Performance Evaluation of IEEE 802.15.4 Receiver in the Presence of Broadband Impulsive Noise

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***Abstract*—A physical layer simulation of an IEEE 802.15.4 transceiver is developed in accordance with the specifications detailed in the IEEE standard. The simulator is validated by comparing the bit-error-ratio (BER) versus signal-to-noise-ratio (SNR) curve found from simulation with that expected from theory. A broadband non-Gaussian impulsive noise model described by a symmetric α-stable (SαS) distribution is designed and used to assess robustness of the IEEE 802.15.4 receiver to impulsive noise.**

Keywords-IEEE standards; IEEE 802.15.4; physical layer simulations; impulsive nosie; Zigbee

I. Introduction

Smart electrical power grids and remote monitoring of the power systems assets have become topics of intense research interest. Wireless sensors are required in both application areas and have therefore gained importance. A wireless sensor node essentially comprises a power source, a sensing device (e.g. pressure, temperature etc.) and a wireless transceiver. The Zigbee transceiver, which is based on the IEEE 802.15.4 standard, is the most popular current wireless sensor technology and has been used in many commercially available wireless sensor network (WSN) solutions. Generally wireless receivers are designed to be optimal assuming that noise will be Gaussian. This may be a useful pragmatic assumption in many environments but in is almost certainly less useful in industrial environments where impulsive noise processes often dominate. Electricity substations, for example, represent an environment in which partial discharge due to imperfect insulation in high voltage plant may, in places, be dominant. Electromagnetic radiation resulting from partial discharge is impulsive with the potential to degrade the performance of a receiver designed to have optimal performance in the presence of Gaussian noise.

This paper addresses the performance degradation that can be expected when an IEEE 803.15.4 receiver is subject to impulsive noise. The paper is divided into five sections. Section-II addresses the IEEE 802.15.4 standard with the emphasis on the physical layer. (The complete standard includes the medium access (MAC) layer.) The implementation of the simulation described in section-III. It also describes the validation of the receiver simulation. Section-IV describes the broadband impulsive noise model and the rationale for the adoption for this model of an SαS distribution process.

II. IEEE 802.15.4 Standard

IEEE standard 802.15.4 specifies the physical (PHY) and Media Access Control (MAC) layers of a Wireless Personal Area Network (WPAN). Zigbee is one popular short range technology and its PHY and MAC layers are designed in accordance with the IEEE 802.15.4 standard. Zigbee devices are low-power and low-cost and have short wakeup time.

A. PHY Layer

The PHY layer may operate in three different ISM (Industrial Scientific and Medical) frequency bands (868 MHz in Europe, 915 MHz in the Americas and Australia and 2.4 GHz globally). The date-rate is 20 kbit/s at 868 MHz, 40 kbit/s at 915 MHz and 250 kbit/s at 2.4 GHz.

Both PHY modes (868/915 MHz and 2.4 GHz) are based on Direct Sequence Spread Spectrum (DSSS) to achieve low power operation and increased immunity to noise/interference from nearby networks. The high data-rate in the 2.4 GHz variation is achieved using Orthogonal Quadrature Phase Shift Keying (OQPSK) in which each symbol (16-ary orthogonal) is mapped to 32 chips of a 2000 kchip/s PN sequence. The spreading

PN sequences are given in [1]. In the 868 MHz mode, Binary Phase Shift Keying (BPSK) is used in which each (binary) symbol is mapped to 15 chips of a 300 kchip/s PN sequence. Receiver sensitivity is specified to be -85dBm for the 2.4 GHz mode and -92 dBm for either of the 868/915 MHz modes. Transmitted power must conform to the appropriate regional radio regulations.

III. SIMULATIONS

Physical layers (PHY) of each the two IEEE 802.15.4 transceiver modes (868 MHz and 2.4 GHz) have been implemented using Simulink/MATLAB.

Simulink blocks are used for binary data generation, modulation and error rate calculations. The functions of spreading, despreading and broadband impulsive noise generation (Section-IV for details) are implemented using MATLAB script functions. The symbol-to-chip mapping (in the spreading/despreading blocks) follows the IEEE 802.15.4 specification (see Table 27 and Table 37 in [1]). Both spreading/despreading and impulsive noise generation blocks are embedded in MATLAB level-2 s-functions. These are imported to Simulink (as user defined custom blocks) for use in the PHY simulations. A block diagram of the Simulink implementation for the 2.4 GHz receiver is shown in Figure 1.

