Integration of OFDM Based Communication System with Alpha-Stable Interference using CupCarbon Simulator

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ABSTRACT

Deploying sensor networks in an efficient and optimal way has become an important topic these days. A sensor network is basically an infrastructure which consists on number of nodes equipped with a sensor, a controller and a communication module. Interference from the neighboring nodes makes it difficult for a communication system to achieve the required throughput and also makes it difficult to predict the network behavior.

CupCarbon is a wireless sensor network (WSN) simulator, recently developed by researchers of Lab STICC, for a better analysis and understanding of WSN. In this paper, we present an optimal way to integrate a PHY layer based on Orthogonal Frequency Division Multiplexing (OFDM) in the simulator and we have also considered the network interference impact in wireless communication. For a flexible and accurate representation, interference is modeled by alpha-stable distribution function. This allows the better estimation of channel conditions to take into account the channel conditions and the density of interferers in a network.

Keywords

Wireless Sensor Networks; Wireless Communications; Orthogonal Frequency Division Multiplexing (OFDM); Impulsive Interference; Gaussian Distribution; Alpha-Stable Distribution; CupCarbon; Smart Cities;

1. INTRODUCTION

Cities are always considered as the beating heart of the world's economy. Cities have recently become mega cities with millions of people living in them and such huge systems/cites are very difficult to manage properly. Smart city is basically following the concept: how citizens use technology to manage and govern the environment involving traffic, energy, businesses and all the services that are supported in the framework of the city. This is the direction that most of the cities will have to adopt to provide the image of efficiency of their system ability [1].

One or more than one sensor networks are embedded in urban environment to make it a smart city. Sensor networks are the deployment of several devices that are equipped with sensing devices to perform collaborative measurements [2].

A sensor Network consists on typically three major elements a node, a data gatherer device (sink) and some external system that processes the information. Nodes are autonomous devices. They consist of a microcontroller, sensor or sensors, communication module, battery and a memory device. Figure 1 shows the basic components of a sensor node. They measure data and send them to the sink. Data gatherer or the sink is the real time data capturer. It behaves as a gateway to external systems in order to transmit useful information. The external systems can be a data storing device, a data managing device or an actuator, which control other devices based on the received information [2].

With the emergence of wireless communication technologies that utilizes the electromagnetic waves, Local Area Networks (LAN) have been set free from the limitation of physical medium. Wireless communication technologies have experienced exponential growth in communication industry and are the potential contributor in advancement of wireless sensor network (WSN). Wireless communication systems provide flexibility, ease and cost saving solutions in deployment and maintenance of sensor network.

There are some aspects that make wireless communication more challenging as compare to wireline communication like probabilistic wireless channel behavior, jamming and interception, limited radio range, interference from other radio signals and many more [3]. These aspects change the characteristics of transmitted wireless signals as they travels from transmitters to receivers. Received signals characteristics depend on the distance between the transmitter and the receiver, the multiple paths that have been taken by the transmitted signal and the surroundings (buildings, trees and other objects).

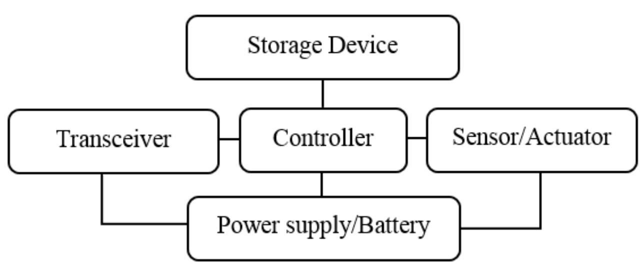

Figure 1. Basic architecture of a sensor node.

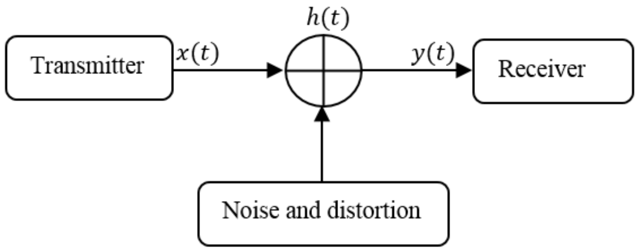

Figure 2. Wireless channel effect on transmitted data.

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. After passing through the wireless channel $h(t)$ the received signal $y(t)$ will be

$$y(t) = h(t) * x(t) + Z(t) \quad (1)$$

where $x(t)$ is the transmitted signal, * is the convolution operator and $Z(t)$ is the noise (see Figure 2).

There are many ways proposed in the literature to model interference [5-6]. The most common noise encountered in communication systems is the Additive White Gaussian Noise (AWGN) also known as the thermal noise. In (1), $Z(t)$ is the Gaussian noise with zero mean and a variance N_0: $Z \sim \mathcal{N}(0, N_0)$. The noise samples are independent and identically distributed (i.i.d.) [5].

