Energy Model in an Open Hardware Wireless Sensor Network

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2014 Published by $\mathcal{DIFU}_{100}ci@$ http://nautilus.uaz.edu.mx/difu100cia

Abstract

Energy model and the characterization of the coverage of the link of a wireless sensor network of open hardware are presented. Measurements of energy consumption of the WSN are shown using different power levels of RF transmitter. Characterization as well as telemetry measurements were performed in open countryside on a network of sensors with wireless connectivity using 63mw xbee pro whip antenna modules. Readings are performed in rough topography, warm temperate climate; the data collecting was recorded in summer, sensors modules assumed in the area of geo-position. Established connectivity, bursts of data were sent and returned to the module Coordinator. The testing shows that according the experiment, a distance of 300 meters between nodes is the best option to keep the reliability of the link.

Keywords:, energy model, coverage, sensor network, telemetry.

1. Introduction

The field of wireless sensor networking, WSN, has had a boom in the last decade in different areas of human development. In these systems of most current concepts of technological development have applied at different stages that make a node, which is the basic element for the operation of these networks. See Figure (1). In the community of digital systems has aroused interest to face the problems of agricultural fields the sensing and actuation with existing technological resources; essentially, in the prediction of frost to establish strategies that will reduce the impact in such a way that its effects are not devastating in the cycle of harvesting [1]. Before these climatic and topographic conditions, the scientific community must cope with novel and innovative proposals, the attenuation of the impact and its effects through the autonomous monitoring of this climatic condition, as well as activate a response that will anticipate the sudden changes in climate and active in time and form the most effective procedure. Since a crop has extensive area and is regularly immersed in irregular topography, such solutions are not in current scientific literature. These extensive areas of cultivation occupy large regions which make the readings of the environmental parameters are not accurate and indicate variations in the recording. Such readings serve small portions of land area whose unique and unrepeatable features enable you to define them as areas of micro-climates. When an area has low temperatures freeze process has started, it is here where the remote sensing can monitor these regions and prevent the effects during the progress of time before the phenomenon of frost covers the entire area.

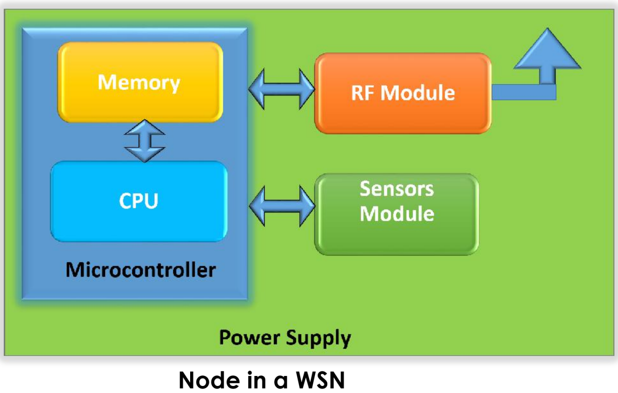

Figure 1. Main elements in a wireless sensor network's node.

The alternative proposed is to establish a network of sensors covering the field with omnidirectional radiation pattern, where digital system will have the ability to remotely control the activation of sprinklers that suppress fall in temperature. In applications such this, where there is a fixed power supply for sensor nodes, is of extreme importance energy efficiency. With this, you know the energy model of the system to predict the expected consumption and estimate the time of duration of the power of nodes without the problem of losing coverage in the area of interest.

2. Procedure

2.1. Coverage Analysis

The integrity of the actions of sensing and control of actuators will depend on the level of signal reception (Pr), equation (1), that manages to reach the higher rank with one sufficient margin to get a 100 % [4]-[11] data integrity. Supposing of the wireless link point - multipoint, equation (2), consider the algebraic sum of the gain and loss of the radio transmitter (radio signal source), through cables, antennas and clearances to the receiver. It is necessary to estimate the value of the signal intensity in different parts of the link to ensure its functionality and the integrity of the communication. Link budget is also known in the calculation as Fade Margin (dimming range) or System Operating Margin (margin of system operation),equation (3). The exact amount of margin of attenuation that is required for a wireless system depends on the desired reliability of the link, but a good rule of common use is 20 to 30 dB. For users, especially for those who want to know the reliability of your wireless connection, this formula is ideal when the transmitter and the receiver are working at a certain distance between them, [12]-[16]. If it is the excellent case, fading margin level will exceed the 22dB. The link should work with high reliability, ideal for applications requiring a high quality link, without interruptions. Will be a good link if fading margin level falls within the range of 14 22dB. The link should allow you a good navigation, satisfying most needs. In the event of a normal link, the level of the margin of fading is 14dB or less. The link will not be stable continuously, but it should work properly. Figure (2) shows the coverage for one network in a range of 1.5 Km and reception level of -80dBmW.

