DETERMINATION of GENERAL PARAMETERS of WSNs DESIGNED for 3-D CLOSED ENVIRONMENTS

E. Gunduzalp, G. Yildirim and Y. Tatar

Abstract—**Use of Wireless Sensor Networks (WSNs) has become widespread in many critical environments. For example, this technology has come into use in tunnels, mines and so on. In this kind of environments, a WSN system design must be far away from randomness and be done systematically. Therefore simulators play a significant role in a WSN system design. Success of a simulator affects directly success of the system. In this paper, we preferred Castalia simulator which is a successful WSN simulator based on OMNET. Many parameters such as different data size, indoor environment features, and various transmission power levels etc., which have an effect on packet reception ratio (PRR), were examined by Castalia. Finally, we explain how to design a WSN system, and what should be considered in a WSN simulation.**

Index Terms— **Wireless Sensor Networks, Path loss model, simulator, Castalia**

I. INTRODUCTION

WIRELESS Sensor Networks (WSNs) are network technologies used for measuring various physical phenomenon such as humidity, temperature, pressure etc. They communicate generally through radio frequency (RF). In RF propagation, some factors such as distance, reflection, absorption, scattering and other RF signals lead to three important effects; path loss, shadowing and multi-path effects. The three effects have to be taken into consideration in a wireless channel modelling.

Today, we have seen many WSN systems that are deployed in closed critical environments like tunnels, mines. Technical features, locations of sensor nodes and environmental parameters of the area directly affect the performance of the system. Therefore simulations are of paramount importance to detect unanticipated results in a system design. There are some significant features in applications in which environment modelling is important. Some of these features are wireless channel model, radio model, MAC support, adoption and scalability. Naturally, a WSN simulator is supposed to have these models.

In this paper, we show some general steps to be considered in design of a WSN system, which is especially deployed in closed environments. For this, we used OMNET++ based Castalia simulator and different scenarios.

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II. RELATED WORK

Castalia is an effective simulator for analysis of various layers of WSNs. For example, the method presented in [1] hides location privacy of resources, and its effect on energy efficiency is observed by Castalia. In [2], a design of Collection Tree Protocol – CTP- and its performance are evaluated with the help of Castalia. In another study, [3], the energy performance of an algorithm that keeps track of mobile nodes is analyzed by it. On the other hand, analyses of various routing algorithms can be done by using the simulator. To give an example, in [4], the success of the RBR (Resource Biased Routing) algorithm is shown by Castalia. In another study, [6], the RPL algorithm, which has gotten famous through IPv6, and the LOADng algorithm are compared on Castalia simulations. A framework called PASES, which is designed to evaluate energy performances in WSNs, is run on Castalia in [7]. Castalia also claims to be successful in WBAN applications. A study [8] does a performance test for evaluating various WBAN MAC protocols. A comprehensive survey about some WSN simulators and their general features can be found in [5].

III. CASTALIA

OMNET++ is a discrete event network simulator, which is based on object oriented and modular as well. Many communication networks can be modeled by it. The C/C++ support provides programmers with a flexible design platform [9]. Castalia is based on OMNET++, and enable to make detailed simulations of WSNs, WBANs and networks consisting of embedded device with low-energy consumption. Researchers are able to test their own protocols and algorithms with a real-like wireless channel, radio unit and node models in it [10]. A network in Castalia is composed of various sub-modules.

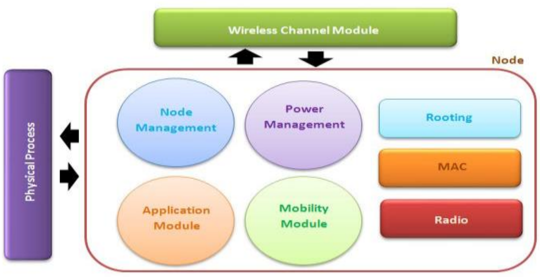


Figure1. The modules in Castalia

The main modules are wireless channel module, node module and physical operation modules. The node module is a composite module and consists of different sub-modules shown in Fig.1.

The radio propagation model of Castalia is modelled in the wireless channel module. As known, in a radio propagation, distance, reflection, absorption, scattering and other radio signals give rise to three important effects; path-loss, shadowing and multi-path effect. Since the effects have direct influence on radio signals, communication quality will be directly affected by them. There are many approaches concerning modelling of radio propagation in literature. Therefore, success of simulators rests on the choice of an appropriate and real-like propagation model. Castalia, which uses the log-normal shadowing model as default, provides a successful wireless channel model. As known, absorption, scattering and multi-path effects make signal estimation quite difficult in a radio propagation model. In this field, the log-normal shadowing model has proven itself to be successful [13]. The model computes possible random losses of a signal according to Eq.1 [12]. In the equation, PL(d) is total reduction of the signal power at distance “d”, expressed as dBm. While PL(d0) represents “reference path loss” for a known distance “d0”, the second term represents “path loss” depending on the distance. The third terms is a Gaussian random variable modelling shadowing effect,the modelling of which is difficult.

$$PL(d) = PL(d_0) + 10\eta log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \quad (1)$$

X_σ is computed according to the Gaussian function in Eq.2 [12-13].

$$X_\sigma = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(X-\mu)^2}{2\sigma^2}} \quad (2)$$

Where, μ is zero, and standard deviation - σ and coefficient – η depend on environment conditions, which are calculated experimentally in many studies in literature [11].

Castalia includes many features to provide the radio model with low-energy consumption. In addition, Castalia allows users to define their own radio file in a standard format.

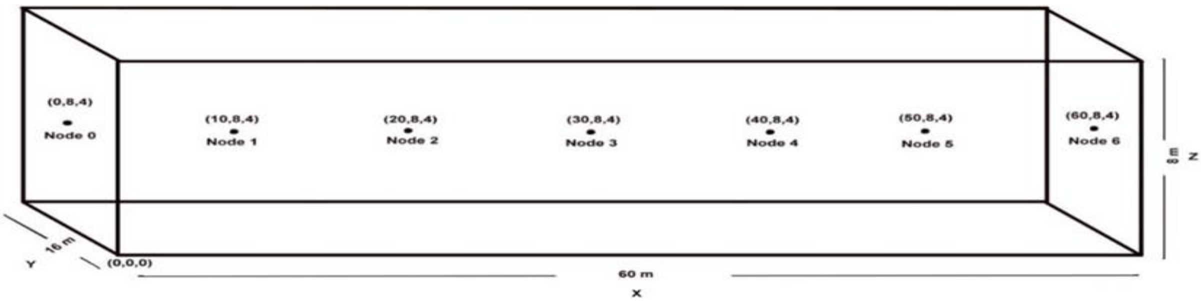
A MAC layer is an important part of a WSN, which explains accesses of nodes to a communication media. Four well-known MAC modules are can be used in Castalia [10]. Those are;

- *Tunable MAC*
- *TMAC and SMAC*
- *IEEE 802.15.4 MAC*
- *IEEE 802.15.6 MAC (Baseline BAN MAC)*