In spite the fact that Gaussian or white noise is used in the modeling of a wide range of communication channels but it is inappropriate for the modeling of impulsive noise [7]. Impulsive noise is a noise which often occurs in wireless and wireline communications in the indoor and outdoor environments. Impulsive noise or non-Gaussian noise can be a major source of error in data transmission and also can be a contributor in the increase of total error rate of the system. In more real wireless environmental circumstances, some noises are impulsive in nature; e.g. atmospheric noise that is caused by lighting, radar noise and so on... Research has shown that Gaussian noise model fails to completely describe the impulsive interference [8]. In particular these rare events with large amplitude have high impact on communication links but cannot take into account with the Gaussian model. Another mathematical model is required to model such interference. Alpha-stable distribution that satisfies the Generalized Central Limit Theorem and presents heavy tails [9-10], allows to take these rare events into account in a more accurate way.

Finding a suitable simulation environment for WSN is a difficult task. Simulation of the wireless sensor network in real time environment is an essential part in deployment of a new network because running the real experiments on WSN testbeds is not cost effective. CupCarbon is an open source WSN simulator which is recently developed for the better analysis and understanding of WSN protocols. This simulator runs under the Java environment and can be downloaded from the Internet (http://www.cupcarbon.com). Simulations in CupCarbon are based on physical layer of Open System Interconnection (OSI) model. It is the only simulator that supports wireless communication interference models and signal propagation models like Gaussian and alpha-stable models. CupCarbon also allows sensor nodes to set their radio visibility according to the urban environment. It provides graphical user interface (GUI) to facilitate the comprehension and visualization of WSN as shown in Figure 3. We have randomly placed 208 nodes on a city map. Communication between the nodes in the same time interval, within a network can cause interference and cause performance degradation of a communication system. Figure 3 depicts the communication between two sensor nodes $S3$ and $S4$ both nodes are within the radio range of each other.

The objective of this research is to include an OFDM based physical layer in a general WSN simulator, CupCarbon. We first study the system behavior with Gaussian noise and alpha-stable interference. We evaluate the performance in terms of bit error rate (BER) and packet error rate (PER). We then include the PHY layer and the interference model in the WSN simulator to have an accurate evaluation of the network behavior.

The rest of this article is organized as follows. Section 2 explains the working of an OFDM transceiver. Section 3 describes the characteristics of noises that are present in the wireless channel. Section 4 describes the Gaussian and alpha-stable distribution functions to model the wireless channel interferences. We will present our simulation results using Matlab and Cupcarbon in Sections 5. Conclusive remarks about this research are drawn at the end in Section 6.

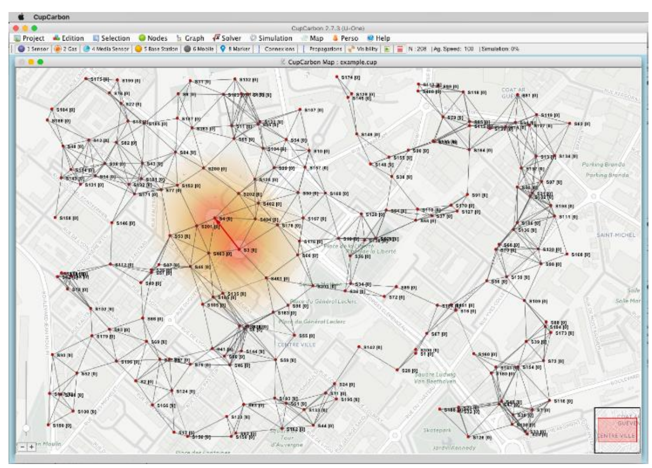

Figure 3. GUI of CupCarbon: a WSN Simulator.

2. OFDM TRANSCEIVER

In the recent decade there has been a tremendous growth in wireless communications. These days, the data rates of wireless communication systems are getting higher as Tele technology is evolving. In the more recent 4G technology the data rates are more than 100Mbps [11]. There is a key technology that is making it realistic for communication systems to achieve high data rates that is Orthogonal Frequency Division Multiplexing (OFDM). OFDM involves Frequency Division Multiplexing (FDM) and multi carrier communication. OFDM is the variant of Multi-Carrier Modulation.