$$P_r = P_r + G_t + G_r - L_p - L_{ccTx} - L_{ccRx} \qquad (1)$$

Where:
P_r= Reception power level in the range,
P_r=Transmission power level of module xbee pro of 18dBmW,
G_t=Omnidirectional transmission antenna gain, 2dB
G_r=Reception antenna gain, 2dB
L_p=Loss of propagation in free air, 103.5 dB
L_{ccTx}=Line and connection loss of transmitter, 0.5 dB
L_{ccRx}=Line and connection loss of receiver, 0.5 dB

$$L_p = 32.4_{dB} + 20\log f_{MHz} + 20\log d_{Km} \quad [dB] \qquad (2)$$

Where:
L_p=Loss of propagation in free air, 103.5 dB
f=Working frequency, 2400 MHz
d=Separation range of sensor, 1.5km

$$M = P_r - S \qquad (3)$$

Where:
M=Margin 17.5 dB
P_r=Reception Power level, -82.5dB,
S=Floor noise sensibility, -100dB

2.2. The Energy Model

Figure (3) shows the elements in a node which build the wireless sensors network. These elements are the microcontroller (that includes the cpu and memory) which we will call it the cpu, RF communication module and

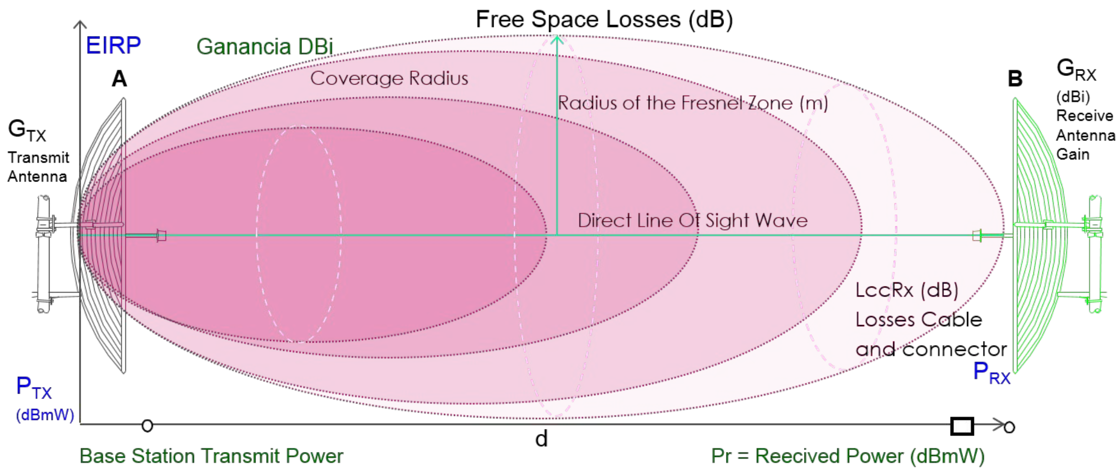

Figure 2. Coverage in a Wireless network in a range of 1500m and a reception signal level of -80 dBmW.

the sensors module. The energy consumption in a node can be expressed as in [2] and is given in equation (4).

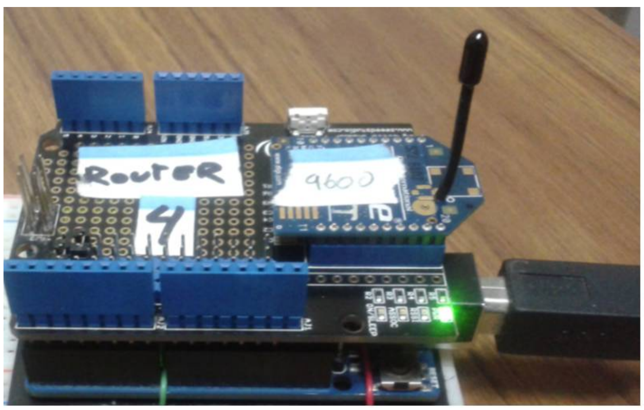

Figure 3. Photo shows the hardware of a node in a wireless sensor network. (Microcontroller, sensor and RF Module).

