IMPULSIVE NOISE MODELLING AND PREDICTION OF ITS IMPACT ON THE PERFORMANCE OF WLAN RECEIVER

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ABSTRACT

As part of a larger project to assess the risk associated with the deployment of wireless equipment in electricity substations the BER performance of IEEE 802.11b and IEEE 802.11a in the presence of impulsive noise has been investigated. Middleton class A noise model is used to simulate impulsive noise environment and Simulink is used to simulate the WLAN physical layer. The observed degradation in performance is compared with that due to additive white Gaussian noise.

1. INTRODUCTION

Deployment of wireless communications equipment in electricity substation for monitoring, control and surveillance applications offers significant potential benefits over wired communications in terms of convenience, flexibility and cost [1, 2]. Typically wireless transceiver designs are based on the assumption that noise is additive, white and Gaussian (AWG) [3]. These transceivers perform fine in normal environments (where optimum reception can be achieved with Gaussian channel assumption) but their applicability in noise intensive electricity substation environment is not risk free and needs thorough investigation [4]. Partial discharges and sferic radiation (from fault and switching transients) are major sources of impulsive noise, in electricity transmission substations and if the risks of deploying wireless communications equipment are to be properly assessed the impact of such impulsive processes requires thorough evaluation [5].

This paper addresses two areas: (i) the modelling of impulsive noise, and (ii) the use of one particular model in a physical-layer performance evaluation of IEEE 802.11b and IEEE 802.11a receivers.

2. IMPULSIVE NOISE MODELLING

Broadly speaking, man-made interference can be ‘intelligent’ where the interfering signal carries meaningful information or ‘unintelligent’ where the interfering signal carries no (conventional) information. The latter includes partial discharge (PD), switching transients and combustion engine ignition noise. This work deals with ‘unintelligent’ interference having impulsive characteristics which may dominate close to a source of PD. Seminal work [6, 8] focussing on the realisation of a tractable analytical model for combined man-made and natural radio noise serves following purposes:

a. It provides a realistic and quantitative description of man-made and natural electromagnetic (EM) interference,
b. It guides experimental protocols for the measurement of such interference,
c. It can be used to identify optimal communication systems and their performance comparison with the sub-optimal systems.

Middleton’s three models (class A, B and C) are statistical physical models which include the non-Gaussian components of natural and man-made noise [6]. These models are canonical in nature i.e. their mathematical form is independent of the physical environment. The distinction between the three models is based on the relative bandwidth of noise and receiver.

Middleton Class A Model: refers to impulsive noise with a spectrum that is narrow compared to the receiver bandwidth and includes all pulses which do not produce transients in the receiver front end [7]. Its probability density function (pdf), derived in [8], and is:

$$f_x(x) = e^{-A} \sum_{m=0}^{\infty} \frac{A^m}{m!\sqrt{2\pi\sigma_m^2}} e^{-\frac{x^2}{2\sigma_m^2}} \tag{1}$$

where $\sigma_m^2 = \dfrac{\frac{m}{A}+\Gamma}{1+\Gamma}$

is noise variance, $A = v_t T_s$ is impulse index, v_t is mean impulse rate and T_s is mean impulse duration. (Strictly, of course, impulses have a duration that tends to zero and we should really be referring to pulses rather than impulses. The term impulse is used, however, since we are addressing what is universally called impulsive noise.) Equation (1) is a weighted sum of Gaussian distributions. By increasing impulse index, *A*, the noise can be made arbitrarily close to Gaussian and by decreasing *A* it can be made arbitrarily close to a conventional Poisson process. The model assumes that the individual impulses are Poisson distributed in time. Small values of *A* mean that the probability of pulses overlapping in time is small. Large values of *A* mean that this probability is large. In the latter case the central limit theorem can be invoked resulting a distribution that tends to Gaussian. The scale factor Γ is the ratio of powers in the Gaussian and Poisson (non-Gaussian) components, i.e.:

$$\Gamma = \frac{(X_G^2)}{(X_P^2)} \tag{2}$$

Figure 1 shows the pdf of Middleton class A noise with various values of *A* for $\Gamma = 0.001$.