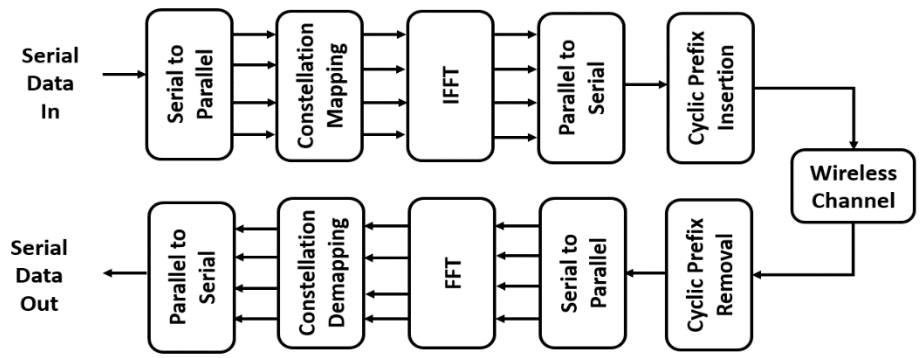

Figure 4. Functional Block Diagram of an OFDM Communication System.

OFDM is employed in several IEEE Wireless Local Area Network (WLAN) standards like, IEEE 802.11a, IEEE 802.11g, IEEE 802.11n, and IEEE 802.11ac. OFDM is broadband wireless technology that supports higher data rates [11].

2.1 Why OFDM for Broadband Systems

A communication system always have certain Bandwidth BW to operate on. The communication system operating on the given bandwidth B has symbol time $T = 1/B$. Broadband systems typically operate over the large bandwidth, so as the BW of the system increases the symbol time will decrease. In wireless communication system signal propagation occurs due to the multipath phenomena in which, multiple copies of signal reaches at the receiver with some delay. This is called the delay spread of the system and it can also be define as difference between the time of arrival of the earliest significant multipath component which could be the Line of Sight (LOS) component and time of arrival of the latest multipath components [11]. If the symbol time of the system becomes less than the delay spread of the system then Inter Symbol Interference (ISI) occurs in the system. ISI is the form of signal distortion in which a symbol interferes with the subsequent symbols. ISI typically occurs in the broadband systems because of the large bandwidth. Addressing the ISI problem is a significant challenge in broadband communication system [12]. OFDM provides the solution for the ISI as it divides the total bandwidth into sub-carriers and the transmit data over these sub-carriers. Each sub-carriers should be orthogonal to each other and have different frequency (see Figure 5).

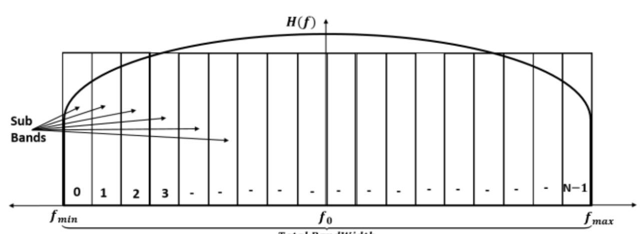

Figure 5. Ground concept of OFDM.

2.2 Basic Concept of OFDM

FDM divides the available bandwidth into many sub-carriers and allows the multiple users to access the system simultaneously. Different users transmit their data on different sub-carriers. Guard bands are used to avoid the interference between these sub-carriers. Guard bands are considered as the wastage of bandwidth. In multicarrier FDM the data from the single user is split into many sub-streams and transmits in parallel over the sub-carriers to make the data rate of the system higher. While in the OFDM the sub-carriers are designed to be orthogonal to each other. Figure 5 shows the ground concept of the OFDM system in which the total bandwidth is divided over the N sub-carriers. This allows the sub-carriers to overlap each other that ensures bandwidth efficiency of the system and achieves higher data rates [12].

2.3 Functional Block Diagram of a OFDM Communication System

Figure 4 shows the block diagram for the OFDM communication system. Let us consider the input signal $S(t)$ and its sampling version $S[n]$ that will share over N sub-carriers. The input data is converted from serial to parallel OFDM symbols.

$$OFDM\ Symbols = \sum_{k=0}^{N-1} X[k]$$

The required amplitude and phase of each sub-carrier is calculated using predefined modulation technique (e.g. BPSK, QPSK or QAM). Then demultiplexing is applied to load OFDM symbols over each sub-carrier. Then these OFDM symbols are transferred to the IFFT block for IFFT operation to generate the transmit samples. For l^{th} sample we get:

$$x_n[l] = \frac{1}{N}\sum_{k=0}^{N-1} X_n[k]\exp(j2\pi l\frac{k}{N}) \quad ; \quad \text{For } l = 0,1,2,\ldots\ldots, N-1$$

where k represent the k^{th} sub-carrier N is the total number of sub-carriers. IFFT/FFT operation in OFDM helps to convert a frequency selective wireless channel into N parallel flat fading channels by dividing the large bandwidth that causes the ISI. These samples are again converted to serial stream. The parallel OFDM symbols are converted into serial stream through the process called multiplexing. At the receiver two consecutive OFDM samples can interfere to each other which is called Inter Block Interference (IBI). Cyclic prefix of length L is added to the serial data at this point to avoid IBI at the receiver and signal will become:

$$x_n[N-L], \ldots\ldots, x_n[N-1], x_n[0], x_n[1], \ldots, x_n[N-L], \ldots\ldots, x_n[N-1]$$

where L shows the length of cyclic prefix. At the receiver this cyclic prefix is discarded because it get effected by IBI. This signal is transmitted over the wireless channel. The exact but opposite operation is taken place at the receiver to convert the received signal into data as shown in Figure 4.