The energy consumption in a node is:

$$E_{node} = E_{cpu} + E_{radio} + E_{sensors} \quad (4)$$

where:

E_{node},is the energy consumed in the microcontroller system, given in joules.

E_{radio},is the energy consumed in the transmitter-receiver radio frequency system.

$E_{sensors}$,is the energy consumed in the sensors system.

The energy consumed in the cpu, is given by equation (5) .

$$E_{cpu} = \sum_{i=1}^{n} P_{cpu-state}(i) * T_{cpu-state}(i) \quad (5)$$

where:

$P_{cpu-state}$, is the power consumed in the state i of the cpu, given in watts.

$T_{cpu-state}$, is the time duration of state i, given in seconds. This time includes the transition time between states.

The power of the transceiver (radio) is shown in equation (6). The transceiver model used is shown in Figure (4).

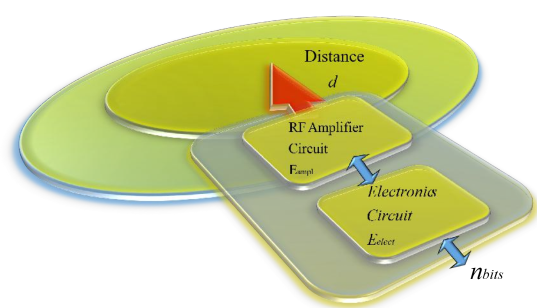

Figure 4. RF transceiver model.

Since the energy consumed by the radio communication of a WSN depends on the distance that is required to cover and the amount of information being transmitted; which in turn depends on the selected power level of the radio, and the number of bits transmitted; the model is as follows:

$$E_{radio}(n, d) = E_{elec}(n)+E_{ampl}(n, d) = E_{elec}*n+E_{ampl}*n*d^2 \quad (6)$$

where:

E_{elec},is the energy consumed in the transceiver circuitry by n processed bits.

E_{ampl}, is the energy consumed in the RF amplifier circuit by transmitting n bits of information in a distance d.

The energy consumption in the sensors system is shown in equation (7).

$$E_{sensors} = E_{elec} + E_{transd} \quad (7)$$

where:

E_{elec},is the energy consumed by the conditioning and analog to digital converting circuitry.

E_{transd},is the energy consumed by the transducer elements.

3. Results

3.1. Link Analysis

In the real range test of the link and coverage outside of a network of sensors, the results obtained are presented within a framework of an irregular topography, giving values that maintain the integrity of the data as well as the quality of the link; as well as the reading errors obtained in plots of packages Sent-Received. Measurement of the packages was carried out to establish the connection between two modules of the network, one of them the Coordinator and an End device for determining the real range presenting modules under normal conditions of use, warm weather, sky clear. The test was performed with two Xbee Pro S2 modules with built-in wire antenna. Figure 3 shows a picture of a system node made by an Arduino microcontroller, an xbee shield and a radio communication module XBee.

The hardware used for modules Coordinator, router and end devices has the microcontroller and RF module as common elements. The interaction between both elements is through serial communication; signals and the interconnection are indicated in Figure (5), [5], [8].

To complete the description of the hardware used in the project, in figure (6) is shown the structure of the modules in a block diagram. A coordinator/router module is shown and the structure of an end device with sensors and possible actuators [7].

For the realization of test coverage and quality link was used the Coordinator module, which is connected to a personal computer by running the Setup program and test XCTU of the radio module manufacturer, Digi International frequency [3]. Remote module which has the function of the end device was placed at different distances in order to determine the range of the communication. Range specifications of the XBee-Pro modules is 1.5 km, so tests were planned of communication at different distances for the characterization of the coverage that we can achieve with these modules. The distances that were used to make the evaluation of the modules like coordinates are shown in table (1).

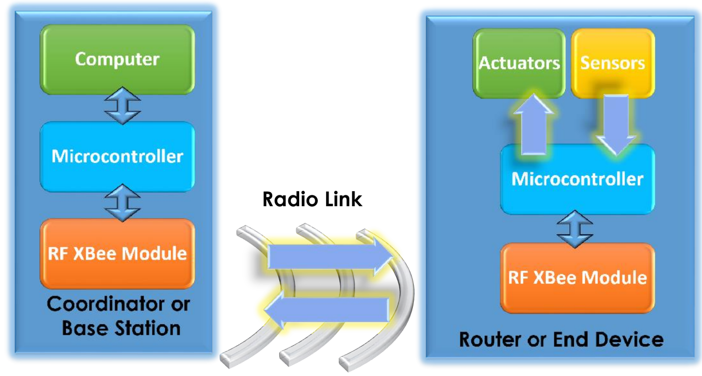

Figure 6. Wireless Interconnect diagram between coordinator and router/end devices.