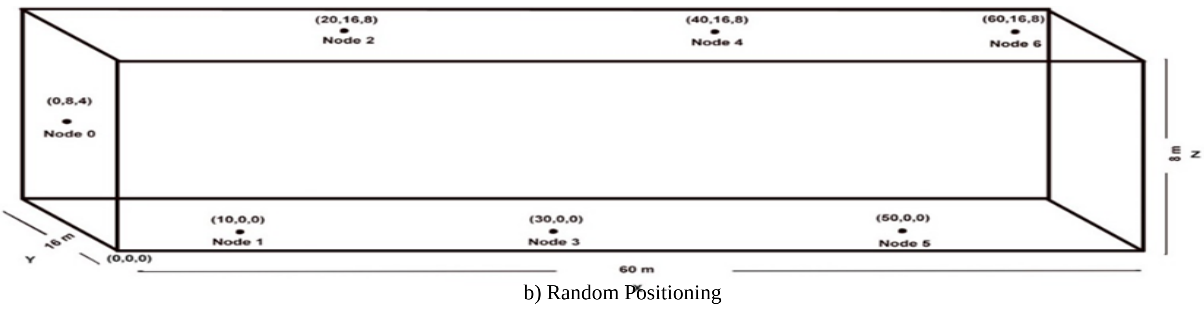
In comparison to the MAC and the physical modules, the routing module of Castalia is weaker [10]. On the other hand, Castalia allows users to design their own routing modules just like the other modules.

IV. IMPLEMENTATION

In the study, a 3D closed area whose dimension is (60, 16, 8) m was modelled for the simulations. Depending on scenarios selected, seven nodes whose interactions would be observed were placed in various coordinates in the area. Since the aim of the study was to show general steps of a WSN simulation, the environment conditions were considered ideal, and non-interference model was used. In the scenarios, the nodes were placed in the area as shown Fig.2 a, and b. In the scenarios, the “Node 0”, broadcasting packet every second, sent totally 500 packets to the others.



a) Horizontal



b) Random Positioning

Figure 2. The deployment of the sensor nodes according to the scenarios

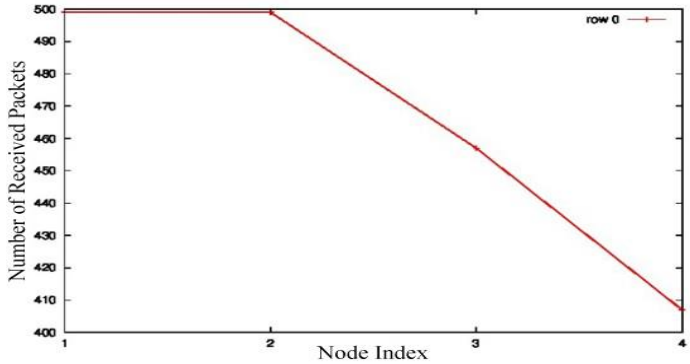
In the scenarios that used the CC2420 radio and the byPassMAC, PRR variations were observed for different Tx output powers, radio sensitivities, data payload sizes and log-normal shadowing model parameters. At first, η, the environment parameter, was selected as 2.4, representing default value for a closed area, but then the system was tried again for the other η values shown in [11] to check the validation of the WSN. A collision-free model was preferred in the experiments. In addition, the Link Quality Indicators - LQIs - of the sensor were achieved and used as comparison values. The parameters of the CC2420 radio used in the simulations are given in Table I.

TABLE I. THE PARAMETERS OF CC2420

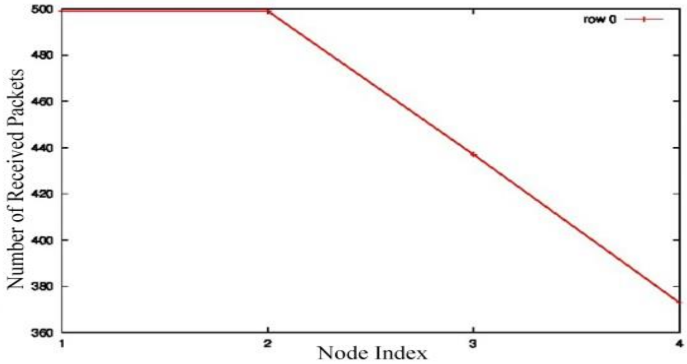
Data Rate (kbps)	Modulation Type	Bits Per Symbol	Band width (MHz)	Noise Bandwidth (MHz)	Noise Floor (dBm)	sensitivity (dBm)	Power Consumed (mW)
250	PSK	4	20	194	-100	-95	62

A. PRR Variation for various Tx power levels

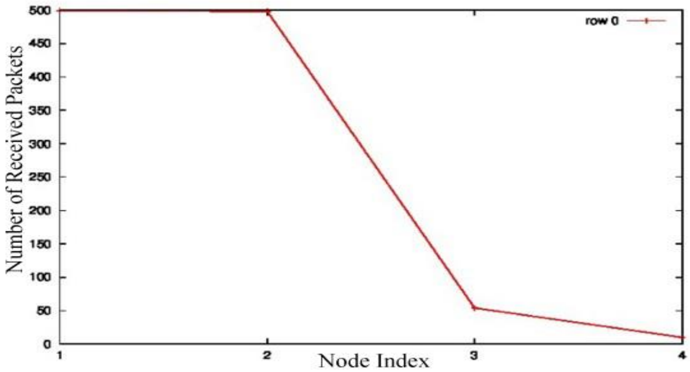
The aim in this experiment is to find the optimum Tx power and an average node distance (d_av). For this, the sender Node 0 broadcasted periodically with powers of 0 dBm, -3 dBm and -7 dBm respectively. The PRR variation of the nodes for the Tx powers were obtained as in the Fig 3 a-f.



