Path Loss Exponent Influence on Distance Estimation between Wireless Sensor Nodes

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***Abstract*—Wireless Sensor Networks (WSN) are challenging and efficient in a large field of applications like object location or distance determination between sensor nodes. In this paper are presented some considerations concerning the method of distance estimation between WSN nodes using the RF power level received by one sensor node. The experimental determinations were made using a WSN system composed of ten wireless modules (one coordinator module and nine WSN nodes). The RF power level received by a sensor node was measured at variable distances, and the dBm values recorded were then used in the distance determination formula. The tests were made in a 3 meters semi-anechoic chamber - in order the results not to be affected by other radio frequency emissions from the surrounding environment - using a 20 Hz-26.5 GHz EMI Test Receiver, a log-periodic antenna and RF cables.**

***Index Terms*—wireless sensor networks, received signal strength indication, distance estimation, path loss exponent, RF power level**

I. Introduction

At first, Wireless Sensor Networks (WSN) were used only for environmental monitoring, the WSN nodes being equipped with high-performance sensors which convert humidity, temperature or pressure into electrical signals [1]. The information collected from the surrounding environment is converted and then transmitted to a specific server application. Nowdays, many research works are investigating the received signal strength - localization techniques based on a set of parameters like path loss exponent or RF power level received at a reference distance. The elaboration of a proper calculus algorithm is as complex as the surrounding environment is directly involved by the means of attenuation and reflection factors. Many applications require not only the collecting process of data but also the location of where it came from. The GPS technique is a known solution for outdoor localization, but in an indoor space the Wireless Sensor Networks seems to be the most efficient. In the first state of our work, we used a setup composed of one sensor node (WSN node) and one coordinator module.

The WSN node RSSI indication (shown by the server application interface) was compared to the RF power level recorded with EMI Test Receiver. The dBm values - corresponding to reader module (gateway) - were measured at a variable distance away from the WSN node. The both RSSI and RF power level values can be used in the distance calculus algorithm, as described in chapter 3.

A picture of the experimental test setup used in our measurements is shown in the figure below.

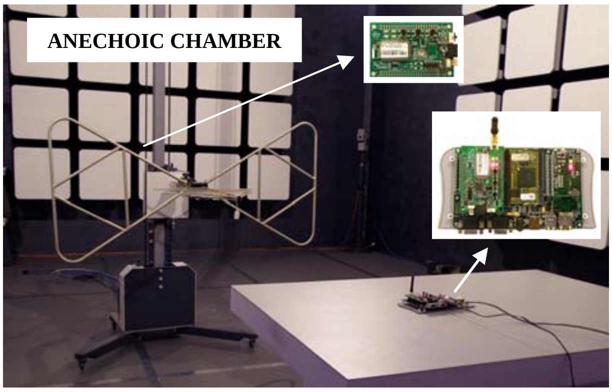

Figure 1. Experimental test setup for WSN node - RF power level measurements (anechoic chamber).

II. WSN Distance Estimation System

As we already know, the main components of a basic wireless sensor node are the microcontroller, transceiver, external memory, power source, AD converter and sensors. One of the WSN nodes used in our measurements is depicted in fig. 2.

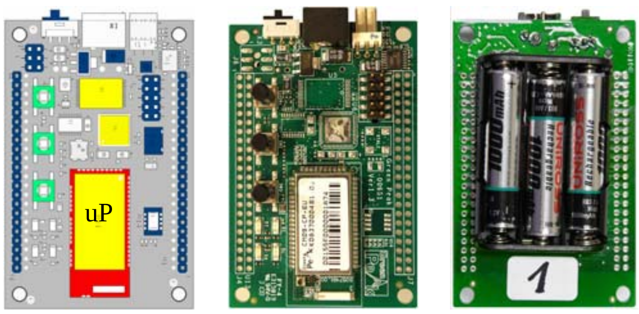

Figure 2. Green Peak Tech. - Wireless Sensor Node (Hardware description).

The WSN node described above is powered up using 3 AAA batteries mounted on a special holder on the back of the board. It operates in the 2.4-2.4835 GHz ISM frequency band, and is certified to meet EN 300 440 international standard. Other main characteristics are listed in table 1.