Table 1. Site identification used in testing.

Site	Coordinates		Description
	Latitude	Longitude	
1	32º 32" 47'	117º 05" 5'	Base 0m
2	32º 32" 47'	117º 05" 4'	at 30m
3	32º 32" 47'	117º 05" 2'	at 100m
4	32º 32" 47'	117º 04" 55'	at 300m
5	32º 32" 47'	117º 04" 49'	at 500m
6	32º 32" 47'	117º 04" 39'	at 800m
7	32º 32" 47'	117º 04" 33'	at 1000m
8	32º 32" 47'	117º 04" 27'	at 1200m
9	32º 32" 47'	117º 04" 17'	at 1500m

Once having the sites, the links were defined. The Coordinator module was placed in the base position (site 1) and the final device is placed first on the site 2 (to 30 m) to achieve the 1 link; then was placed at site 3 (100 meters) to achieve the link 2, and so on. The links are specified in table (2).

To determine the link of the quality, the Received Signal Strength Indicator, RSSI, was evaluated; which is a parameter that indicates the power level with which the signal is received. Signal RSSI is given in dBm and is referenced to 1mW of power [6], [9]. To interpret the values obtained from RSSI, values in table (3) are used as a general rule to determine whether or not a value is

Table 2. Identification of the links.

Link	Description
1	Site 1 to 2
2	Site 1 to 3
3	Site 1 to 4
4	Site 1 to 5
5	Site 1 to 6
6	Site 1 to 7
7	Site 1 to 8
8	Site 1 to 9

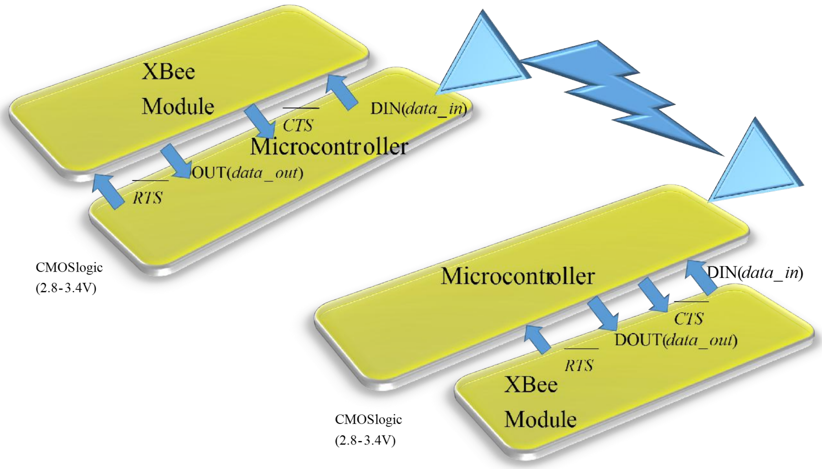

Figure 5. Interconnection diagram of microcontroller and xbee RF module.

Table 3. Values suggested for RSSI.

RSSI range	Signal quality
Better than -40 dB	Exceptional
-40 dB to -55 dB	Very good
-55 dB to -70 db	Good
-70 dB to -80 dB	Marginal
-80 dB and below	Intermittent or not operational

Table 4. Results of RSSI and percentage of packages successfully sent-received. This was at maximum power of RF modules, 63 mW.

	63mW	
Link	Packages ok	RSSI
1	99%	-42 dBm
2	99%	-64 dBm
3	99%	-80 dBm
4	98%	-94 dBm
5	0%	-
6	0%	-
7	0%	-
8	0%	-

acceptable.

To complement the assessment, is also monitoring the quality of the link and the amount of 64 byte packets that were transmitted from the module Coordinator and returned by the end device. Coordinator and end device software were configured and tested using XCTU software provided by the company which manufactures modules, Digi International. The test setup is shown in Figure (7).

Also is included in Figure (8) the link test carried out at a distance of 500m, where the connection between the modules, was still achieved just that with a lower level of reliability.

The results of the tests are presented in table (4), where you can see that the most appropriate link, however the link for appropriate values of RSSI is at 300 meters. Note. Power level 4 was used for transceivers modules for these tests.

3.2. Power consumption analysis

Below is shown the power consumption for the different stages of a node of the sensors network. Measurements of waveforms of current were made on an oscilloscope of 1Gs/s; 1? resistance was used in series with the load to get signals. Figure (9) shows microcontroller's power consumption measurements plus the radio at power level 4.