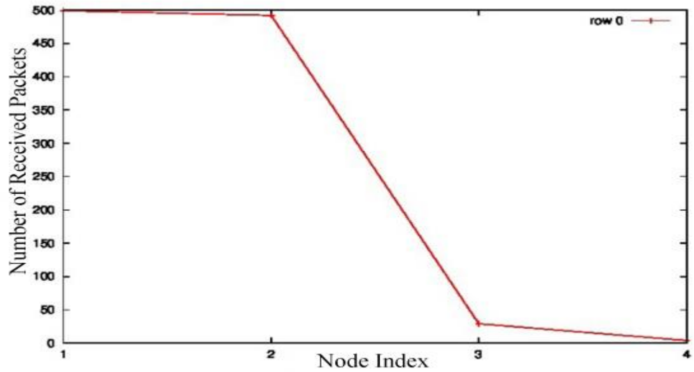
a) Horizontal, Tx = 0 dBm



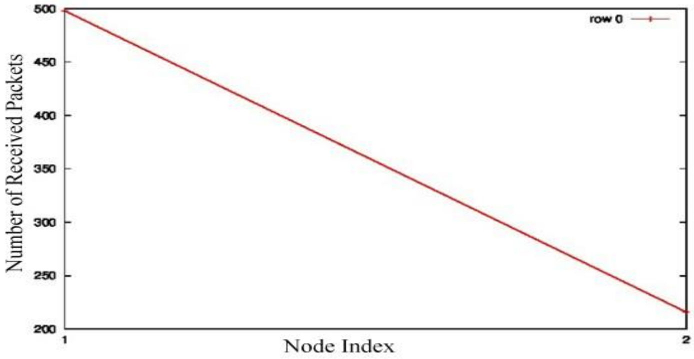
b) Random, Tx = 0 dBm



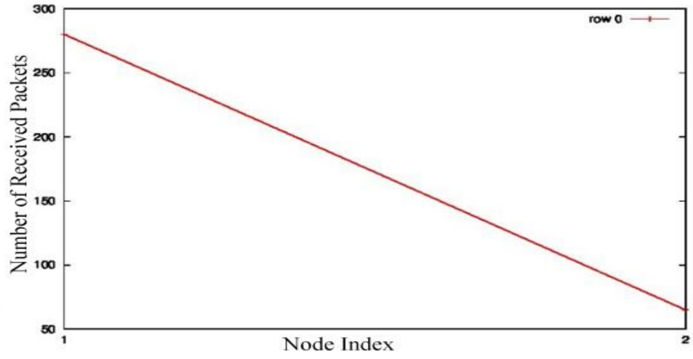
c) Horizontal, Tx = -3 dBm



d) Random, Tx = -3 dBm



e) Horizontal, Tx = -7 dBm



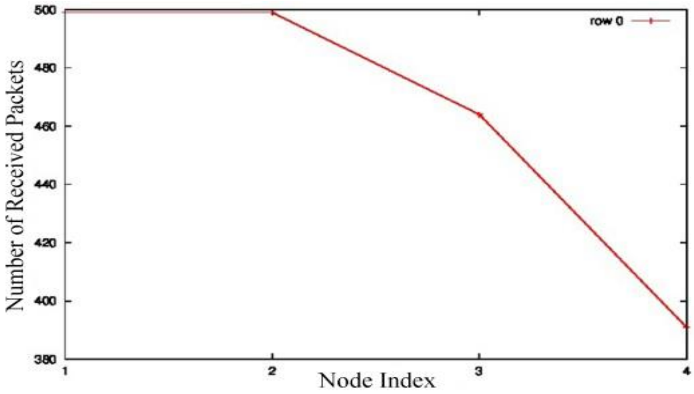
f) Random, Tx = -7 dBm

Figure 3. The PRR Variations for various Tx power levels

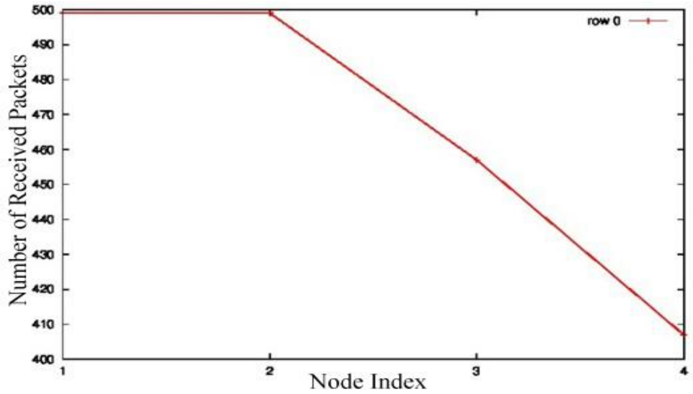
Since WSNs are generally multi-hop applications, distance between sensors nodes is important. This will affect directly the energy efficiency and performance of the system. As it is understood from the figures above, Tx= -3 dBm output power seems suitable for a distance of 20 m in both the horizontal and the random scenarios. Thus a gain of 3 dBm can be achieved compared to Tx=0 dBm, which provide an energy saving.

B. PRR Variation for various radio sensitivities

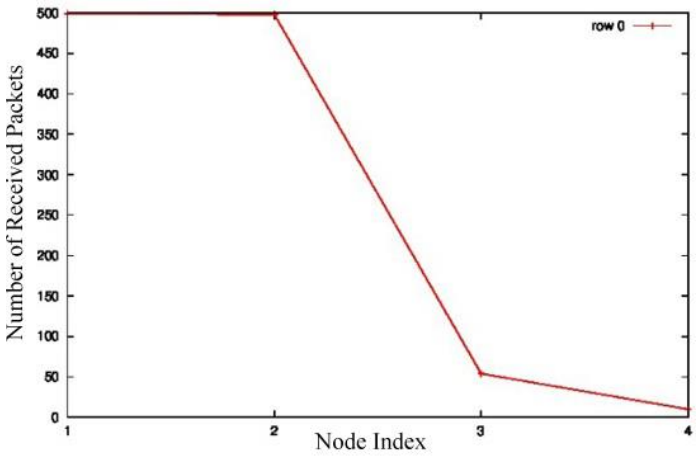
Radios with receiver sensitivity of between -95 dBm and -110 dBm have been frequently used in practical applications. In the experiments, the PRR variations were observed for the two sensitivity values in the both scenarios. The Tx powers used are 0 dBm, -3dBm and -7 dBm. The PRR values of the experiments are shown in Fig.4 a-m.



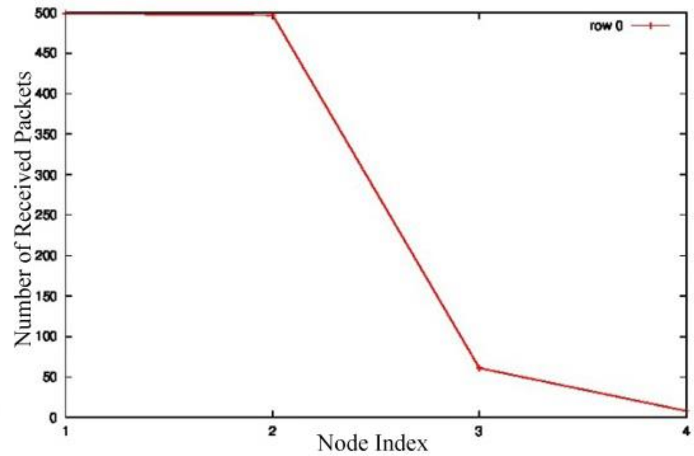
a) Horizontal, Tx = 0 dBm, sensitivity= -95 dBm



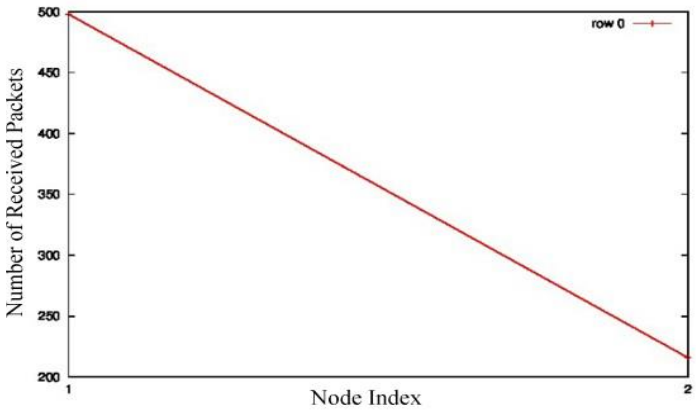
b) Horizontal, Tx = 0 dBm, sensitivity= -110 dBm



