Modeling Interference for Wireless Sensor Network Simulators

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ABSTRACT

Any radio signal gets exposed to some attenuation over distance, and is received at the receiver as its distorted version and is superposed with other wireless signals transmitted in the neighborhood. In wireless communications, the useful signal is usually decoded by assuming the sum of all other wireless signal transmissions as noise. Interference between coexisting transmissions can cause severe performance degradation in wireless sensor networks (WSNs).

In this paper we have reviewed interference models for wireless sensor networks. Since a decade or more, densification of networks increases the impact of interference. New models have been proposed but are not yet included into network simulators. This could be source of a big difference between simulations and real deployments.

Keywords

Wireless Sensor Networks; Wireless Communications; Impulsive Interference; CupCarbon; Smart Cities.

1. INTRODUCTION

The evolving field of WSNs have an extensive range of potential applications in industry, science, transportation, civil infrastructure and security etc. WSNs comprised sensing (measuring), computation, and communication into a single tiny device called sensor node [1] [2]. WSNs typically consist in a large number of heterogeneous sensor devices that contain processing capability, sensor(s) and/or actuator(s), a power source (batteries and eventually some energy harvesting modules), multiple type of memory and a radio frequency (RF) based transceiver as shown in Figure 1. This large number of sensors are densely deployed over a large field and inter-networked together. They monitor physical or environmental conditions that generate sensor readings and deliver them to a sink node in order to be further processed [2].

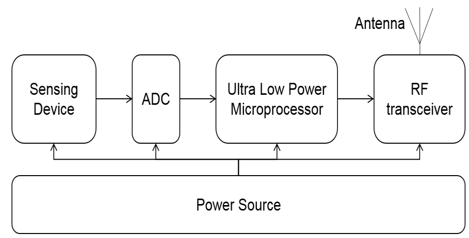

Figure 1: single node architecture

Wireless communication systems provide flexibility, ease and cost saving solutions in deployment and maintenance of sensor network. WSNs utilize numerous wireless communication protocols, such as Bluetooth, ZigBee, ultra-wideband, Wi-Fi. Two of most common wireless standards for wireless communications in WSNs are IEEE 802.11 also known as Wi-Fi and IEEE 802.15.4 also referred to as ZigBee, allow data transmission in standardized manner. Choosing which standard is best for particular application can be decided by examining its power consumption, required data rate and data transmission range. Wireless connectivity is an essential part in sensor networking, however it comes at a cost of increased energy usage, mainly due to the high power consumption during data transmission. Wireless sensor networks based on IEEE standard 802.11 or Wi-Fi have become pervasive in enterprise and industrial environments. No doubt, IEEE standard 802.11 was not intended with sensor applications in mind, but innovations in implementations have enabled the use of this standard, while sustaining all sensor requirements [3].

In a wireless sensor network composed of many spatially scattered wireless nodes, communication is constrained by various impairments such as the wireless propagation effects, network interference, and thermal noise. The effects of signals propagation in the wireless environment include the attenuation of radiated signals with distance (also called path loss), the blocking of signals caused by large obstacles (also called shadowing), and the reception of multiple copies of the same transmitted signal (also called multipath fading). The network interference is due to accumulation of unwanted signals radiated by other transmitters from inside or outside of the network, which undesirably affect signal reception at receiver nodes in the network. The thermal noise is introduced by the receiver electronics and is usually modeled as additive white Gaussian noise (AWGN).

Due to the scarcity of radio spectrum, it is not completely possible for large wireless networks to communicate without interference. Probably other radio devices will make transmission using the same radio frequency band at the same time. Consequently, at the receiver, many undesired signals from interfering transmitters will add to the desired transmitter's signal. This phenomena is called interference and it causes a performance degradation of communication networks [4].