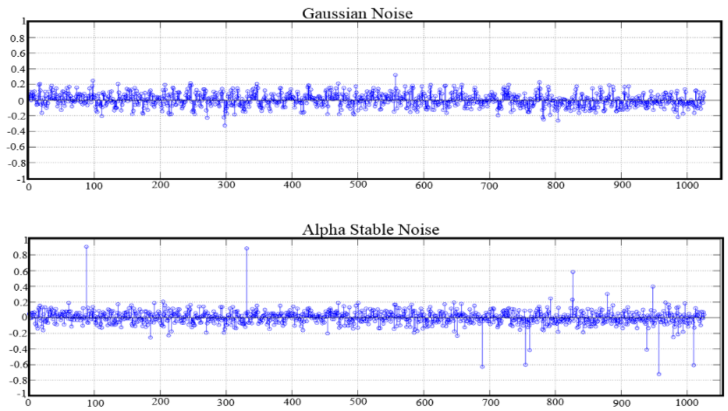

Figure 6. Comparison of Gaussian noise and alpha-stable noise.

3. CHARACTERISTICS OF NOISE IN WIRELESS CHANNEL

Noise always affects the transmitted signal when it passes through the wireless channel. There are many types of noises that could add to transmitted signal and cause the distortion in the received signal. It is necessary to categorize these noises for the better understanding of the wireless channel. Figure 7 shows the different type of noises that are present in the wireless environment.

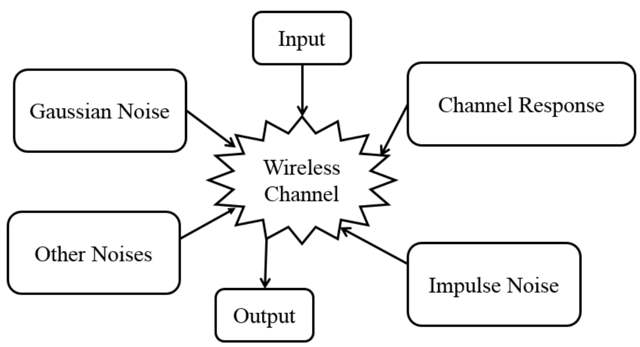

Figure 7. Characterization of Noise in Wireless Channel.

3.1 Interference

The interference is due to accumulation of signals at the receiver radiated by other transmitters in the network. Interference can distort the received signal. In WSN the interference can occur due to the neighboring nodes or other devices that are transmitting at the same time and with the same frequency. In a communication system interference could be incidental or intentional, powerful or resource constrained, narrowband or broadband and static or adaptive [4-5].

Consider a sensor network with n number of transmitting nodes and a receiver. If the node with transmitter T_0 wants to send data to the node with receiver R_x, the received signal will be:

$$Received\ Signal\ R_x = h_0 X_0 + \sum_{i=1}^{n} h_i X_i \tag{2}$$

The term $h_0 X_0$ is the desired signal with channel response h_0. $\sum_{i=1}^{n} h_i X_i$ is the interfering signals from the other nodes that are accumulated at the receiver and can be divided into further two parts:

$$\sum_{i=1}^{n} h_i X_i = \underbrace{\sum_{i=1}^{u} h_i X_i}_{Impulsive\ noise} + \underbrace{\sum_{i=u}^{n} h_i X_i}_{Gaussian\ noise} \tag{3}$$

So interference noise in wireless environment can be categorize into the Additive White Gaussian Noise or AWGN and Impulsive noise. Details of each is given in the next subsections.

3.1.1 Additive White Gaussian Noise

Additive White Gaussian Noise or AWGN is one of the channel impairments for the wireless communication system. It is called Additive because received signal is the addition of transmitted signal and noise. White noise means that this noise has uniform frequency spectrum over the certain frequency band. It has flat power spectral density and that is why the autocorrelation of the noise is zero in time domain [5]. Gaussian noise means that the noise samples follows Gaussian distribution and hence called Additive White Gaussian Noise or AWGN as shown in Figure 6.

3.1.2 Alpha-Stable Noise

Alpha-Stable noise or the impulse noise consists of irregular pulses or spikes that occurs for short duration and also known as rare events in the channel. These pulses have comparatively high amplitude than Gaussian noise [7]. These pulses may occur in bursts or for the short duration as shown in Figure 6.

Figure 6 shows the noise distribution over the sub-carriers for both Gaussian noise and alpha-stable noise. On x-axis we have sub-carries and y-axis shows the amplitude values of noise pulses. It can analyze from the graph that Gaussian and alpha-stable noise are almost same but the only difference is of high amplitude pulses that are present in case of alpha-stable noise [13].