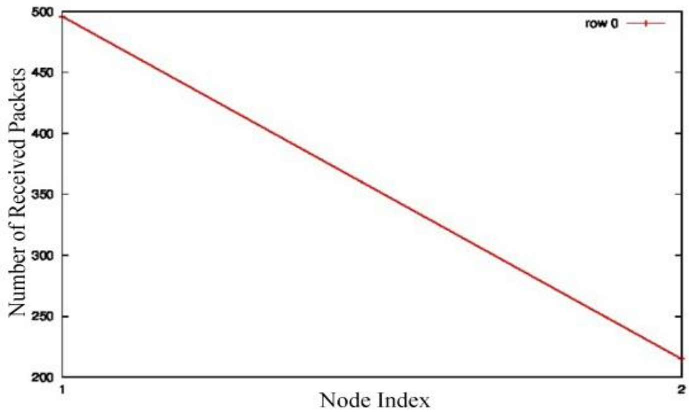
c) Horizontal, Tx = -3 dBm, sensitivity= -95 dBm



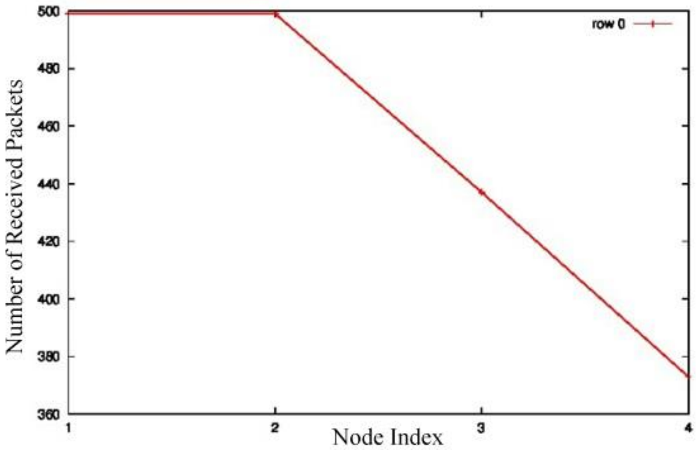
d) Horizontal, Tx = -3 dBm, sensitivity= -110 dBm



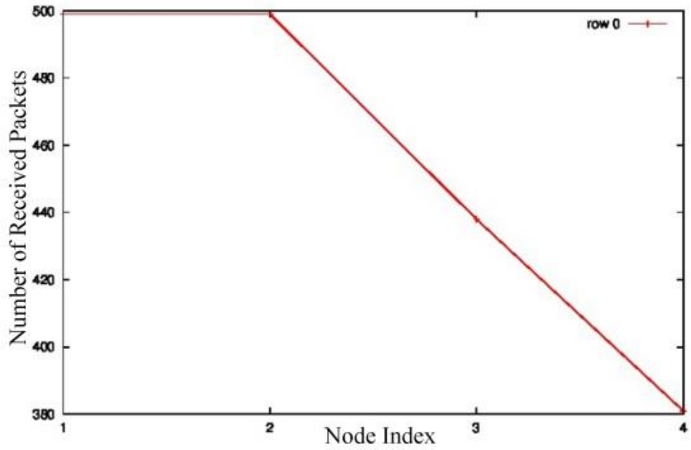
e) Horizontal, Tx = -7 dBm, sensitivity= -95 dBm



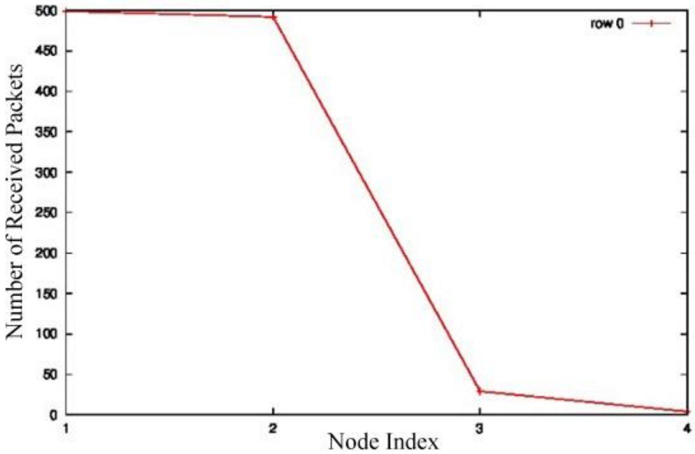
f) Horizontal, Tx = -7 dBm, sensitivity= -110 dBm



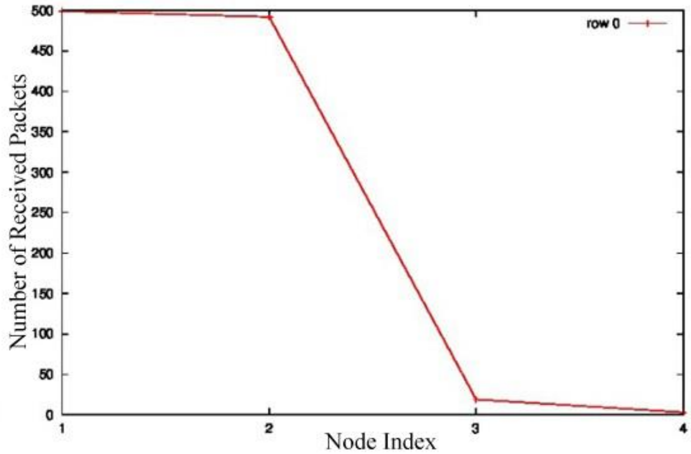
g) Random, Tx = 0 dBm, sensitivity= -95 dBm



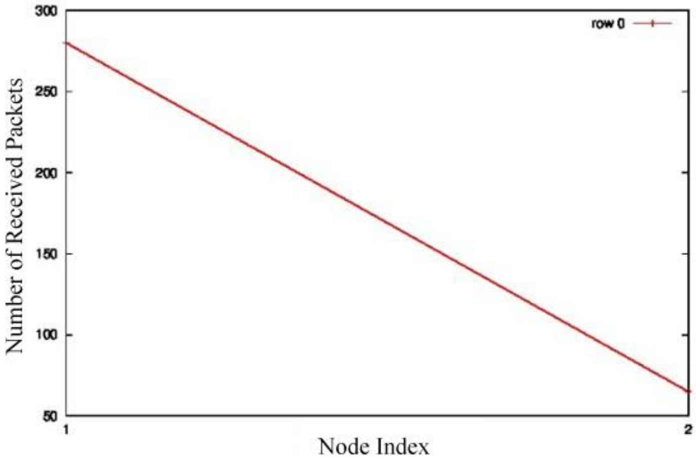
h) Random, Tx = 0 dBm, sensitivity= -110 dBm