TABLE I. Green Peak Tech. - WSN Node

Characteristics	Description
Radio	IEEE 802.15.4 compliant
Operating frequency	2.405 GHz min., 2.480 GHz max.
No. of channels	16
Data rate	250 kbps
Antenna	On chip (optional: external)
Indoor range	40-100 m
Outdoor range	160-400 m
Security	AES 128 bit

Digital Object Identifier 10.4316/AECE.2010.01020

The energy usage of a Green Peak node is managed by an insight energy budget calculator, which calculates a set of parameters used in the communication stack. For instance, the average time between data packets, the data transfer latency, status update period or sleep period can be calculated so that the energy consumption of a WSN node to be minimal.

After setting up the parameters described above, an output file named wsn_network_configuration.h was automatically generated by the energy budget calculator (which is a Microsoft Excel application). This file is then loaded in the starterkit application and the new parameters will be available after recompiling the software program. A Green Peak WSN network configuration example is shown in fig. 3.

```
/*****************************************************
*WSN network configuration file
/*****************************************************

#ifdef UW_APP_DIVERSITY_UBINETZ
#define UW_APP_AVERAGE_DATA_TRANSFER_ORDER      19
#define UW_APP_STATUS_UPDATE_ORDER              18
#define UW_APP_LIVE_CREDIT_ORDER                18
#define UW_APP_DATA_TRANSFER_LATENCY_ORDER      15
#define UW_APP_MINIMAL_APP_CALLBACK_ORDER 0
#define UW_APP_MAXIMAL_APP_CALLBACK_ORDER 31

#define UW_APP_MAX_NODES                        50
#define UW_APP_AVERAGE_HOPS                     13
#define UW_APP_MAX_HOPS                         20
#endif
```

Figure 3. WSN Network Configuration File.

The WSN nodes used in our measurements were programmed to emit at a 4 seconds time interval. The gateway module was also programmed to communicate with the existing wireless sensor nodes by sending radio signals at each 4 seconds time period. If no endpoint is present in the network, the gateway will continue to search for nodes by emitting once in a minute. As specified in the WSN system technical documentation, a network info message corresponds to each detected wireless device. This information contains 13 bytes of data grouped as shown in table 2. Some parameters are specific to software application, while the LQI byte represents a characterization of the strength or quality of the received data packets. The LQI (Link Quality Indicator) represents the level of interference within an IEEE 802.15.4 channel and measures the received energy level for each received packet [2].

TABLE II. NETWORK INFO FORMAT

Bytes	1	2	1	8	1
FIELD	Channel	PanID	Association status	MAC address	**LQI**

III. RSSI MEASUREMENT/DISTANCE ESTIMATION IN WIRELESS SENSOR NETWORKS

A. Received Signal Strength Indication (RSSI)

In Wireless Sensor Networks, the RF Signal Strength (also called the Received Signal Strength - RSS) is measured at a certain distance away from the WSN node, and is usually expressed in dBm [3]. On the other hand, the RSSI (Received Signal Strength Indicator) can be obtained by converting these dBm values into percentages or integer negative numbers. In the Green Peak software application for instance, the RSSI indication is represented by a negative odd number. This indicator is displayed for all WSN nodes which are active in the network. As detailed in chapter 5, the WSN node RSSI value is almost equal with the power level received from the coordinator module (gateway), therefore a correlation between RSSI indicator and receiver dBm values is obvious [3].

B. Distance Estimation between Wireless Sensor Nodes

One of the methods used for determination of distance between sensor nodes is based on measuring the RF power level received by one node. This localization technique is dependent on a set of parameters like path loss exponent and the RF power level received at a reference distance, and is strongly influenced by environmental factors and climatic conditions. A classical indoor propagation model [4] can be calculated using the formula below:

$$P = P_{ref} + 10 \cdot n \cdot \lg\left(\frac{d_x}{d_{ref}}\right) + \xi$$

Where, d_{ref} and d_x are the reference and the measured distance, respectively. P_{ref} and P are the received signal strength at the distance of d_x and d_{ref}, respectively. n is the path loss exponent, also known as attenuating coefficient, while ξ represents the so-called *shadow factor*, a parameter which can be neglected. After some mathematical calculus and proper approximations, the resulted formula used in the distance estimation determination is:

$$d_x = d_{ref} \times 10^{\frac{|P_{ref} - P|}{10 \cdot n}}$$

$$d_x = 10^{\frac{|P_{ref} - P|}{10 \cdot n}}, d_{ref} = 1m$$

In practice, there are many ways to express this calculus algorithm, depending on the type of the sensor nodes used in the distance determination measurements. In both indoor and outdoor space - especially, the path loss exponent (n) is very sensitive to environmental attenuation and reflection factors.