Reconstruction of the input signal is possible if we have an appropriate model of the medium or channel between the transmitter and the receiver. This model is called channel model and it should be accurate enough to represent the behavior of the wireless channel. To mitigate the noise effect from the received signal, the channel model plays a key role. Let $x(t)$ be the transmitted signal. After passing through the wireless channel $h(t)$ the received signal $y(t)$ will be:

$$y(t) = h(t) * x(t) + Z(t) \tag{1}$$

where $*$ is the convolution operator and $Z(t) = I(t) + N(t)$ is the sum of the interference and the thermal noise.

The densification of networks make modeling of wireless network interference is an important question, with numerous applications to the analysis and design of wireless communication systems, the development of new interference mitigation techniques, the control of electromagnetic wave emissions, among many others. Recently, wireless interference modeling has been receiving increased interest in the context of ad hoc and cellular networks but also in the case of ultra wide band communications. The traditionnal approach is to model the interference by Gaussian random process [5–10] which can be seen as a logical consequence of the central limit theorem. It has however been shown that this assumption is not accurate in many practical situations and WSNs can be one of them.

Rest of article is organized as follows. Section 2 defines some of WSN constraints. Section 3 reviews some of interference models for WSNs that can also embed into WSN simulators. Section 4 illustrates some main-stream simulation tools used in WSNs. Conclusive remarks about this research are drawn at the end in Section 5.

2. WIRELESS SENSOR NETWORK CONSTRAINTS

Some aspects of wireless channel make wireless communication more challenging as compare to wired communication like probabilistic wireless channel behavior, limited radio range, interference from other radio devices and many more [11]. These aspects change the characteristics of the transmitted signal as it travels through the wireless channel and can make it difficult if not impossible to recover.

2.1 Low transmit power / short range

A sensor node is equipped with an energy source (battery) as shown in Figure 1. This energy resource is limited when in many cases it has to operate for many years or decades and can not be replaced. Wireless sensor nodes remain on high energy constraint which is not protocol specific. To reduce energy consumption, assigned power for transmission always remain low compared to other wireless communication systems. Minimum transmit power defined by the physical layer [12] [13] is 1 mW (0 dBm).

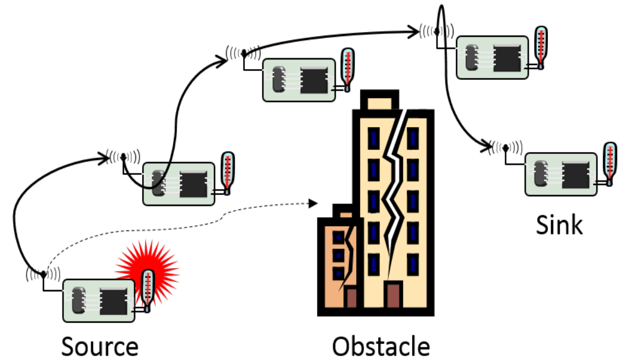

Figure 2: Multihop communication in WSN

2.2 Multi-hop Communication

In the radio module of a node, the wireless transmission is often done using an Omni-directional antenna. Ideal Omni-directional antennas, called "isotropic" do not exist, it is a theoretical antenna which broadcasts the same signal in every direction. In reality, the electromagnetic wave radiations are unevenly distributed in space, determined by the antenna radiation pattern. While wireless communication is a core technique in wireless sensor networks, a direct communication between a sender and a receiver is faced with limitations. In particular, communication over long distances is only possible using prohibitively high transmission power. The use of intermediate nodes as relays can reduce the total required power. Hence, for many forms of WSNs, so-called multi-hop communication will be a necessary ingredient [14].

2.3 Interference

Performance of radio communication based WSNs is greatly influenced by the interference. Interference in WSNs cause packet lost, their retransmissions, link instability and inconsistent protocol behavior. The traditional way to solve this problem is to license frequency bands to primary network users who are the only ones allowed to transmit in that frequency. This method is been used in AM/FM radio, over-the-air TV broadcasts and even in cellular communications. The frequency bands are auctioned to wireless telephone carriers. This approach has removed interference problem, meanwhile it results in low utilization when the primary owner does not use the allocated frequency spectrum frequently.