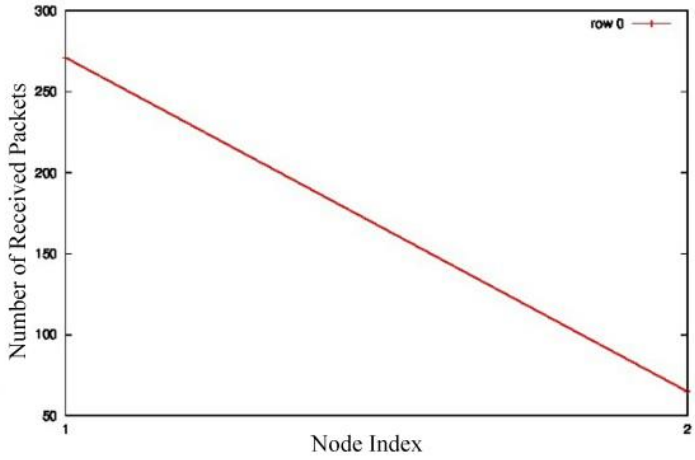
j) Random, Tx = -3 dBm, sensitivity= -95 dBm



k) Random, Tx = -3 dBm, sensitivity= -110 dBm



l) Random, Tx = -7 dBm, sensitivity= -95 dBm



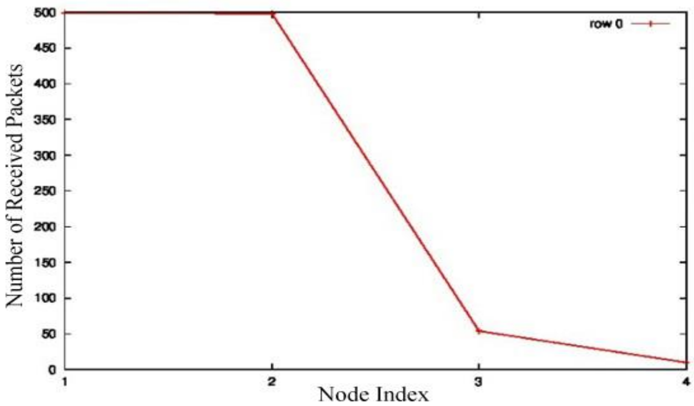
m) Random, Tx = -7 dBm, sensitivity= -110 dBm

Figure 4. The PRR Variation for radios with various sensitivities

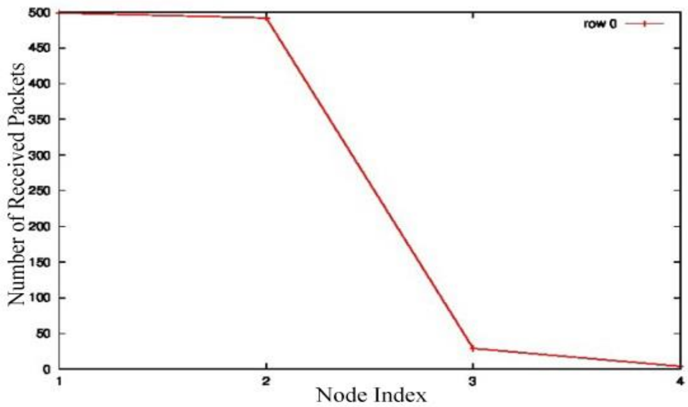
As it is seen in the Figures, there is not important difference in the PRR variations for the both receive sensitivities. Accordingly, a radio with sensitivity of -95 dBm is adequate for a WSN system, which has nodes with -3 dBm Tx power and a d_av of about 20 m. Thus, when it is considered that more sensitive radios are expensive, there is no need additional cost for the selected values aforementioned.

C. PRR Variation for various data payload

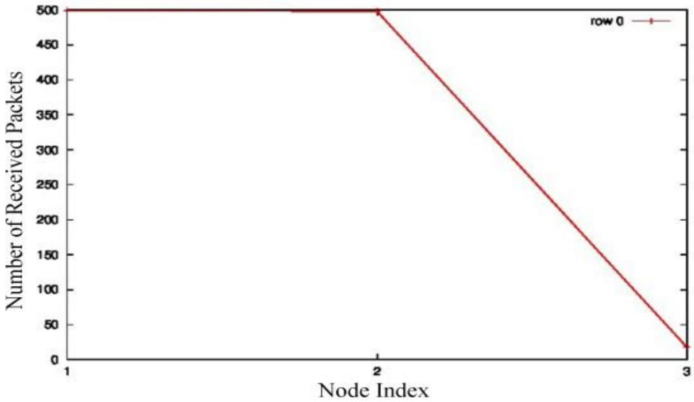
Payload size is a performance criterion in a WSN system. For example, the 802.15.4 standard states that 1% PRR must be achieved in -85 dBm receiver sensitivity and 20 byte payload [10]. In the experiment, different payload (20, 50 and 80 byte) was used for the given Tx, d_av values. The results obtained are given in the Fig.5 a-f. As it is seen from the Figures, increase in the payload doesn't affect the performance a lot for the multi-hop system running with the given parameters.



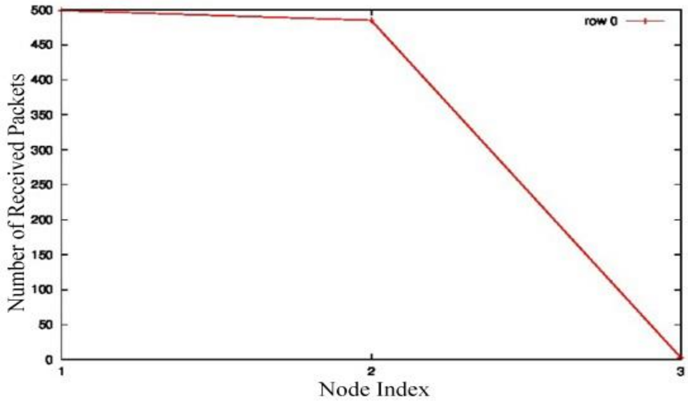
a) Horizontal, Tx = -3 dBm, payload = 20 byte



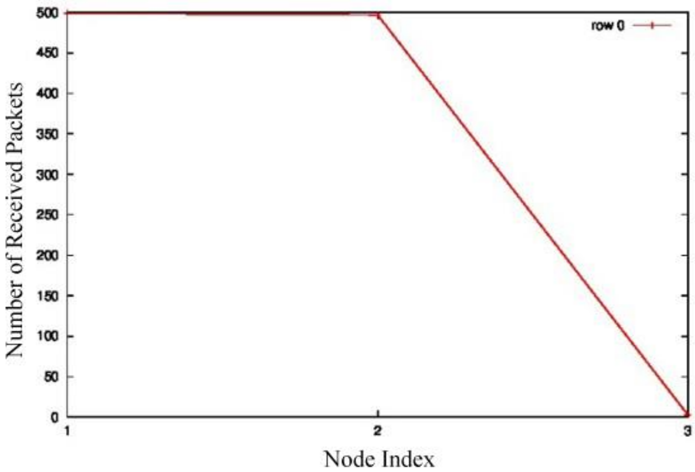
b) Horizontal, Tx = -3 dBm, payload = 20 byte