A. *Validation*

The simulations are validated by comparing the simulated BER versus SNR curves in the presence of white Gaussian noise with those predicted from theory for an ideal, matched filter, inter-symbol-free receiver. Figure 2 presents the validation results.

IV IMPUSLIVE NOISE MODEL

Impulsive noise models can be divided into two classes based on the relative bandwidth of the receiver and noise ‘impulses’ [2]. Narrowband impulsive noise models assume that receiver bandwidth is larger than the impulse-noise bandwidth and that, consequently, the noise pulses do not produce transients at the receiver front end. Broadband impulsive noise models assume that receiver bandwidth is smaller than the impulse-noise bandwidth and that, consequently, significant transients are produced in the receiver front end.

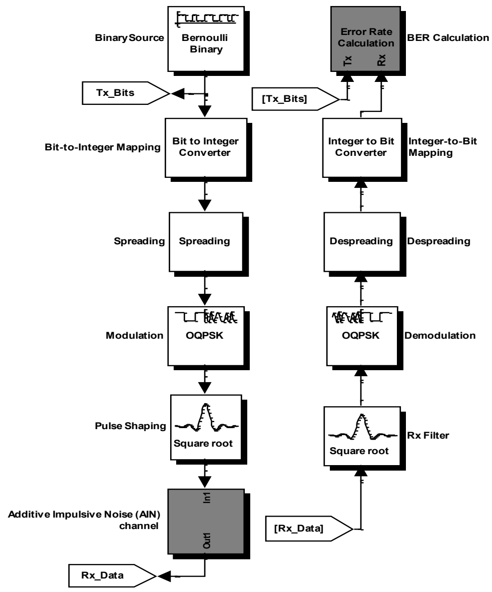

Figure 1 Simulink implementation of PHY layer of IEEE 802.15.4 transceiver for 2.4 GHz PHY mode

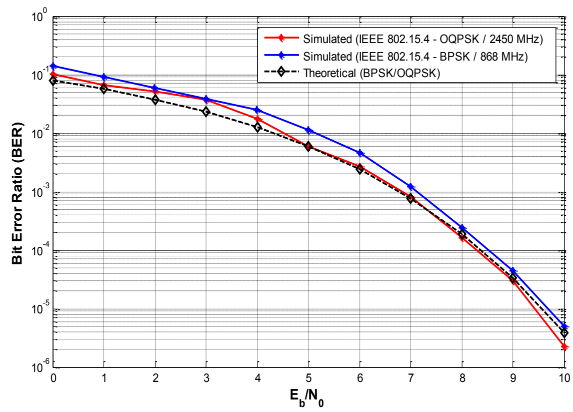

Figure 2 Validation of the IEEE 802.15.4 physical layer simulation

The Middleton Class A noise model has been popular for the statistical modelling of narrowband impulsive noise. The Middleton Class B noise model is the conceptual standard for the statistical modeling of broadband impulsive noise. Its practical application, however, is limited by its mathematical complexity and the requirement to estimate six parameters. The symmetric α-stable (SαS) process, however, can potentially be used to approximate the Middleton class B model [3]. The relationship between Class B noise and the SαS process has been established via their characteristic functions and analysis shows that the pdf of an SαS process is a close approximation to the pdf of class B noise [4].

B. Symmetric α-Stable (SαS) distribution

Cauchy introduced SαS distributions when he generalized the Gaussian characteristic function *exp*($-w^2$) to *exp*($-|w|^{\alpha}$). Besides the Gaussian case (α = 2), there exists only one closed-form solution (for α = 1), sometimes referred to as the Cauchy distribution. The characteristic function of an SαS process is given by:

$$\Phi(\omega) = e^{j\delta\omega - \gamma|\omega|^{\alpha}} \quad (1)$$

where α ($1 \le \alpha \le 2$) is the characteristic exponent that determines the shape of the distribution. δ is the location parameter and γ is the dispersion of the distribution (describing the spread of the distribution around δ). For α in the range {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.

Since there is no closed-form expression for the SαS pdf a power series expansion, derived in [4], is employed in this work. Figure 2 shows the pdf of an SαS impulsive process which is close to Gaussian near zero but decays more slowly than Gaussian in the distribution tails. (Gaussian tails are exponential but SαS tails are algebraic.) Tail thickness of the pdf depends on the value of α; the smaller the value of α the thicker the tails.