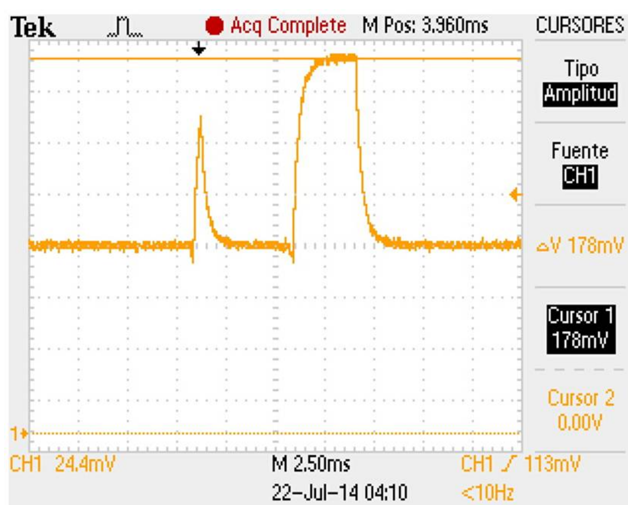

Figure 9. Current consumption measurement of the microcontroller plus the transceiver at power level 4.

Summarized all the different states of the cpu, giving

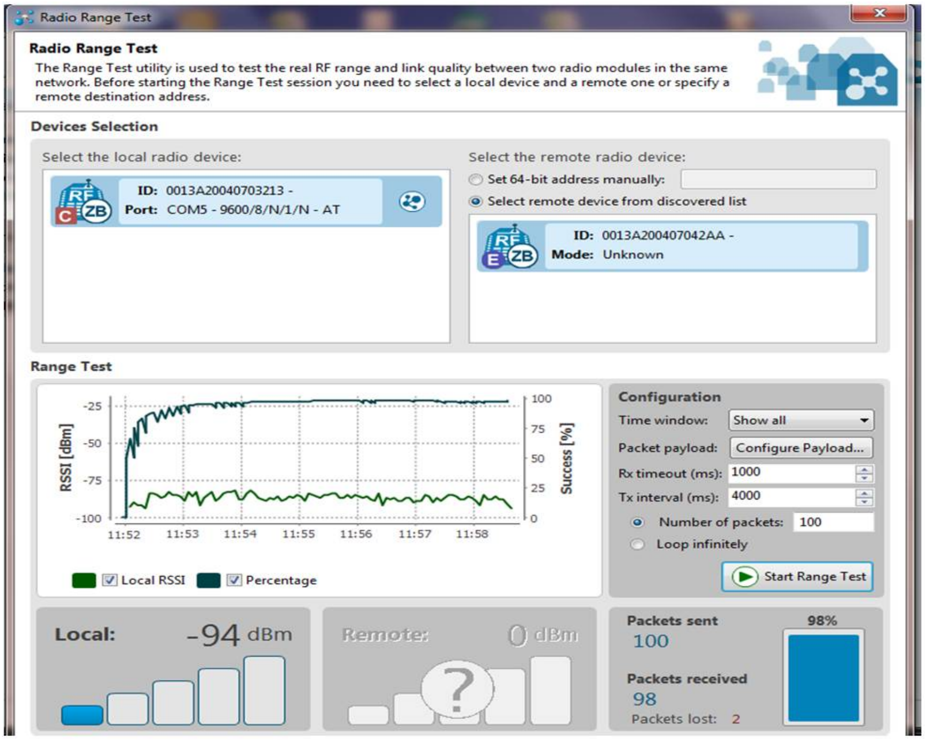

Figure 7. Snap shot at the end of link test at a distance of 30m. XCTU configuration and test software of Digi international.