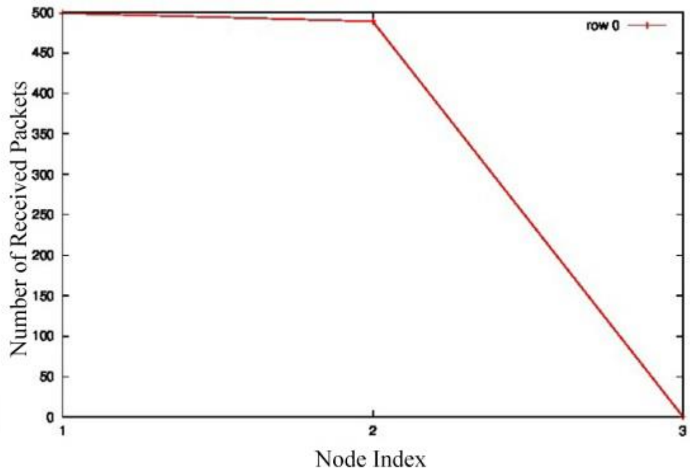
c) Horizontal, Tx = -3 dBm, payload = 50 byte



d) Horizontal, Tx = -3 dBm, payload = 50 byte



e) Horizontal, Tx = -3 dBm, payload = 80 byte

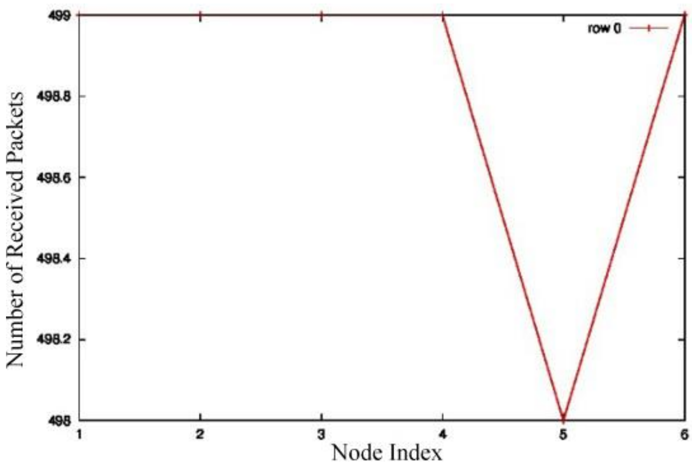


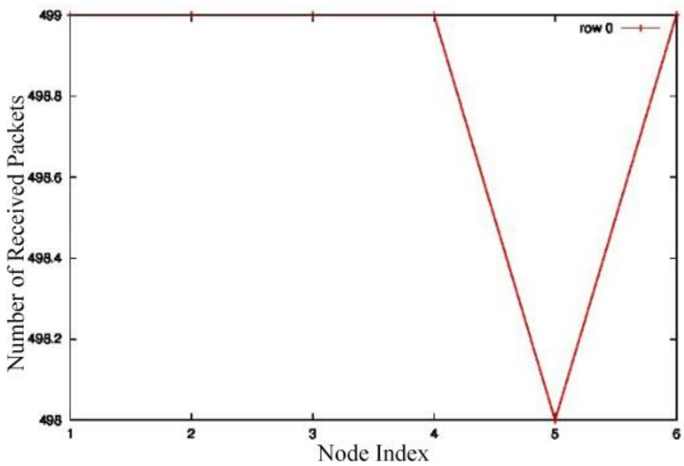
f) Horizontal, Tx = -3 dBm, payload = 80 byte

Figure 5. PRR Variation for various data payload

D. PRR Variation for various η values

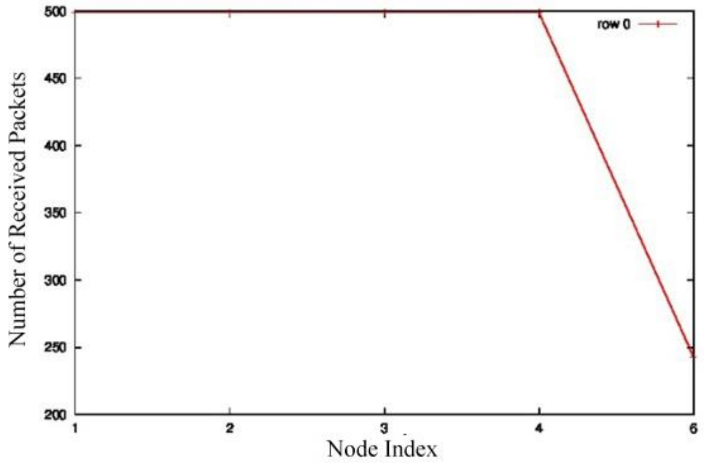
The parameters *η and σ in* Eq.2 are coefficients, and varies by environmental conditions. In literature, the *η* parameter is between 1.6 (LoS) and 2.4 in free-space building. Since the environment was considered ideal and free space, the selected parameters were tried for *η=1.6, 2 and 2.4.* The *σ* was selected between 0 and 13. The results are shown Fig.6 a-n. But it shouldn't be forgotten that a system must be tested in a real-like parameters, so the environmental features must be known in advance. As seen in the Figures, the system can run seamlessly for Tx=-3dBm, d_av=20 m and the *η – the σ* values.

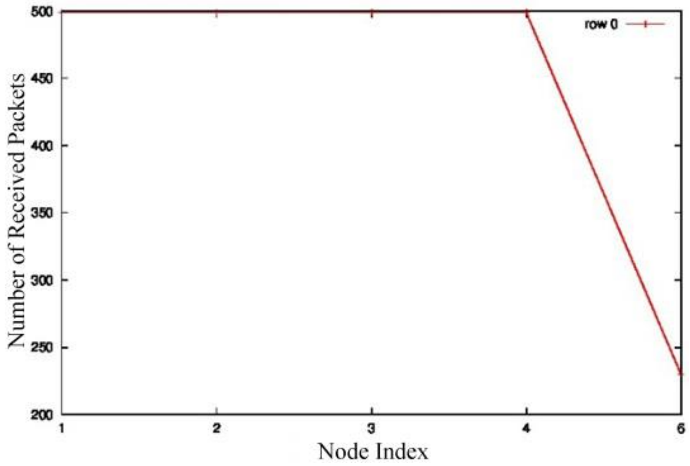




a) Horizontal, Tx = -3 dBm, η = 1.6, sigma(σ) = 4

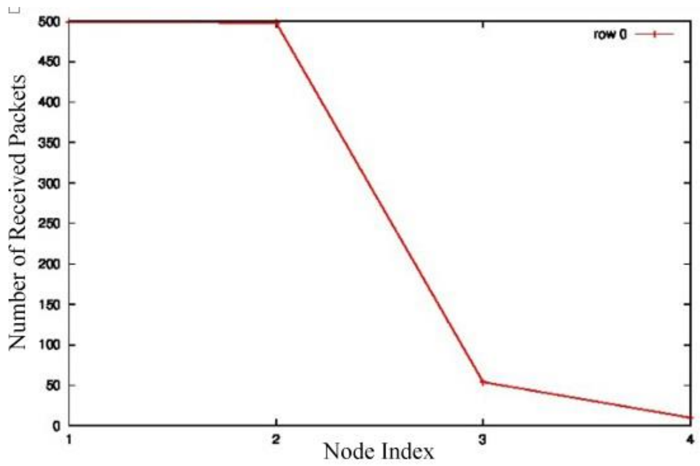
b) Random, Tx = -3 dBm, η = 1.6, sigma(σ) = 4