4. NOISE MODELS FOR WIRELESS CHANNEL

Modeling the channels helps analyzing the performance of large wireless communication systems like WSN. Channel model provides information that how wireless channel parameters (e.g. carrier frequency, bandwidth, delay spread and Doppler spread) affects the transmitted signal and how channel behaves from the communication point of view. Description of two well-known distribution functions that are used to model the channel noise, is given below:

4.1 Gaussian Distribution

For the wireless channel the fundamental performance analyzer parameter is its capacity. The channel capacity is the maximum rate of communication for which negligible error probability can be assured. Unlike the AWGN channel, there is no single definition of wireless channel capacity that is appropriate for all scenarios.

Let us understand the Gaussian distribution in context of wireless communication channel. In Equation 2, the received samples have noise term $\sum_{i=u}^{n} h_i X_i$ and it follows the Gaussian distribution and can obtain from the following probability density function (PDF):

$$f_X(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{4}$$

where δ is the mean and σ is the noise variance. For zero mean noise ($\mu = 0$) the Equation 4. will become:

$$f_X(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}} \tag{5}$$

The reason to assume noise component of these interferer are following the Gaussian distribution can be explained by the Central Limit Theorem (CLT). According to CLT, the combined effect of large number of these identical but independent components should approach the Gaussian distribution [5].

4.2 Alpha-Stable Distribution

Arbitrarily occurrence of random impulses with high amplitude makes the channel noise non-Gaussian. A mathematical model is also needed for the characterization of the channel with impulsive noise. There is only one distribution that characterize the impulsive noise present in the wireless channels as compare to Gaussian distribution. Alpha-stable distribution is special form of Gaussian distribution with heavy tails that better suited for rare events modeling [14].

Unlike Gaussian distribution, there is no closed form expression or the probability density function of the alpha-stable noise, but it can describe by using its characteristic function [13], which is:

$$\emptyset(\theta) = \begin{cases} exp\left\{-\sigma^{\alpha}|\theta|^{\alpha}\left(1 - i\beta sign(\theta) tan\frac{\pi\alpha}{2}\right) + i\delta\theta\right\} if \alpha \neq 1 \\ exp\left\{-\sigma|\theta|\left(1 + i\beta\frac{2}{\pi} sign(\theta) ln|\theta|\right) + i\delta\theta\right\} \quad if \alpha = 1 \end{cases}$$

where

$$sign(\theta) = \begin{cases} 1 & if & \theta > 0 \\ 0 & if & \theta = 0 \\ -1 & if & \theta < 0 \end{cases}$$

where α, β, σ and δ are the four parameters of alpha-stable distribution and are explained below.

- α is the index of stability and it sets the degree of the impulsiveness of the distribution. It always has value between ($0 < \alpha \leq 2$). At $\alpha = 2$ this distribution becomes Gaussian distribution.
- β is skewness parameter. It specify the distribution curve if skewed towards right or left. It has value between ($-1 < \beta \leq 1$).
- σ is scale/dispersion parameter and measures the spread of the noise samples around the mean. It always has value $\sigma > 0$.
- δ is called location parameter. It corresponds to the median if $0 < \alpha < 1$, and corresponds to the mean if α have value$1 < \alpha \leq 2$. It always has value ($\delta \in \mathbb{R}$).

It is difficult to provide a simple estimation technique for parameters of alpha-stable distribution due to lake of analytical expressions for most of its densities. There are several methods proposed in literature for this purpose e.g. Maximum likelihood methods, quantile methods and characteristic function based method [13].

In [4], Moe Z. Win et. al. have represented an estimation method for α the index of stability and σ scale/dispersion parameter as:

$$\alpha = \frac{2}{b} \tag{6}$$

$$\sigma = \lambda\pi C_{2/b}^{-1} E\left\{\left|Q_{i,n}\right|^{2/b}\right\} \tag{7}$$

where b is channel attenuation coefficients, λ is density of interferers, Q_i represent an arbitrary quantity which is associated with interferer i and C_α is defined as

$$C_\alpha \triangleq \begin{cases} \frac{1-\alpha}{\Gamma(2-\alpha)\cos(\pi\alpha/2)} & ; \quad \alpha \neq 1 \\ \frac{2}{\pi} & ; \quad \alpha = 1 \end{cases} \tag{8}$$

where $\Gamma(.)$ denotes gamma function.

5. SIMULATION RESULTS

In this paper, we have analyze the performance of OFDM based wireless communication system with Gaussian noise and alpha-stable noise. All the simulations are performed in Matlab and these techniques are also applied to the wireless sensor network simulating tool called CupCarbon.