Climatic conditions as temperature and humidity also significantly influence the attenuating coefficient estimation.

IV. TEST SETUP

The RF power levels used in the distance estimation algorithm were measured in a 3 meters semi-anechoic chamber using a Rohde & Schwarz - 26.5 GHz EMI Test Receiver, a calibrated log-periodic antenna and high-quality RF cables. Measurements were made in the frequency range from 2.4 GHz to 2.42 GHz.

The coordinator node was placed on a 0.8 meters height non-conductive table, at 1 m, 1.5 m, 2 m, 2.5 m and 3 m distance away from the log-periodic antenna (and WSN node). The test antenna was then connected to ESU 26 EMI Test Receiver using a RF cable, while the maximum levels of the RSS were recorded at a central frequency of 2.4095 GHz. The dBm values obtained for each measured distance were then compared with the RSSI negative number indicated by the Green Peak Software interface.

The test setup used in our measurements is described in fig. 4.

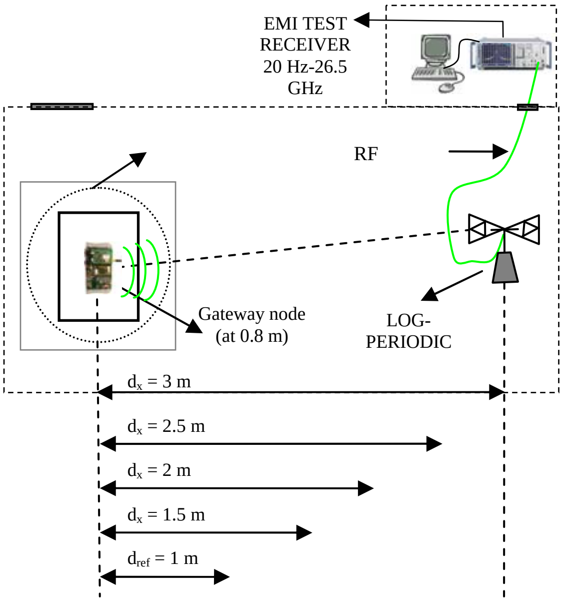

Figure 4. Test setup for distance estimation between sensor nodes (anechoic chamber).

We chose d_{ref} = 1 meter as reference distance. The experimental results are presented in chapter 5.

V. Experimental Results

A. *The first set of measurements (day 1)*

In fig. 5 we have a screen capture from EMI Test Receiver corresponding to WSN node RF power level measured at d_{ref} = 1 meter. The climatic conditions (48 % humidity, pressure 978 mbar, temperature 19.1 ^{0}C) were recorded using a portable Humidity/Pressure/Temperature Data Logger mounted in the anechoic chamber.

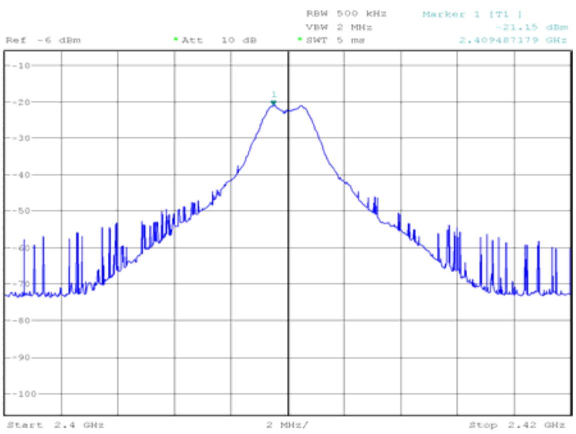

Figure 5. RF Power level for d_{ref} = 1 meter (-21.15dBm).

The coordinator node is represented by "0001" code in fig. 8, 10, 12 and 14, while "19D0" and "1A6E" are the two WSN nodes used in our measurements. Let us mention that the both "19D0" and "1A6E" WSN nodes are identical. The Green Peak value of RSSI is shown near the WSN node identifier.

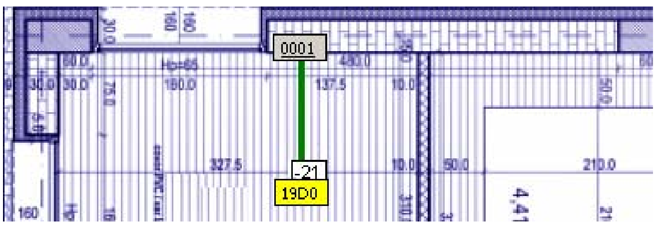

Figure 6. RSSI from Green Peak Software (d_{ref} = 1 meter).