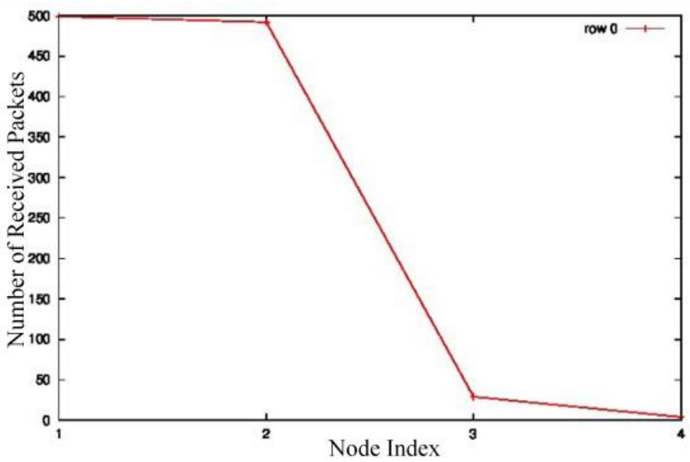




c) Horizontal, Tx = -3 dBm, η = 2, sigma(σ) = 4

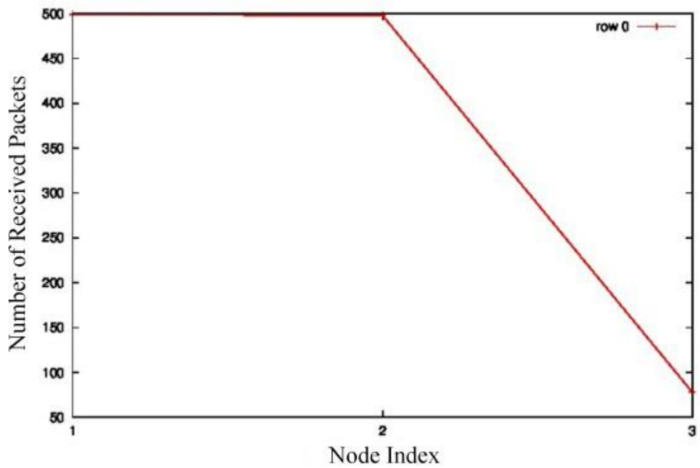
d) Random, Tx = -3 dBm, η = 2, sigma(σ) = 7

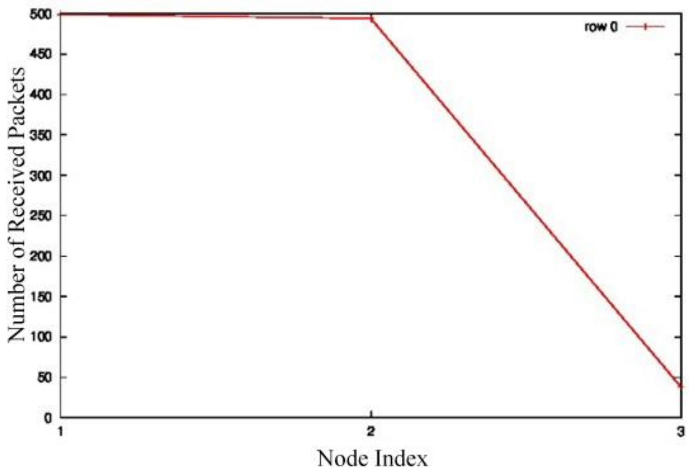




e) Horizontal, Tx = -3 dBm, η = 2.4, sigma(σ) = 7

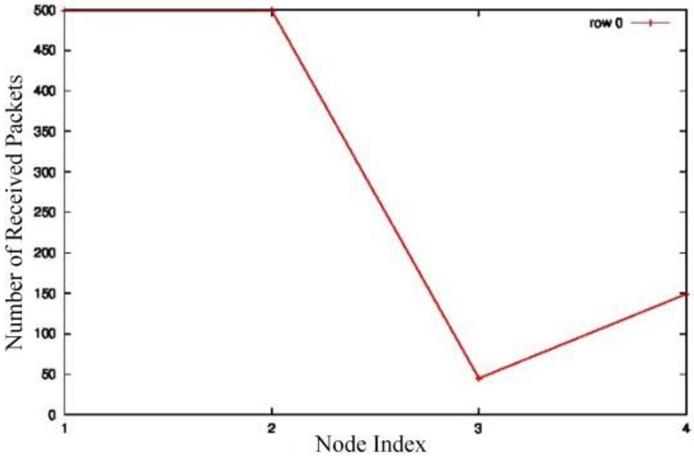
f) Random, Tx = -3 dBm, η = 2.4, sigma(σ) = 10



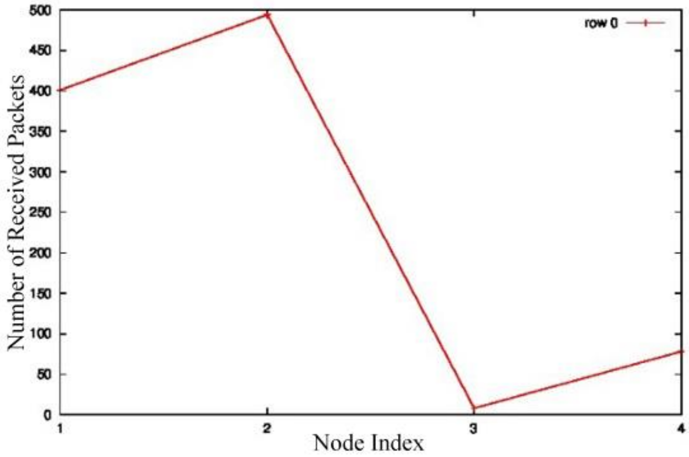


g) Horizontal, Tx = -3 dBm, η = 1.6, sigma(σ) = 0

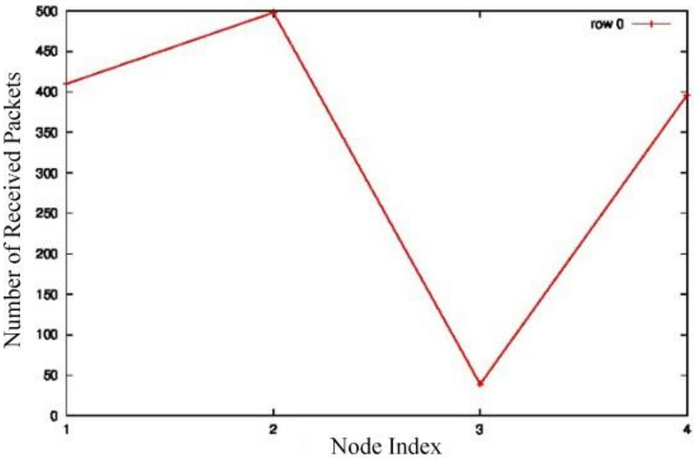
h) Random, Tx = -3 dBm, η =1.6, sigma(σ) = 0