This disadvantage of static frequency allocations has led to the use of shared or unlicensed frequency bands that can be used by multiple networks at the same time. The 2.4 GHz band is an example of this paradigm, used by 802.11 (WiFi), 802.15.1 (Bluetooth) and 802.15.4 (Zigbee) data networks and even cordless telephones.

Next section reviews some of interference models for WSNs that can also embed into WSN simulators.

3. MODELS FOR WIRELESS CHANNELS

Low power wide area networks (LPWAN) technology specialized for interconnecting devices with low transmission power. Low power technologies are primarily designed for machine to machine networking environments. The data rates associated to LPWAN technologies are very low, as is the power consumption of connected devices. There is a battle going on for the most suitable infrastructure technology for WSNs. Among these the two most talked about contenders are Sigfox and LoRa. This section provides details of protocols suitable for LPWAN.

- **SigFox:** it supports narrowband (or ultra narrowband) technology with standard radio transmission method called binary phase-shift keying (BPSK) (going up). Which allows the receiver to only listen in a very small part of spectrum that mitigates the noise impact. It requires an inexpensive endpoint radio and a more sophisticated base station to manage the network. These transmissions use unlicensed frequency bands [15].
- **LoRa:** Stands for Long Range Radio.It is a spread-spectrum technology with a wider band (usually 125 kHz or more). LoRa uses the entire channel bandwidth to broadcast a signal which makes it resistant to channel noise, long term relative frequency, doppler effects and fading [16] [17].

According to [18] [19] wireless interference models can be viewed as the combination of following three components.

- **Propagation model:** it describes the radio propagation impact on received signal, such as deterministic path loss, small-scale fading and large-scale fading [18].
- **Interferers (i.e., other transmitters) spatial distribution model:** it specifies how possible interferers are distributed over the given network area, ranging from a random distribution and terminal placement [18].
- **Network operation model:** it defines inter relationship among terminals of a sensor network. This inter relationship is mainly defined by the medium access control (MAC) technique implemented in the network, which can be classified as random access techniques (e.g., CSMA and Aloha) or deterministic access techniques (e.g., TDMA, CDMA and FDMA). The MAC technique determines when and which nodes will access the medium (radio channel) in the communication network [18].
- **Traffic model:** it defines the transmitter activity.

In [18] interference models are divided into three broad classes also shown in Figure 3:

- **Statistical models:** these models focus on the unwanted signals or interference signal at receiver modeled as a random process, and provide a statistical characterization of this process, typically stated in terms of distribution functions or some related function. A significant model in this class is based on the assumption that wireless nodes are randomly distributed according to Poisson Point Process (PPP), that, under certain additional conditions, leads to an Îś-stable distribution for the aggregate interference model. Statistical model class also includes models based on the assumption that wireless nodes are arbitrarily positioned, such that randomness of interference results from propagation effects or user activity [18].

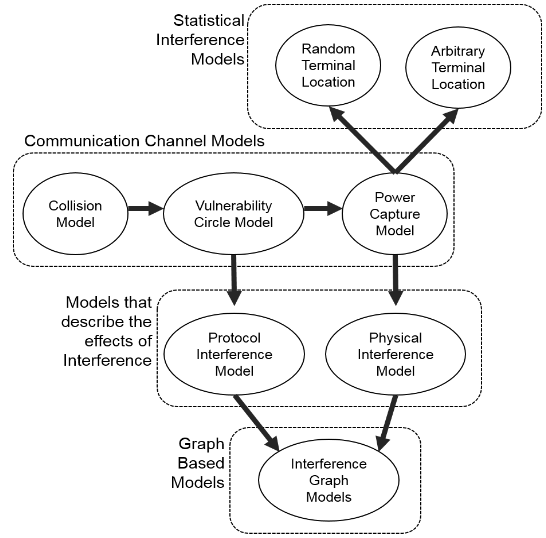

Figure 3: Unified view of interference models shown in [18]

- **Models that describe the effects of interference:** Two largely used interference models namely, the Protocol Interference Model and the Physical Interference Model belong to this class. The Protocol Interference Model defines a pairwise interference relationship between wireless nodes, and is based on local constraints. On the other hand, Physical Interference Model assumes aggregate interference observed by the receiver, due to all other wireless transmitters. When the Protocol and Physical models are interpreted in the context of Graph Theory, we have the graph-based interference models [18].
- **Graph-based models:** These models are particularly suitable for solving problems in the context of topology control and transmission scheduling.