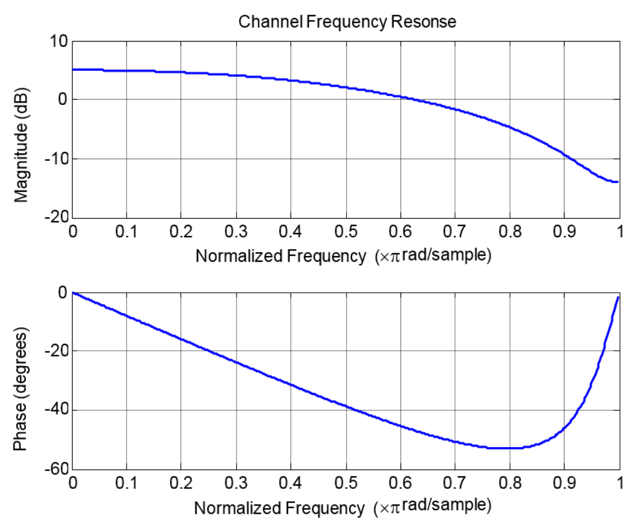

Figure 8. Channel frequency response for [1 0.8].

Figure 8 shows the frequency response of wireless channel that is used in OFDM transceiver. Frequency response of the channel shows the magnitude and the phase of the channel as the function of frequency, so on the x-axis we have normalized frequency and on the y-axis we have magnitude and phase of the channel, consecutively. We have considered two channel taps [1 0.8] taken from [15].

Figure 9(a) shows the BER of an OFDM system with Gaussian noise. The horizontal axis shows the E_b/N_0 (normalized SNR) in dBs. The vertical axis shows the bit error rate BER of an OFDM system. Simulations were performed 10,000 times for BER value and then we averaged them out for the better understanding of our system performance. From the graph we can observe that the minimum BER value at $\frac{E_b}{N_0} = 0\ dB$ is $10^{-2.68}$ and for the maximum BER value at $\frac{E_b}{N_0} = 10$ (in this case) is $10^{-3.285}$. We take the E_b/N_0 vector values from 0 to 10 in dBs.

Figure 9(b) shows the packet error rate PER of an OFDM system with Gaussian noise in WSN scenario. The horizontal axis shows the E_b/N_0 (normalized SNR or energy per bit per noise ratio) in dBs. The vertical axis shows the packet error rate PER. These simulations were also performed 10,000 times for PER value and then we average out the PER result for the better understanding. From the graph we can see that for the value of E_b/N_0 from 0 dBs to 6.8 dBs the PER has constant value (10^0) after this it shows the decaying effect till the value of $\frac{E_b}{N_0} = 10\ dBs$.

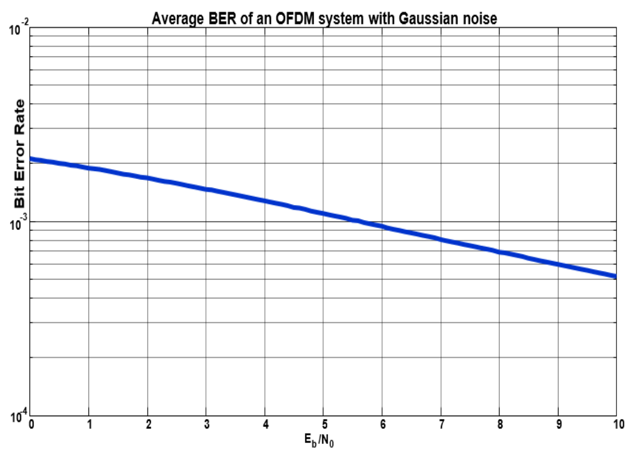

Figure 9(a). BER performance of OFDM system with Gaussian noise in WSN applications.

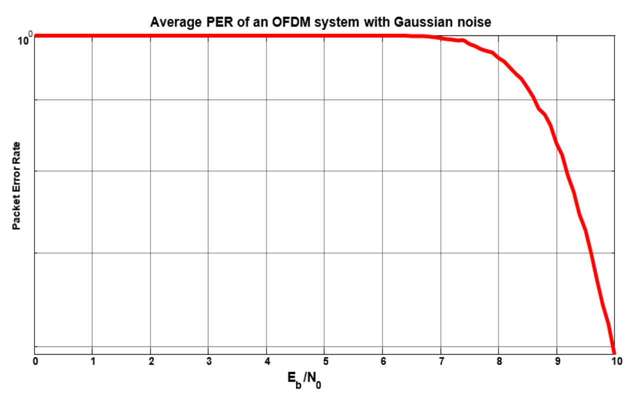

Figure 9(b). PER performance of OFDM system with Gaussian noise in WSN applications.