Middleton Class B Model: refers to impulsive noise with a spectrum that is broad compared to the receiver bandwidth. Class B noise impulses produce transients in the receiver. Although it can accurately model a broadband impulsive noise environment its practical applications are limited because of the complicated form of its pdf which has five parameters [6] and an empirically determined inflection point [9].

Middleton Class C Model: Class C noise is a linear sum of class A and class B noise. In practice class C noise can often be approximated by Class B [6].

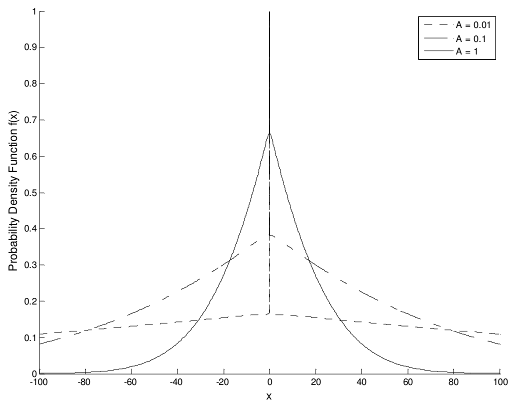


Figure-1: Probability density of the amplitude of Class-A noise for different values of A and $\Gamma = 0.001$

Symmetric Alpha Stable (SαS) Model: can also be used for statistical modelling of impulsive noise [10]-[11]. The relationship between Class B noise and SαS has been analysed via their characteristic functions [12]. The analysis shows that the pdf of an **SαS** process in the presence of zero-mean Gaussian noise (designated SαS+ G) is a close approximation to the pdf of class B noise [13]. The characteristic function of an SαS process is given by:

$$\Phi(\omega) = e^{j\delta\omega - \Gamma|\omega|^{\alpha}} \tag{3}$$

where $1 \le \alpha \le 2$ is the characteristic exponent which determines the shape of the distribution. $\delta(-\infty, \infty)$ is a location parameter and $\Gamma > 0$ is the dispersion of the distribution describing the spread of the distribution around δ). For α in the range of {1, 2} δ can be identified as the distribution mean and for α in the range {0, 1} it can be identified as the distribution median. No closed-form expression exists for the SαS distribution other than in the cases of $\alpha = 2$ (Gaussian) and $\alpha = 0$ (Cauchy). A power series expansion can be derived, however, and is given [14] by:

$$f_x(x) = \begin{cases} \frac{1}{\pi x}\sum_{k=1}^{\infty} \frac{(-1)^{k-1}}{k!}\Gamma(\alpha k+1)x^{-\alpha k}\sin(\frac{k\alpha\pi}{2}) & \text{for } 0<\alpha<1 \\ \frac{1}{\pi(x^2+1)} & \text{for } \alpha=1 \\ \frac{1}{\pi\alpha}\sum_{k=0}^{\infty} \frac{(-1)^{k}}{2k!}\Gamma(\frac{2k+1}{\alpha})x^{2k} & \text{for } 1<\alpha<2 \\ \frac{1}{2\sqrt{\pi}}\exp[-\frac{x^2}{4}] & \text{for } \alpha=2 \end{cases} \tag{4}$$

Figure 2 shows the pdf of an SαS impulsive noise process which is close to Gaussian near zero but decays slower than Gaussian in the tails. (Gaussian tails are exponential but SαS tails are algebraic. The tail thickness depends on the value of α. The smaller the value of α, the thicker the tails.)

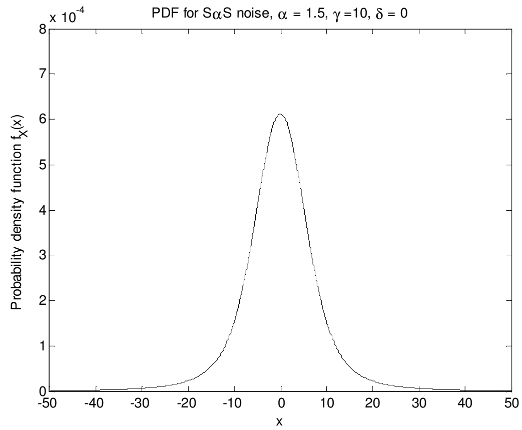


Figure 2 Probability density function of SαS process.

3. WLAN *

IEEE 802.11b and IEEE 802.11a WLAN standards are used in this work and their brief overviews is given below.