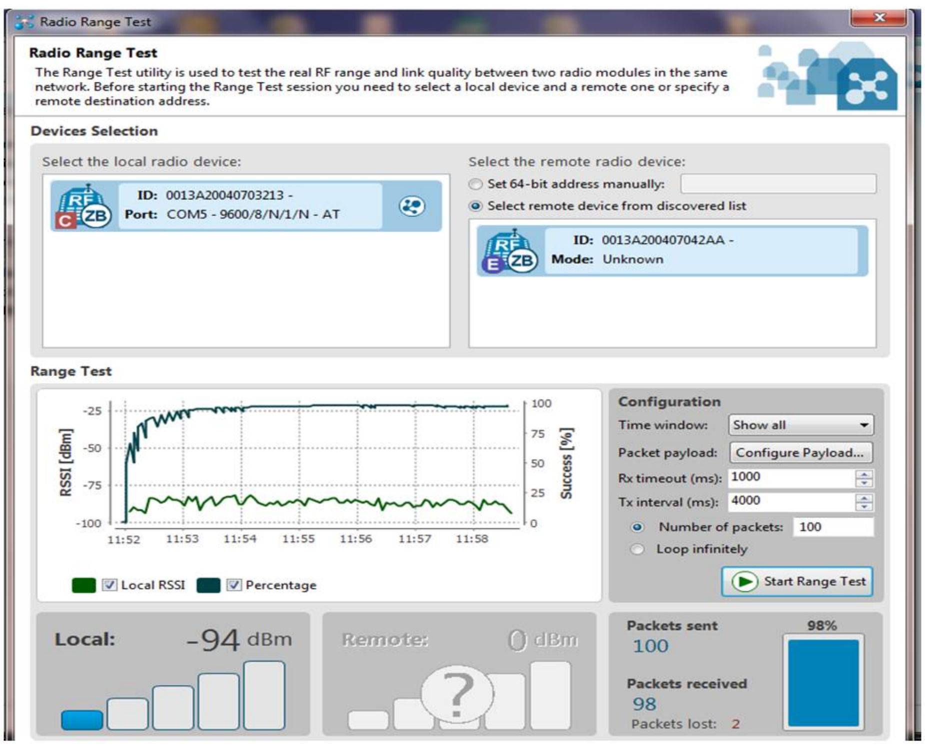

Figure 8. Snap shot at the end of link test between coordinator and end device at a distance of 500m.

a number of constant energy consumption, based on equation (5):

CPU Power = 41.2mA * 5v = 0.206 w E_{cpu} = 0.206w * 4 s = 0.824 μJoules

RF transceiver modules, power consumption varies according to the level of transmission power. The relationship of the energy with respect to the transmission power is given in table (5). RF module in idle/receive mode = 47.6mA * 3.3v = 0.157 w

RF module in sleep mode = 10μA

RF module power consumption: Conditions: Vcc = 3.3V, Energy per bit (RF data rate 250,000 bps, bit time is 4 s). Data based in equation (6).

The energy consumption in sensors module, in our case, is based on Temperature and Humidity sensor RHT03. This sensor a digital output calibrated temperature and humidity sensor. The power supply used for this component is 5 V. It transmits 8 bit integral RH data+8 bit decimal RH data+8 bit integral T data+8 bit decimal T data+8 bit checksum for a total of 40 bits. The component is shown in figure (10).

Table 5. Energy consumption at different power levels of transceiver.Note: According datasheets of xbee modules, power level 4 is calibrated to 18dBm; the other values are estimated.

Power level	Current (mA)	Power (w)	Energy (μJ)
0 (10 dBm)	87	0.287	1.148
1 (12 dBm)	91	0.300	1.200
2 (14 dBm)	103	0.340	1.360
3 (16 dBm)	113	0.372	1.488
4 (18 dBm)	137	0.451	1.804

Figure 10. Temperature and Humidity sensor RHT03 of MaxDetect Technology Co.

The sensor transmits every bit in about 27 s. The electronic circuit consumption is included in the same component package as the transductor, so:

$E_{sensors} = E_{elec} + E_{transd} = 1.2mA * 5V * 27\mu s = 0.162\mu$Joules

$E_{sensors}$ for 40 bits of data = 6.48μJoules per sensing.

4. Conclusions

Table (4) shows the results of the test link at 500 meters where it can be seen that the value of RSSI is - 94 dBm and 98% of received packets. While the number of packets sent and received is high, in certain conditions of rain or other obstructions the link may fail. According to the values in table 4 results, lower to - 80 dBm values are not recommended due to lack of reliability in the link. The foregoing it is concluded that for modules XBee Pro series2 63mW power antenna wire, the more appropriate in our test suite link is more advisable to use the link 300 meters. Even when 500 meters has a 98% of received packets, is not recommended to use this distance because undertakes the integrity of the connection. It is recommended that there is a maximum distance of 300 meters between each node in the network of sensors to achieve the desired coverage. We must combine the table (4) and (5) to determine the desired option according to the level of power to be transmitted, the desired range and the amount of energy that must be consumed by the system.

For future work, we recommend the analysis of the life time and replacement of a certain type of battery used on the nodes to estimate the optimal time duration for network operation.

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