As we might see in the figures below, the RF power level and the RSS indicator value are almost identical.

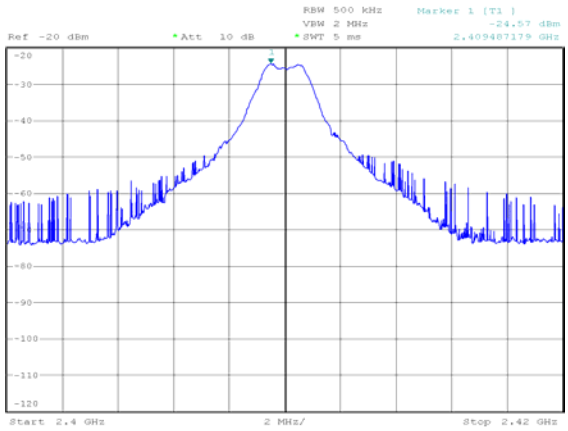

Figure 7. RF Power level for d_x = 1.5 meters (-24.57dBm).

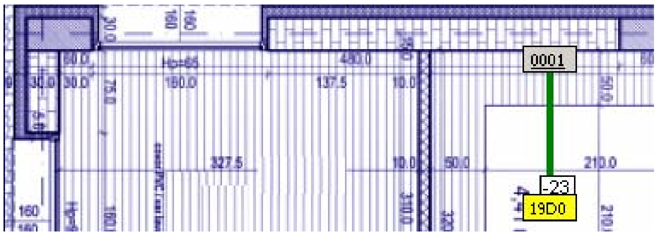

Figure 8. RSSI from Green Peak Software (d_x = 1.5 meters).

$$d_x = 10^{\frac{|P_{ref}-P|}{10\cdot n}}, d_{ref} = 1m,$$ where:

P_{ref} = -21.15 dBm; P = **-24.57** dBm; d_x = **1.5 meters**; n = 2

$$d_x = 10^{\frac{|-24.57+21.15|}{10\cdot 2}} = 10^{\frac{|-3.42|}{20}} = 10^{0.1710} = 1.48\, meters$$

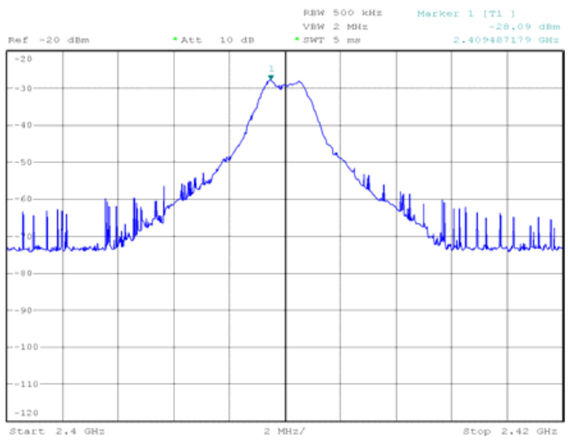

Figure 9. RF Power level for d_x = 2 meters (-28.09dBm).

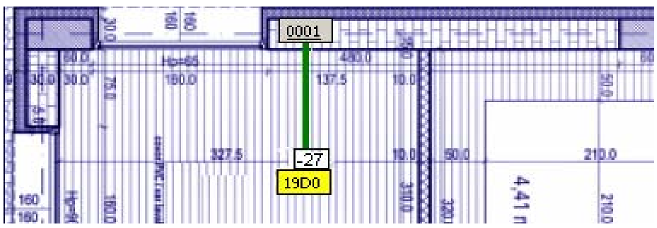

Figure 10. RSSI from Green Peak Software (d_x = 2 meters).

$$d_x = 10^{\frac{|P_{ref} - P|}{10 \cdot n}}, d_{ref} = 1\,m, \text{ where:}$$

P_{ref} = -21.15 dBm; P = **-28.09** dBm; d_x = **2 meters**; n = 2.25

$$d_x = 10^{\frac{|-28.09+21.15|}{10 \cdot 2.25}} = 10^{\frac{|-6.94|}{22.5}} = 10^{0.3084} = 2.03\,meters$$