IEEE 802.11b operates in the 2.4 GHz band and variously uses direct sequence spread spectrum (DSSS) or frequency hopping spread spectrum (FHSS). It supports

*Reproduced from the authors existing paper [17] transmission rates of 1, 2, 5.5 and 11 Mbps. The different transmission rates are obtained with varying the modulation type. 1 Mbps is realized using differential binary phase shift keying (DBPSK) whilst 2 Mb/s uses quadrature phase shift keying (DQPSK). Higher data rates of 5.5 Mb/s and 11 Mb/s use complimentary code keying given in Equation-5.

$$c = \{e^{j(\varphi_1+\varphi_2+\varphi_3+\varphi_4)}, e^{j(\varphi_1+\varphi_3+\varphi_4)}, e^{j(\varphi_1+\varphi_2+\varphi_4)}, -e^{j(\varphi_1+\varphi_4)}, e^{j(\varphi_1+\varphi_2+\varphi_3)}, e^{j(\varphi_1+\varphi_3)}, -e^{j(\varphi_1+\varphi_2)}, e^{j\varphi_1}\} \quad (5)$$

where $c = \{c_0 \ to \ c_7\}$

IEEE 802.11a operates in the 5 GHz band and uses orthogonal frequency division multiplexing (OFDM). It can support data rates of 6, 9, 12, 18, 24, 36, 48 and 54 Mbps. The different transmission rates are obtained by varying the modulation order and/or the channel code rates. The system uses 52 subcarriers that are modulated using BPSK, QPSK, 16- or 64-quadrature amplitude modulation (QAM). The error correction coding uses a convolution encoder with a coding rate of 1/2, 2/3 or 3/4.

4. SIMULATIONS

Physical layer of IEEE 802.11b and IEEE 802.11a WLAN standards is simulated using MATLAB and Simulink. Basic simulations for both standards are adapted from [16]. These simulations are tailored to work with built noise model and thoroughly validated against the theoretical BER. Validation results for 1 and 2 Mb/s modes of IEEE 802.11b are shown in figure 3(a) and (b) respectively.

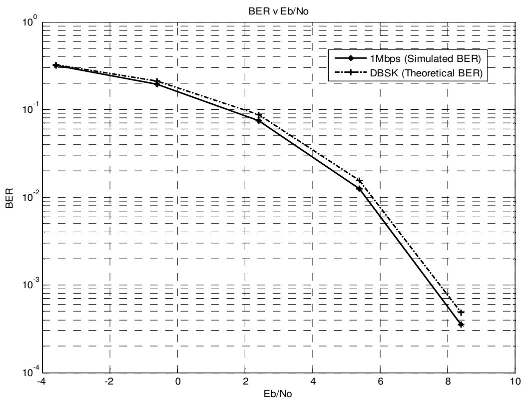


Figure 3(a) Validation of Simulink IEEE 802.11b receiver model (1Mbit/s mode).

The Middleton class A noise model has been implemented as complex baseband equivalent of RF bandpass, using MATLAB and Simulink. A low pass filter of 22MHz bandwidth (WLAN receiver bandwidth MHz) is applied to the generated impulse noise. The pdf of the simulated noise is compared to the theoretical pdf in Figure 4.

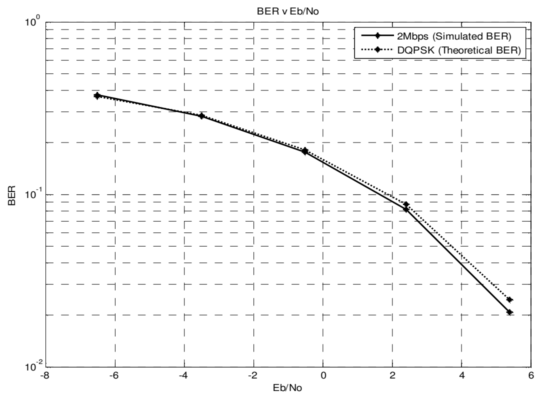


Figure 3(b) Validation of Simulink IEEE 802.11b receiver model (2 Mbps mode).