In [20] [21], Alberto Rabbachin et al proposed a statistical model for aggregate interference in cognitive networks which accounts for the sensing procedure, spatial distribution of wireless terminals, secondary spatial reuse protocol, and environment-dependent conditions (e.g. path loss, shadowing, and channel fading). They considered two types of secondary spatial reuse protocols:

- **Single threshold protocol:** the i^{th} secondary user is active if $(KP_pY_i)/(R_i^{2b}) \leq \beta$ or $R_i^{2b}Y_i \leq \zeta$.where β is the activating threshold, ζ is the normalized threshold, P_p is the transmitted power of the primary user, Y_i is the squared fading path gain of the channel from the primary user to the i^{th} secondary user, K is the gain accounting for the loss in the nearfield, R_i is the distance between the primary and the i^{th} secondary user, and b is the amplitude pass-loss exponent. Activity of secondary network users can be characterized by Bernoulli random variables [20].
- **Multiple threshold protocol:** Transmission power of the secondary network users is sets according to the detected power level of the primary network uplink signal. They considered $N-1$ normalized threshold values to identify N different sets of active secondary users [20] [21].

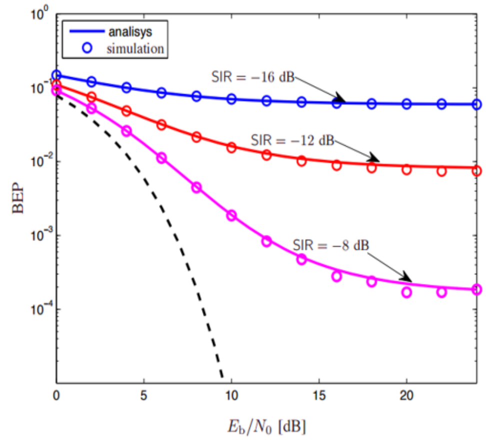

Figure 4: Bit error probability of BPSK versus E_b/N_0 in the presence of the cognitive network interference. $\lambda = 0.1 users/m2$ and $\zeta = 40dBm$. For comparison, the BEP in the without interference is also plotted (dashed line).

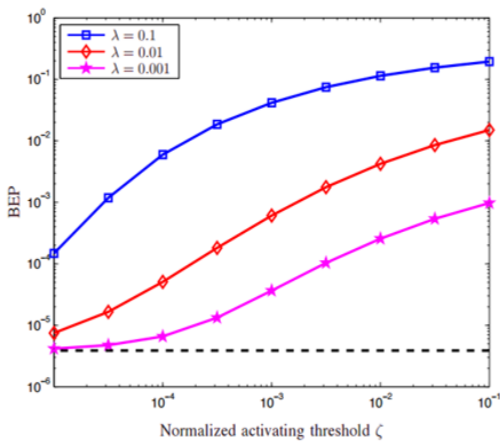

Figure 5: Unified BEP of BPSK as a function of the normalized activating threshold ζ for the single-threshold protocol. $E_b/N_0 = 10dB$ and $SIR = 10dB$. For comparison, the BEP in the without interference is also plotted (dashed line).

Their obtained results are also shown in Figure 4 (Bit error probability versus E_b/N_0 for BPSK system) and Figure 5 (Unified BEP of BPSK as a function of the normalized activating threshold ζ for the single-threshold protocol).