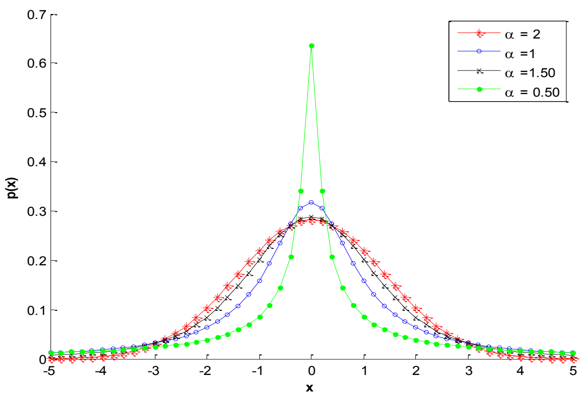

Figure 3 SαS pdfs for different value of α

Samples of impulsive noise with different values of α are shown in Figure 4.

C. Generalized SNR

The SαS distribution does not have finite second order moments and all SαS signal processing is based on fractional lower order moments (FLOM) [5]. The use of a traditional signal-to-noise ratio (SNR) is therefore not possible. BER performance has thus been characterized as a function of generalized SNR (GSNR) which can be written (after [6]) as

$$GSNR = 10\log_{10}\left(\frac{s}{\gamma}\right) \quad (2)$$

where s is signal power and γ is the dispersion of the SαS distribution.

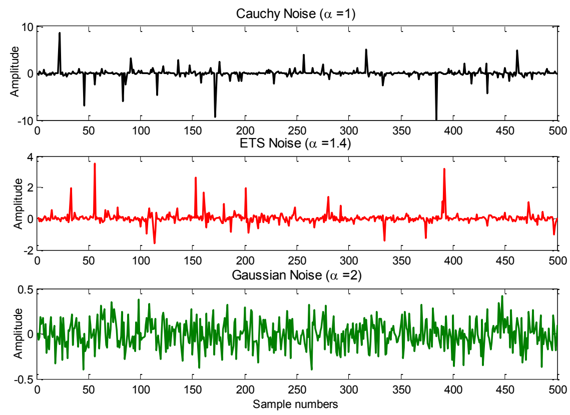

Figure 4 Noise samples

V RESULTS AND CONCLUSIONS

The performance of an IEEE 802.15.4 receiver in the presence of broadband impulsive noise is presented in Figure 4. The noise is generated using the model described in Section IV with parameters covering a wide range of noise distributions e.g. Cauchy, Gaussian and other.

BER performance is evaluated with respect to its performance in the presence of additive Gaussian noise. For the 2.4 GHz mode performance degradation, is 6 dB in the presence of impulsive noise with a Cauchy distribution (α =1) and 2 dB in the presence of impulsive noise (α = 1.4) recorded in an electricity transmission substation (ETS). The details of the ETS noise (and parameter estimation) are given in [7]. For the 868 MHz mode the performance degradation is 4 dB in the presence of impulsive noise with Cauchy distribution (α =1) and 0.5 dB in the presence of noise recorded in the ETS.

VI APPLICATIONS

The work reported here has application in the electricity supply industry where wireless sensor equipment must operate reliably in an intensely impulsive noise environment.

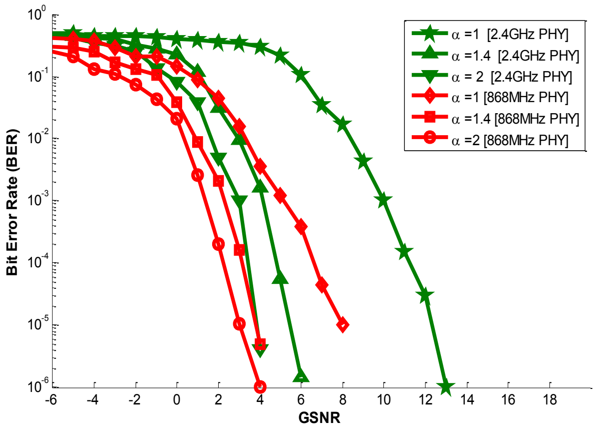

Figure 5 BER performance of IEEE 802.15.4 receiver (868 MHz and 2.4 GHz PHY modes) in the presence of broadband impulsive noise.

ACKNOWLEDGMENT

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