Figure 10(a) shows the BER of an OFDM system with alpha-stable noise in WSN scenario. The horizontal axis shows the value for $\log(\frac{1}{sigma})$, sigma σ is dispersion parameter of alpha-stable distribution. Dispersion parameter σ and performance of the system have inversely proportional to each other. As the value of σ increase the performance of communication system will decrease which means that communication system will have more bit errors. We have flip the sigma σ values for this graph to make it more understandable. The vertical axis shows the bit error rate BER of an OFDM system. Simulations were performed 10,000 times for BER value and then we averaged them out for the better understanding of system performance.

Figure 10(b) shows the packet error rate PER of an OFDM system with alpha-stable noise. The horizontal axis shows different values of $\log(\frac{1}{sigma})$. The vertical axis shows the packet error rate PER of an OFDM system with alpha-stable noise. These simulations were also performed 10,000 times for PER value and then we average out the PER result for its better understanding.

Values of other parameters of alpha-stable distribution for the BER and PER performance are index of stability $\alpha = 0.5$, skewness parameter $\beta = 0$ and location parameter $\delta = 0$.

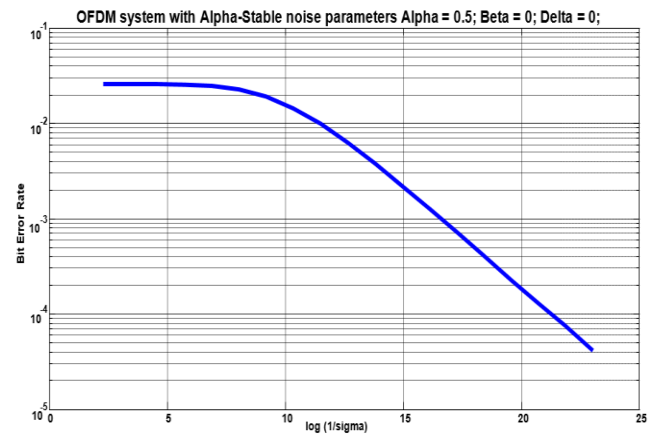

Figure 10(a). BER performance of OFDM system with alpha-stable noise in WSN applications.

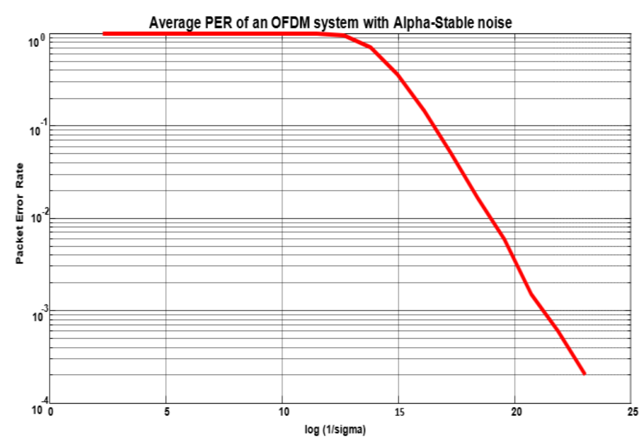

Figure 10(b). PER performance of OFDM system with alpha-stable noise in WSN applications.

5.1 CupCarbon: A WSN Simulator

CupCarbon is a WSN simulator which is recently developed by researchers of Lab-STICC. This simulator also takes into account the real time signal propagation and interference effects [16-17]. We have tested OFDM based communication system with alpha-stable channel noise in CupCarbon and analyzed that this can give us the real time interference realization. We have utilized Carrier

Sense Multiple Access (CSMA) MAC protocol that is embedded in CupCarbon. According to CSMA protocol, if data packet delivers at the destination node then it will send an acknowledgment ACK message to sender node, otherwise sender/transmitter node will wait for time S and will retransmit the data packet and will repeat this procedure for three times.

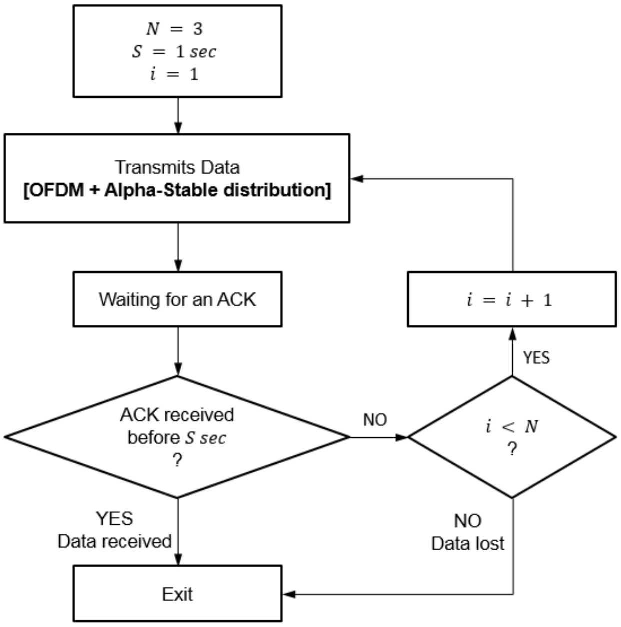

Figure 11. Flow chart for node to node data transmission in CupCarbon.