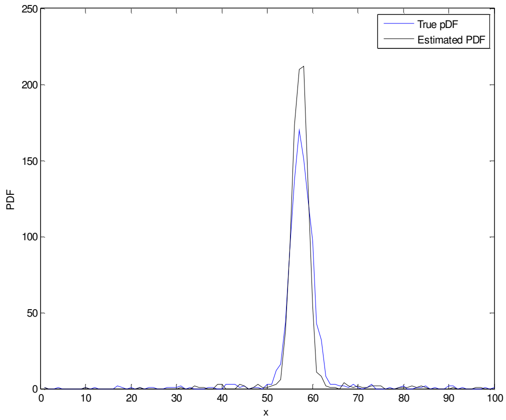


Figure 4 Validation of Simulink noise model.

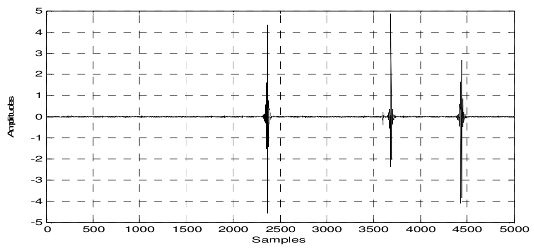
5. RESULTS

The Middleton class A model is used to generate impulsive noise. It is tuned to generate impulsive noise which broadly represents following two scenarios.

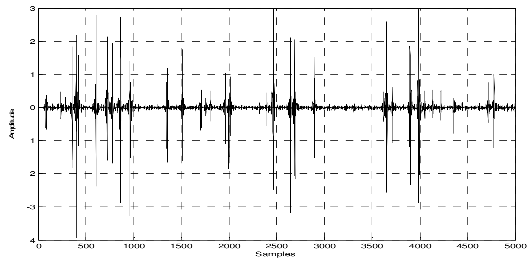
First is when the wireless equipment is deployed very close to high voltage equipment and where impulsive noise (because of partial discharges and switching transients) dominates the Gaussian noise. For this scenario, noise is generated with parameters A = 0.001 and $\Gamma = 0.001$; as the impulsiveness of noise depends on the product of A and Γ, thus with these values the generated noise is highly impulsive and impulsive noise power component dominates the Gaussian component.

Second is when the wireless communications equipment is deployed inside electricity substation but precautions are being taken and it is not close to any major source of partial discharges (well established techniques and equipment is commercially available which can be used to locate the partial discharge sources). For this scenario, impulsive noise is generated using $A=0.01$ and

Γ=0.01 ; with these parameters generated noise is moderately impulsive. The time realization (of 5000 samples) of the generated class A impulsive noise for both scenarios (highly and moderately impulsive) is shown in figure 5 (a) and (b).



(a)



(b)

Figure 5(a) and (b) Time realization of highly impulsive (A =0.01 and Γ=0.01) and moderately impulsive (A =0.01 and Γ=0.01) Middleton class A noise

Figures 6(a) and (b) compare the predicted performance of an IEEE 802.11b receiver in the presence of impulsive noise with that in the presence of AWGN for 1, 2, Mbit/s modes respectively, for both scenarios.

Figure 6(a) shows performance evaluation of IEEE 802.11b (1 Mb/s mode). For lower values of SNR (below 7 dB) the highly impulsive noise (A=0.001 and Γ= 0.001) is more benign than AWGN but for higher values of SNR (above 7 dB), the BER for impulsive noise is poorer by 7.5 dB than AWGN. For second scenario (moderately impulsive with A =0.01 and Γ= 0.01), the performance assessment of 1 Mbit/s mode shows that, impulsive noise is benign and BER for AWGN is poorer by 6 dB than impulsive noise. Similar performance differences are apparent for 2 Mb/s mode.

Figure 6(c) depicts the performance comparison of IEEE 802.11a in the presence of class A noise (both highly and moderately impulsive cases) and AWGN. It is clear from the figure that performance degrades by 3.5 dB and 6 dB when exposed to moderately and highly impulsive noise respectively.

Figure 6(d) compares the BER performance of IEEE 802.11b (1Mb/s mode) and IEEE 802.11a (6 Mb/s). It shows that for lower values of SNR (below 6.5 dB), IEEE 802.11b performs better but for higher SNR values (above 6.5 dB) it shows poor performance when compared to IEEE 802.11a.