In [22] Mario and Nikolaos offered a framework for the approximation of interference distribution in wireless networks with spatial randomness. They utilized known probability density functions using the moment matching method for three node distributions:

- Poisson Point Process (PPP)
- Strauss
- Poisson Cluster Point

In order to approximate the interference distribution, they proposed to use generalized distributions, like normal inverse Gaussian and the generalized inverse Gaussian distributions, as well as simpler, two-parameter probability distributions, such as the inverse Gaussian, the inverse gamma, and the gamma distribution. Their numerical results show the effectiveness of inverse Gaussian distribution in approximating the interference as shown in Figure 6, 7 and 8 created by base stations distributed according to the Strauss point process, as well for Poisson cluster processes. The inverse gamma distribution also gives satisfactory results in certain cases, while the normal distribution fails significantly to model the aggregate interference.

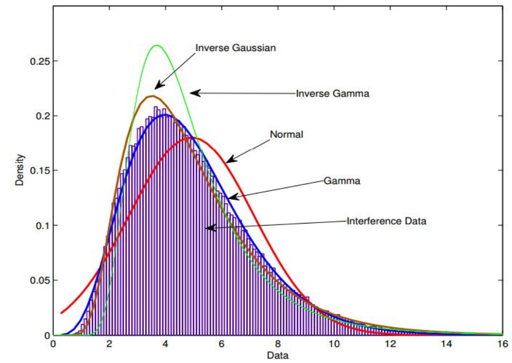

Figure 6: Empirical PDF of interference for the PPP and the corresponding fits.

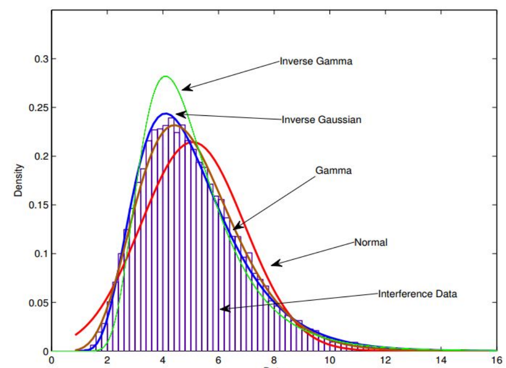

Figure 7: Empirical PDF of interference for the Strauss process and the corresponding fits.

4. WIRELESS CHANNEL INTERFERENCE MODELS IMPLEMENTED IN THE NETWORK SIMULATORS

The simulation of networks is an essential tool for testing protocols and their prior performance deploy. Researchers often use network simulators to test and validate proposed protocols and algorithms before their real time deployment. Indeed, such an establishment may be costly and difficult, especially when talking about a large number of nodes distributed large scale. This is the reason for which the simulation of networks is essential. Moreover, rapid growth in the field of wireless communications entails the need of creating new simulators that have more specific capabilities to tackle interference and multipath propagation effects that

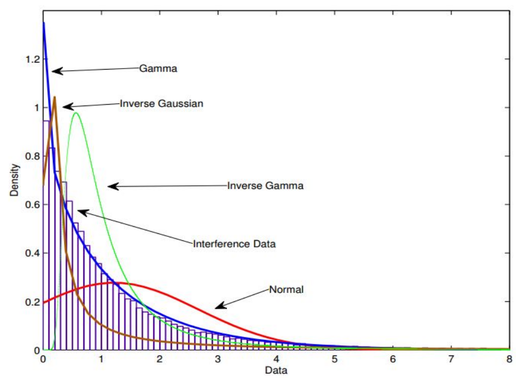

Figure 8: Empirical PDF of interference for the Poisson cluster process and the corresponding fits.

are present in wireless environment. Finding a suitable simulation environment that allows researchers to verify new ideas and compare proposed future solutions in a virtual environment is a difficult task. A network simulator must be quite reliable, accurate and fast to be really usable. However, the accuracy is not only depends on the implementation of protocols and layers of the OSI model but also the interference model implemented [23]. The objective of this section is to list the different interference models implemented in the best-known wireless sensor network or general wireless network simulators.