Figure 11 shows the flow chart to explain the mechanism that is used in CupCarbon. Where N shows the number of times a transmitter can resend the data packet to receiver node. S is the waiting time in seconds for the acknowledgement from the receiver node and i is a loop variable. A node will transmits data to another node in the network and will wait for $S = 1\,sec$ for ACK response. If transmitter node receives the ACK message from the receiver node in $\leq 1\,sec$ then it will either continue the communication by sending next data packets or exit the communication otherwise transmitter node will resend its previous data packet assuming that it was lost in first place. Transmitter node can retransmit the data packet to the receiver for maximum of $N = 3$ times and will wait for the ACK response for $S = 1\,sec$ after each transmission. If ACK message from the receiver will not receive at transmitter node then the receiver node will considered a dead node.

Figure 12 depicts the packet delivery realization of an OFDM based system in case of alpha-stable noise. In this case, we have considered two sensor nodes $S3$ and $S4$ in the urban environment and both nodes are within the radio range of each other in a wireless sensor network. Right up part of the Figure 12 shows that node $S3$ have initialized the communication and transmits data to node $S4$ over the wireless medium, transmission of data is marked by red arrow in direction from node $S3$ to node $S4$. Right bottom part of the Figure 12 shows that node $S4$ has successfully received data from node $S3$ and send him an ACK message which is marked by black arrow in the opposite direction. According to the retransmission algorithm that is also shown in Figure 11. This transmission over the wireless channel can be effected by impulsive noise and can face four different cases as shown in left part of the Figure 12, which are explained below:

- Case 1: node $S4$ will successfully receives data in first transmission by node $S3$ and will send an ACK message back to transmitter node.
- Case 2: node $S4$ will receive the data in second retransmission by node $S3$ and will send an ACK message back to transmitter node.
- Case 3: node $S4$ will receive the data in third retransmission by node $S3$ and will send an ACK message back to transmitter node.
- Case 4: if $S3$ will not receive ACK message from node $S4$ within $S = 1\,sec$, then after third retransmission of data it will declare node $S4$ as a dead node and will not make any communication link in future.

We have used alpha-stable distribution parameters with values index of stability $\alpha = 1.8$, skewness parameter $\beta = 0$, dispersion parameter $\sigma = 0.001$ and location parameter $\delta = 0$ in the simulation of a wireless sensor network using CupCarbon.

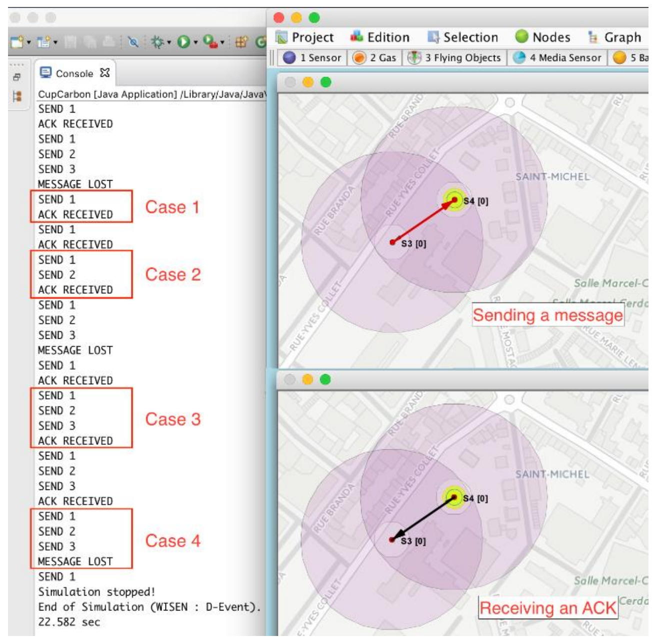

Figure 12. Data transmission and Acknowledgment message visualization in CupCarbon.

6. CONCLUSION

In this paper, we have proposed an optimal way to integrate and include a PHY layer based on OFDM in the CupCarbon simulator and we have also considered the alpha-stable network interference impact on wireless communications in WSN applications. First, we study the behavior of wireless communication system with Gaussian noise and alpha-stable interference and then evaluates its performance in terms of bit error rate (BER) and packet error rate (PER) in Matlab. We modeled the network interference using Gaussian distribution and alpha-stable distribution functions for a flexible and accurate representation of wireless channel. This allows us the better estimation of wireless channel. We then include the PHY layer and the alpha-stable interference model in CupCarbon simulator to have an accurate evaluation of the wireless sensor network behavior.

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