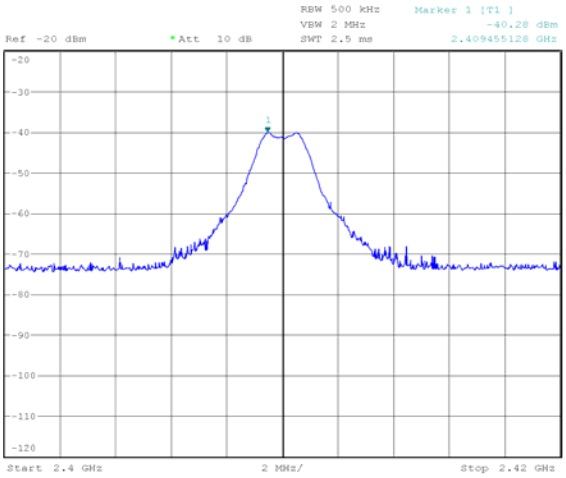

Figure 11. RF Power level for d_x = 2.5 meters (-40.28dBm).

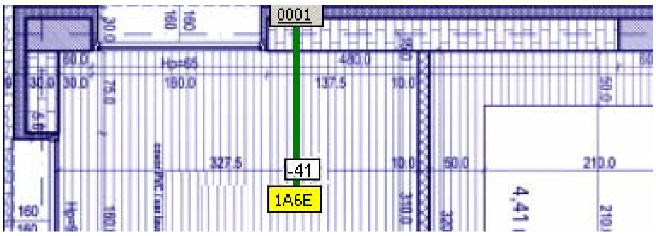

Figure 12. RSSI from Green Peak Software (d_x = 2.5 meters).

$$d_x = 10^{\frac{|P_{ref} - P|}{10 \cdot n}}, d_{ref} = 1\,m, \text{ where:}$$

P_{ref} = -21.15 dBm; P = **-40.28** dBm; d_x = **2.5 meters**; n =4.75

$$d_x = 10^{\frac{|-40.28+21.15|}{10 \cdot 4.75}} = 10^{\frac{|-19.13|}{47.5}} = 10^{0.4027} = 2.53\,meters$$

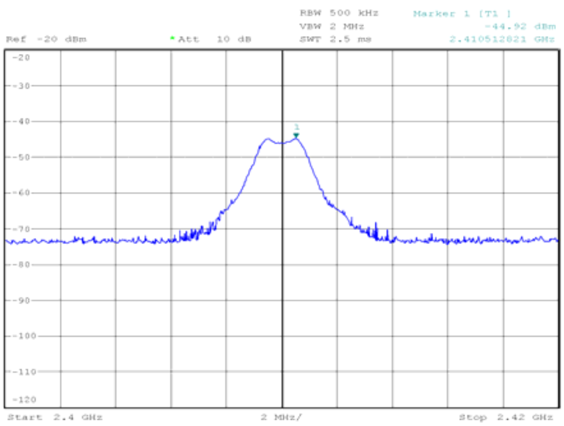

Figure 13. RF Power level for d_x = 3 meters (-44.92dBm).

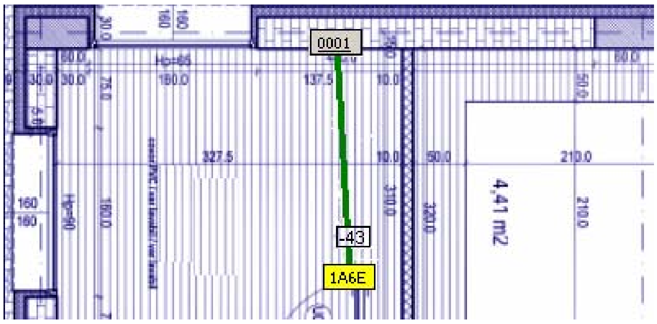

Figure 14. RSSI from Green Peak Software (d_x = 3 meters).

$$d_x = 10^{\frac{|P_{ref} - P|}{10 \cdot n}}, d_{ref} = 1\,m, \text{ where:}$$

P_{ref} = -21.15 dBm; P = **-44.92** dBm; d_x = **3 meters**; n = 5

$$d_x = 10^{\frac{|-44.92+21.15|}{10 \cdot 5}} = 10^{\frac{|-23.77|}{50}} = 10^{0.4754} = 2.99\,meters$$

Based on measurements listed below, we can conclude that the calculus algorithm we used gives us a good precision in determination of distance between the WSN node considered and the coordinator module (gateway).