4.1 NS-2

Ns-2 (http://www.isi.edu/nsnam/ns/) is one of the most known network simulator. The protocols behavior and simulator itself are C++ based, while interpreted scripts performing the simulation itself are to be OTcl based. In spite the fact that ns-2 is considered to be too general and inappropriate for wireless sensor network simulations by some researchers, an example of ns-2 usage is a simulation of Low Energy Adaptive Clustering Hierarchy (LEACH) protocol used for routing and clustering of sensor nodes in a network. The ns-2 has a rich set of IP network focused protocols [24], because it has never been intended to design for WSNs, thatâĂŹs why it does not scale very well and has some troubles if the number of nodes count in a network exceeds the number of 100. It also cannot simulate problems of the bandwidth or the power consumption constraint in WSNs.

4.2 Castalia

Castalia is a simulator for Wireless Sensor Networks (WSN), Body Area Networks (BAN) and general networks (e.g. low-power embedded devices etc.). Since 2007, it is developed in the Networked Systems theme at NICTA [25]. Castalia is used by researchers and developers to test their proposed or already existed distributed algorithms and/or protocols in realistic wireless channel and radio models, with a realistic wireless nodes behavior especially relating to access of the radio channel. Castalia's significant features include: model for temporal variation of path loss, fine-grain interference and RSSI calculation, physical process modeling, node clock drift, and several popular MAC protocols implemented. Castalia provides tools to help run large parametric simulations, process and visualize the results.

4.3 MiXiM

MiXiM is an OMNeT++ modeling framework created for mobile and fixed wireless networks (e.g. wireless sensor networks, body area networks, ad-hoc networks, vehicular networks, etc.). MiXiM simulator focusses on the lower layers of the protocol stack, and proposes comprehensive models of radio wave propagation, interference estimation, radio transceiver power consumption and wireless MAC protocols. MiXiM is merger of several earlier OMNeT++ frameworks. It is planned to merge MiXiM into the INET Framework [26].

4.4 Worldsense

Worldsens (http://www.senslab.info/?cat=13) consists of two simulators: WSNet and WSim. WSNet is an event-driven simulator based on C language [27]. It allows simulations of large scale wireless sensor networks. The so-called blocs simulate components of the wireless terminals and properties of the radio channel. WSim also allows simulation of hardware platform using microcontroller binary codes [28].

4.5 TOSSIM

TOSSIM (http://docs.tinyos.net/index.php/TOSSIM) is a simulator based on TinyOS operating system. It enables simulation of application written in nesC language (network embedded system C) for real hardware. The simulation scenario can be written either in Python or C++ [29].

Table 1 shows summary the channel/interference models associated with some of the wireless network simulators.

Table 1: SUMMARIZES THE INTERFERENCE MODELS ASSOCIATED WITH EACH NETWORK SIMULATOR

	General or specific	**Wireless channel noise model**
`NS-2 (simulator) (available online)`	General simulator	Free space. Two ray ground reflection. Log normal shadowing.
`Castalia (simulator) (available online)`	WSN simulator	Free space Log normal shadowing. Temporal variation. Additive interference.
`MiXiM (simulator) (available online)`	General simulator	Free space Log normal shadowing using adapted free space. Jakes Fading.
`WSNet (simulator) (available online)`	designed for WSNs	Disk Model. Free space. Two-ray ground reflection. Log normal shadowing. Rayleigh fading. ITU indoor model. Nakagami fading.
`TOSSIM (emulator) (available online)`	General simulator	Log normal shadowing Noise modelling

5. CONCLUSIONS

A wireless communications are largely differs from a wireline communications in the intrinsic difficulty in abstracting its physical layer in terms of few simple per link parameters. In contrast with wired links which have fixed capacities independent of one another, in a wireless network, the links suffer from mutual interference creating a need to model the wireless channel interference. Several works in the literature have made use of simplified interference models. In this paper we have looked in detail at some of already existing interference models for wireless sensor networks.

6. ACKNOWLEDGMENTS

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