5. CONCLUSIONS

The results suggest that narrowband impulsive noise is more benign than additive white Gaussian noise in both moderately and highly impulsive environments for low SNR values but for high SNR values it substantially degrades the BER performance of both IEEE 802.11b and IEEE 802.11a WLAN receivers.

ACKNOWLEDGMENT

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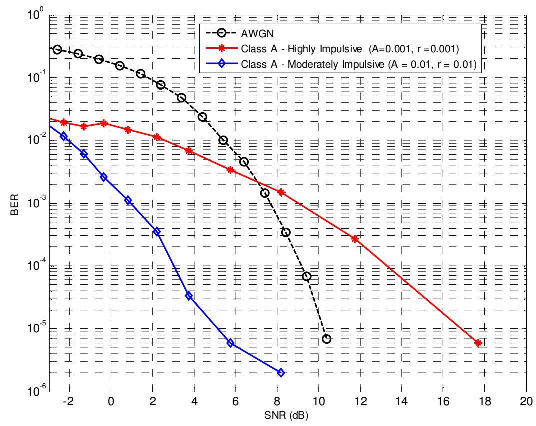

Figure 6(a) Predicted impulsive noise performance of IEEE 802.11b (1 Mbps mode) compared with AWGN performance.

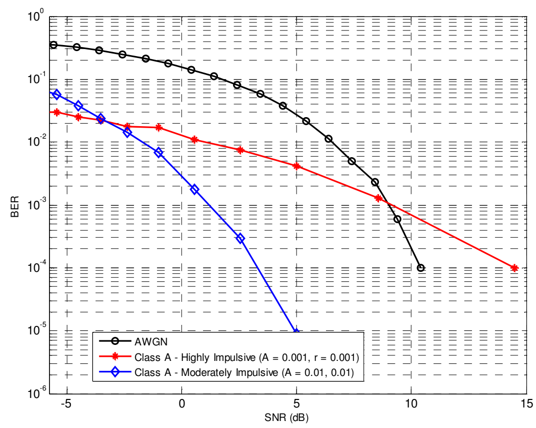

Figure 6(b) Predicted impulsive noise performance of IEEE 802.11b (2 Mbps mode) compared with AWGN performance.

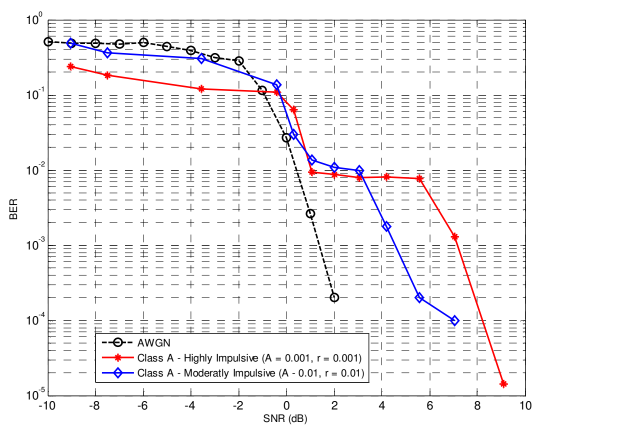

Figure 6(c) Predicted impulsive noise performance of IEEE 802.11a (6 Mbps mode) compared with AWGN performance

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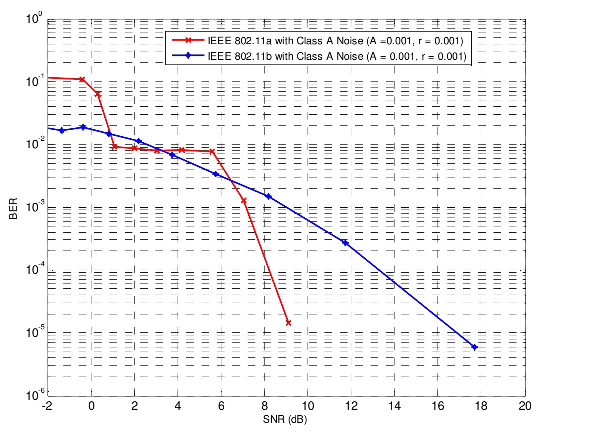

Figure 6(d) Performance comparison of IEEE 802.11b (Mode-1) and IEEE 802.11a (Mode-1)

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