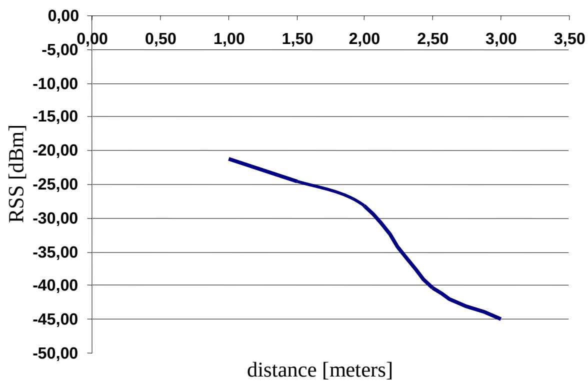

Figure 15. RSS [dBm] variation with distance [meters].

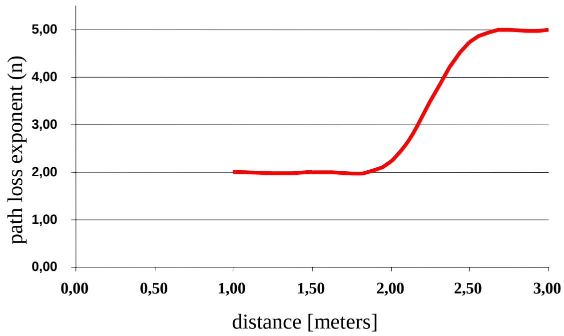

Figure 16. Path loss exponent representation.

As we might see in fig. 15, the RF power level of a WSN node is exponential decreasing with distance, while the path loss exponent significantly increases (Fig. 16).

B. The second set of measurements (day 2)

The second set of measurements was performed after two days, in the same shielded enclosure, using exactly the same test setup described in fig. 4. Climatic conditions recorded this time were: 34 % humidity, 986 mbar and 21.9 ^{0}C.

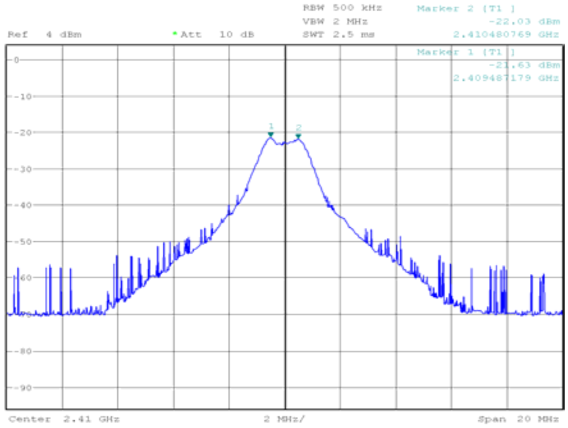

Figure 17. RF Power level for d_{ref} = 1 meter (-21.63dBm).

In this chapter are listed only the results obtained by measuring the radiated emissions from the WSN node (RF power levels), this values being used in the distance estimation formula.

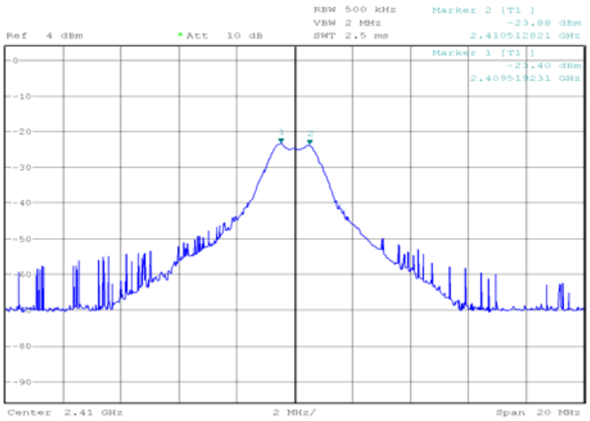

Figure 18. RF Power level for d_x = 1.5 meters (-23.82dBm).

$$d_x = 10^{\frac{|P_{ref} - P|}{10 \cdot n}}, d_{ref} = 1\, m \text{, where:}$$

P_{ref} = -21.63 dBm; P = **-23.82** dBm; d_x = **1.5 meters**; n = 1.3

$$d_x = 10^{\frac{|-23.82 + 21.63|}{10 \cdot 1.3}} = 10^{\frac{|-2.19|}{13}} = 10^{0.1684} = 1.48\, meters$$

