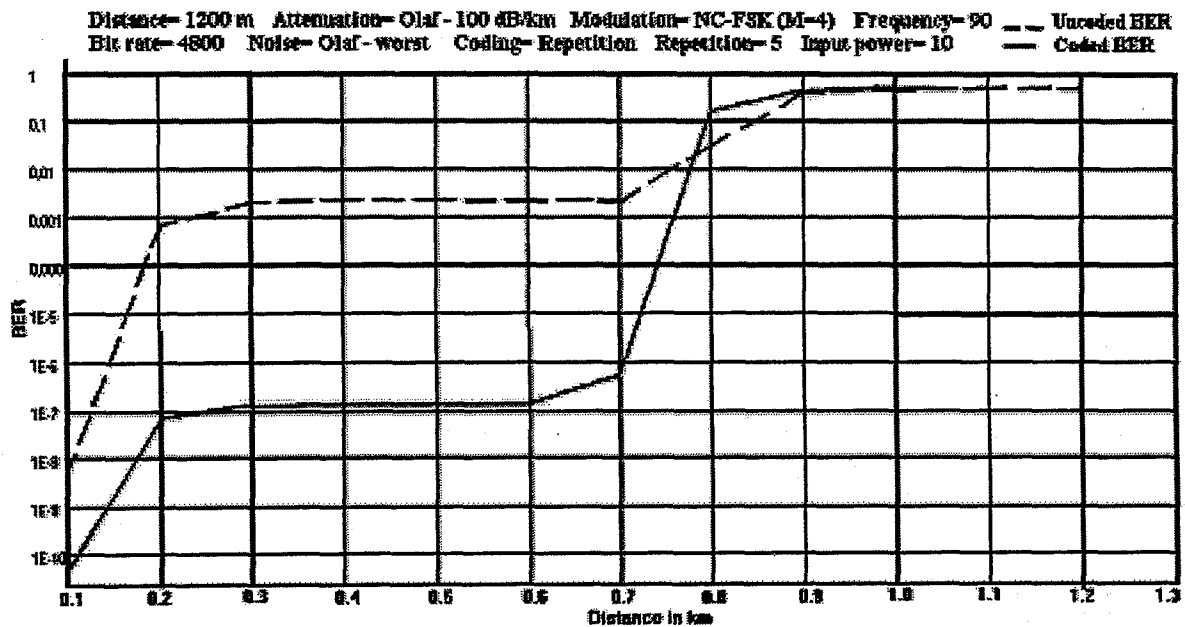


Figure 4. BER versus distance for the Middleton model

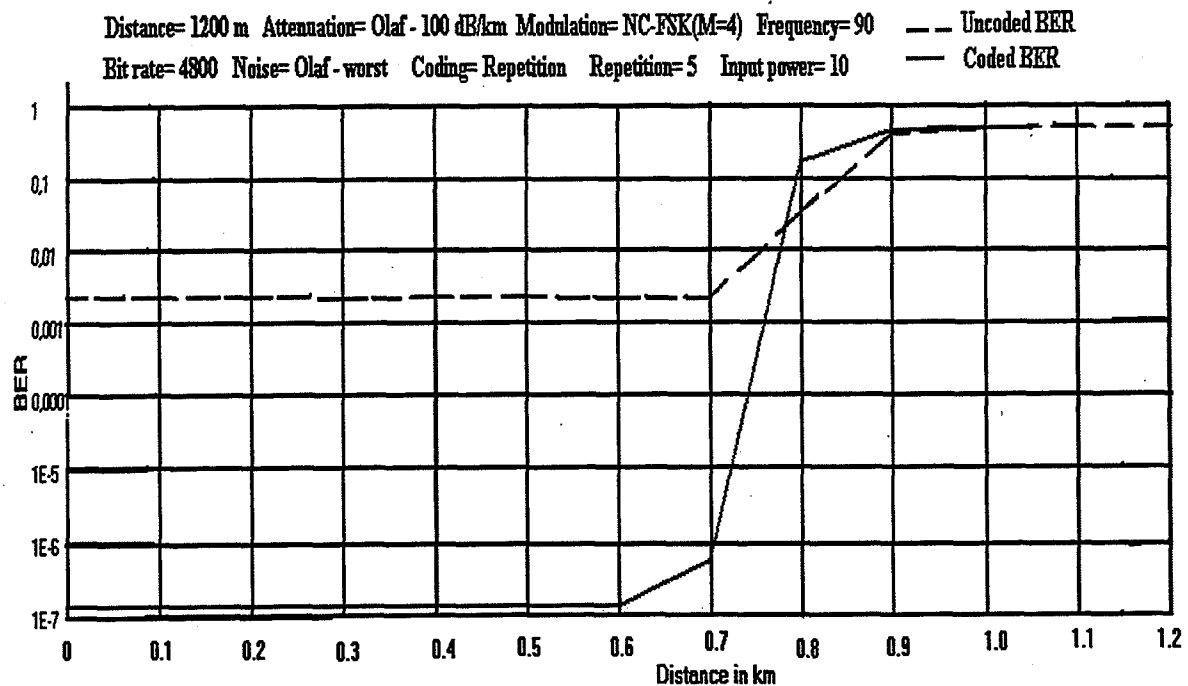


Figure 5. BER versus distance for the Tranter model

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References

1. O.G. Hooijan, On the channel capacity of the residential power circuit used as a digital communications medium, IEEE Communications Letters, vol.2, no.10, pp.267-268, October 1998.
2. EN 50065-1 Signalling on low voltage electrical installations in the frequency range 3 kHz to 148.5 kHz, Part 1 : General Requirements, frequency bands and electromagnetic disturbances, January 1994.
3. Technical Report IEC 1334-1-4, Distribution automation using distribution line carrier systems-Part 1: General considerations – Section 4 : Identification of data transmission parameters concerning medium and low –voltage distribution mains (1st edition), November 1995.
4. W. Henkel, T. Kessler, and H. Y. Chung, Coded 64-CAP ADSL in an impulse-noise environment – modelling of impulse noise and first simulation results, IEEE Journal Selected Areas Communications, vol. 13, no. 9, pp.1611-1621, December 1995.
5. Middleton D. , Statistical-physical models of electromagnetic interference, IEEE Trans. Electromagnetic Compatibility. Vol. 19, no. 3, pp.. 106-127
6. IEC/TR2 61334-5-1, Distribution automation using distribution line carrier system- part 5: lower layer profiles – section 1: spread frequency shift keying (S-FSK) profile
7. European standard final draft pr EN 50090-2-2, Home and Building Electronics system (HBES), march 1995, CENELEC, Brussels.
8. Ebel W.J., Tranter William H. ,The Performance of Reed-Solomon Codes on a Bursty-Noise Channel IEEE Transactions on Communications, vol.43 no.2/3/4, 1995
9. Spaulding A.D., Middleton D.,Optimum reception in an impulsive interference environment - Part II: Incoherent reception, IEEE Trans. Comms, vol. 25, No.9, pp.924-934.
10. Blahut., Richard E., Theory and Practice of Error Control Codes, Addison-Wesley publishing company, 1983