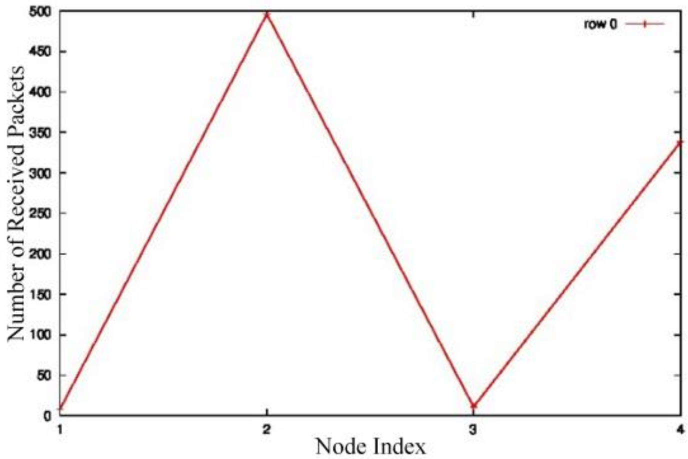
i) Horizontal, Tx = -3 dBm, η = 1.6, sigma(σ) = 7



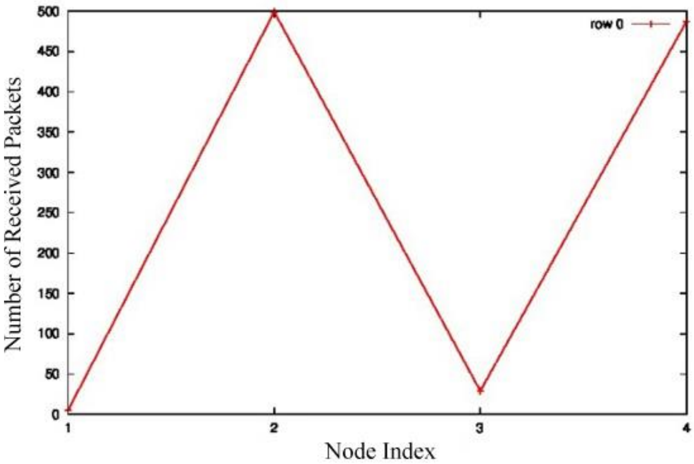
j) Random, Tx = -3 dBm, η =1.6, sigma(σ) = 7



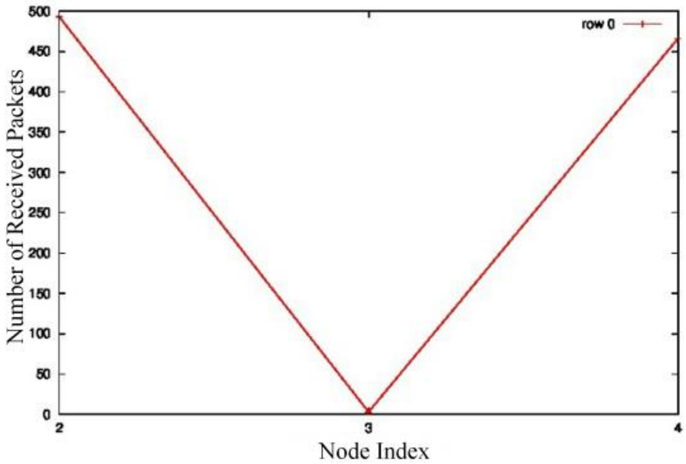
k) Horizontal, Tx = -3 dBm, η = 1.6, sigma(σ) = 10



l) Random, Tx = -3 dBm, η =1.6, sigma(σ) = 10



m) Horizontal, Tx = -3 dBm, η = 1.6, sigma(σ) = 13



n) Random, Tx = -3 dBm, η =1.6, sigma(σ) = 13

Figure 6. PRR Variation for various n and sigma(σ) values

TABLE II. THE LQI TABLE

Receiver / Transmitter	**node=0** Sen1/Sen2	**node=1** Sen1/Sen2	**node=2** Sen1/Sen2	**node=3** Sen1/Sen2	**node=4** Sen1/Sen2	**node=5** Sen1/Sen2	**node=6** Sen1/Sen2
index=0	*0/0*	*100/100*	*99/99*	*99/99*	*100/100*	*69/64*	*100/100*
index=1	*100/100*	*0/0*	*100/100*	*100/100*	*100/100*	*100/100*	*100/100*
index=2	*100/100*	*100/100*	*0/0*	*100/100*	*100/100*	*100/100*	*100/100*
index=3	*100/100*	*100/100*	*100/100*	*0/0*	*100/100*	*100/100*	*100/100*
index=4	*100/100*	*100/100*	*100/100*	*100/100*	*0/0*	*100/100*	*100/100*
index=5	*89/87*	*100/100*	*100/100*	*100/100*	*100/100*	*0/0*	*100/100*
index=6	*100/100*	*100/100*	*100/100*	*100/100*	*100/100*	*100/100*	*0/0*

E. LQI Values

LQI tables can provide supplementary information about the performance evaluation. Accordingly, their analysis may be useful from technical point of view. In the scenarios, each node, positioned horizontal and random as in Fig2, sent 100 packets. In Castalia, each node has a table for recording LQI values. When a node receives a packet, the sender of which is known, it increases the counter of the sender. In the study, the LQI table obtained from the experiments is given in Table 2. As seen in the table, the LQI values validated the PRR values obtained according to the values chosen.

V. CONCULUSION AND DISCUSSION

For a good performance pre-assessment, some main parameters of a WSN system designed must be chosen well. The parameters affect directly the life time of the WSN, the energy consumption, the network traffic, data loss and so on. Some of the parameters are the transmission power, the receiver sensitivity and the environments parameters. In the paper, simulation of a WSN system deployed in a 3D closed area and the selection of its parameters were carried out. For this, Castalia simulator and two different scenarios were used. In the study, the PRR variations were observed for different Tx powers, different payloads, different receiver sensitivities and various environment parameters. In addition, the LQI table of the experiment was presented for comparison. As a result, the optimum parameters of the WSN and the closed area were specified. Thus, a design model approach, far from randomness, and its steps were presented shortly. Also the effect of the main parameters on the result was shown. Although the used features are not all parameters to be considered for a WSN design, they must be always taken into account. With various combinations and interference models, these experiments can be diversified.

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