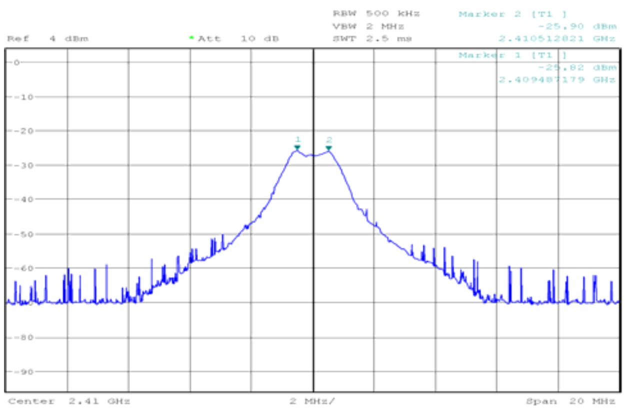

Figure 19. RF Power level for d_x = 2 meters (-25.82dBm).

$$d_x = 10^{\frac{|P_{ref} - P|}{10 \cdot n}}, d_{ref} = 1\, m \text{, where:}$$

P_{ref} = -21.63 dBm; P = **-25.82** dBm; d_x = **2 meters**; n = 1.4

$$d_x = 10^{\frac{|-25.82 + 21.63|}{10 \cdot 1.4}} = 10^{\frac{|-4.19|}{14}} = 10^{0.2992} = 1.99\, meters$$

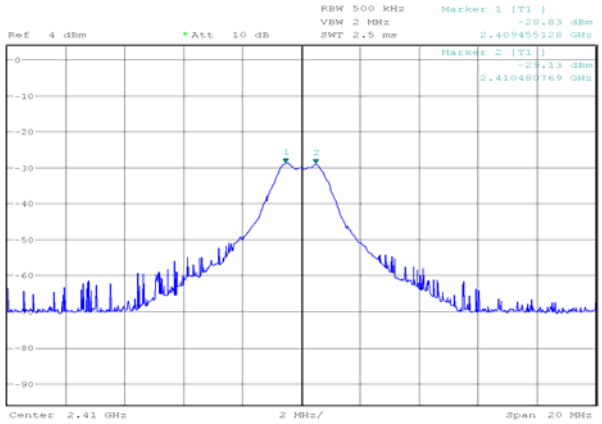

Figure 20. RF Power level for d_x = 2.5 meters (-28.83dBm).

$$d_x = 10^{\frac{|P_{ref} - P|}{10 \cdot n}}, d_{ref} = 1\, m \text{, where:}$$

P_{ref} = -21.63 dBm; P = **-28.83** dBm; d_x = **2.5 meters**; n = 1.8

$$d_x = 10^{\frac{|-28.83 + 21.63|}{10 \cdot 1.8}} = 10^{\frac{|-7.2|}{18}} = 10^{0.4} = 2.51 meters$$

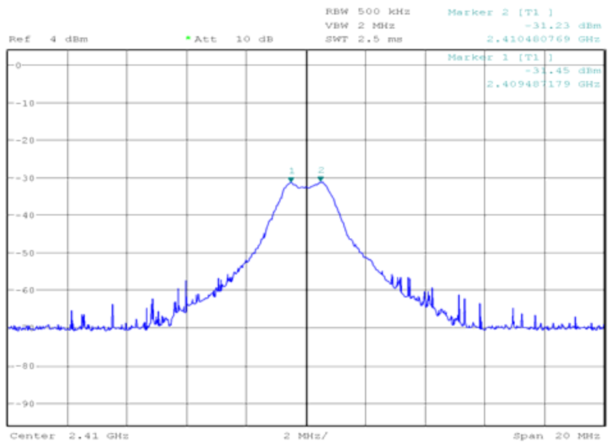

Figure 21. RF Power level for d_x = 3 meters (-31.23dBm).

$$d_x = 10^{\frac{|P_{ref} - P|}{10 \cdot n}}, d_{ref} = 1\, m \text{, where:}$$

P_{ref} = -21.63 dBm; P = **-31.23** dBm; d_x = 3 **meters**; n = 2

$$d_x = 10^{\frac{|-31.23 + 21.63|}{10 \cdot 2}} = 10^{\frac{|-9.6|}{20}} = 10^{0.48} = 3.01 meters$$

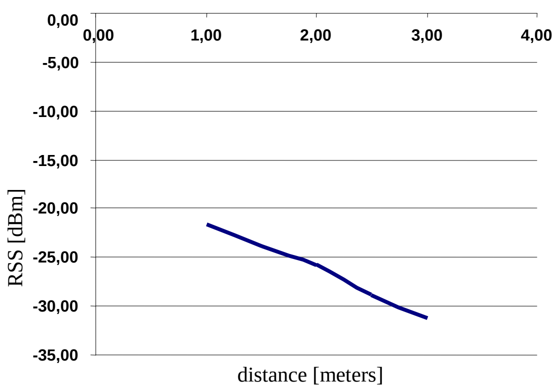

Figure 22. RSS [dBm] variation with distance [meters].

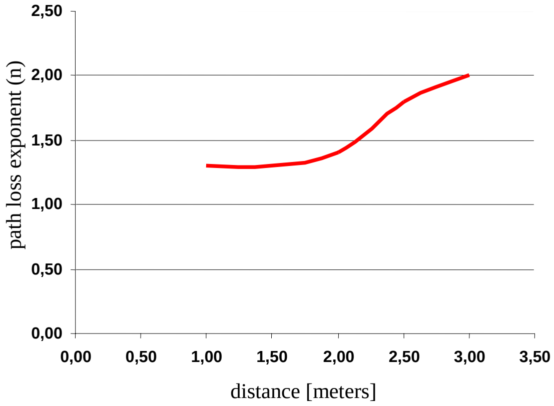

Figure 23. Path loss exponent representation.

As we might see in fig. 22, the RF power level of the WSN node considered is almost linear decreasing with distance. On the other hand, the path loss exponent has a friendly increasing representation, being influenced not only by distance but also by the climatic conditions recorded.

Another picture taken during our tests is shown in fig. 24. For the RSSI measurements the log-periodic antenna was vertical polarized and placed at 1 meter height.

Figure 24. RF power level measurements.

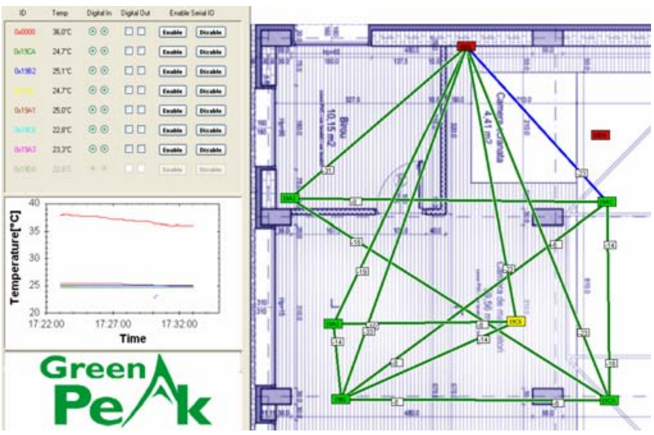

Figure 25. WSN System - Green Peak Software program (representation of WSN nodes and RSSI values).

VI. Conclusions

Several measurements were made in order to establish a correlation between WSN node RF power level and RSSI indication. Using these experimental results obtained we calculated the distance between a certain WSN node and the coordinator node (named gateway).

It has been noticed that a high humidity level and a value of temperature below 20 ^{0}C influence the path loss exponent and by here, the integrity of the RF signal received from the WSN node. By measuring the radiated emissions of the gateway module at a 3 meters distance - for instance, we get the received signal strength corresponding to the WSN node measured. As shown in chapters 5.1 and 5.2, the RSSI indication and the dBm values recorded were almost equal. In this manner, the result of distance calculation and by supplementary calculus, the position coordinates can be transmitted from node to node to the coordinator module. From here, the information can be processed and transmitted to a specific software application.

The WSN distance estimation system proposed in this paper is composed of nine wireless sensor devices and was manufactured by Green Peak Technologies.

Initially developed for monitoring the climatic condition, by collecting and displaying information concerning the temperature variations in a certain environment, the WSN system can now be extended to implementation in a positioning application.

References

[1] J.K. Hart, K. Martinez, Environmental Sensor Networks: A revolution in the earth system science?, Earth-Science Reviews, pp. 177-191, 2006

[2] 802.15.4 - IEEE Standard for Information Technology - Telecommunications and information exchange between systems. Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs), 2003

[3] E. Coca, V. Popa, G. Buta, Wireless Sensor Network nodes performance measurements and RSSI evaluation, SIITME - International Symposium for Design and Technology of Electronics Packages - Gyula, Hungary, 2009

[4] NI Wei, WANG Zong-xin, Indoor Location Algorithm Based on the Measurement of the Received Signal Strength, Higher Education Press and Springer-Verlag, 2006

[5] Joe-Air Jiang Cheng-Long Chuang Chia-Pang Chen Tzu-Shiang Lin, A RSSI-based environmental-adaptive dynamic radiation power management for Wireless Sensor Networks, Circuits and Systems, APCCAS, 2008