915 MHz Wireless Sensor Network Reliability Evaluation when Working in an Industrial Electrical Power Substation

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ABSTRACT

The electrical energy spent in manufacturing process is responsible for a large amount of the operational costs. Thus, the consumed energy control and monitoring is important to improve the energy quality use and minimize losses. This task is more convenient for wireless sensors networks, that needs to operate in an industrial environment, exposed to spurious radiations, and in industrial substations of medium voltage lines. This work aims to evaluate the effect of medium voltage substation radiation in a sensor network, operating at 915 MHz, compared with an environment without this type of infrastructure. The work characterizes and compares the two environments, considering the path loss, standard deviation and signal statistic. The results show that the interference effect from substations does not have significant effect in the system performance.

Keywords: Sensors' network, industrial substations monitoring, 915 MHz wireless sensors.

RESUMO

A energia eléctrica utilizada no processo industrial é responsável por uma grande parcela dos custos operacionais. Assim, o controle da energia consumida e monitoramento é importante para melhorar a qualidade de energia e minimizar as perdas. Esta tarefa é mais conveniente para redes de sensores sem fio, que precisa operar em um ambiente industrial, as quais ficam expostas a radiações espúrias, e em subestações industriais de linhas de média tensão. Este trabalho tem como objetivo avaliar o efeito da radiação subestação de média tensão em uma rede de sensores, operando em 915 MHz, em comparação com um ambiente sem este tipo de infraestrutura. O trabalho caracteriza e compara os dois ambientes, considerando a perda de percurso, desvio padrão e dados estatísticos do sinal. Os resultados mostram que o efeito de interferência de subestações não tem relevância significativa no desempenho do sistema.

Palavras-chave: Rede de sensores, monitorização subestações industriais, sensores sem fios de 915 MHz.

INTRODUCTION

The industrial sector is responsible for operating more than 42% of the total energy, and for more than half consumed electricity (including cogeneration). The connected loads management combined with the production system is essential to achieve better efficiency; in other words, higher productivity with lower energy consumption, (ALLEN, 2005). Thus, a fast and automatic power monitoring and control system is essential.

Many questions regarding efficiency and reliability come up when controllers and sensors are connected via a radio system. Some professionals believe that a radio system is not reliable when it is immersed in an atmosphere contaminated by electrical field and/or electromagnetic interferences caused by large motors or 13.8 KV transmission lines, (NORDMAN, 2004).

This work evaluates a wireless sensor network (WSN) operating in the 915 MHz band. The objective is the evaluation of radio link characteristics in two situations: in an electrical power substation environment and outside of this environment.

An experiment set up was utilized to evaluate the effect of the substation compared with a condition without the effect of the substation. The characteristics analyzed com compare the two situations are: path loss, standard deviation and signal statistics. The results show that the level of interference caused by the substation does not change the WSN reliability.

This work is organized as follow. Section II presents the fundamental of signal propagation utilized to analyze the experiment results. Section III presents the Radiuino platform utilized to evaluate the propagation conditions. Section IV presents the wireless communication system parameters. Section V presents the results and analyzes. Section VI presents the conclusions.

SIGNALS PROPAGATION

To characterize the wireless communications it is essential to understand the propagation processes. While the environment that uses cables is almost deterministic, the wireless communication is probabilistic, and thus, an uncertainty level must be considered. The radio waves in the atmosphere scatter and mix up, depending on the obstacles, (NASCIMENTO, 1992). The follow items consider the models utilized in the work.

Reference free space loss

The free space model developed by Friis, (RAPPAPORT, 2009) is the reference for all the signal intensity prediction methods currently used. It begins with the free space attenuation to determine the received signal intensity in a given distance. Equation 1 represents the Friis formula with the system loss.

$$L_{RL} = 10\log\left(\frac{4\pi d}{\lambda}\right)^2 + L_S \qquad (1)$$

Where d is the distance, λ is the wave length and L_S is the system loss, (KARL, 2005). This last factor considers the non-ideal feature of the radio frequency circuits, like connectors and antenna mismatch, caused by the RF circuit, cable loss, etc.

The power received in the reference distance could be calculated by the Equation 2.

$$P_{RX}(d_0) = P_{TX} + G_{base} + G_{sensor} - L_{RL} \qquad (2)$$

Log-Distance Model

The Log-Distance model is widely used to characterize the environment type. This model assumes that the received power of a signal, in a distance d, can be calculated considering a factor called path loss (β) and a received power in a reference distance d_0 closer to the transmitter.

From the transmitter, a reference distance is defined, and in this space it is considered the free space attenuation. Beyond this distance, the signal will undergo a higher attenuation than in free space, and the path loss dependent. Usually, the distance d_0 must be at least 10 times lower than the distance d. In this work is used a reference distance of 1 meter, as recommended by NASCIMENTO, 2004). This is a practical consideration that can be changed depending on the environment. Then, the power in a distance d can be determined, taking account of the power measured in d_0, as indicated in Equation 3.

$$P_{RX}(d) = P_{RX}(d_0) - 10\beta\log\left(\frac{d}{d_0}\right) \qquad (3)$$

Where β is the path loss coefficient that characterizes the propagation environment. Measuring the powers in d_0 and d it is possible to calculate β. Thus, total loss is the log-distance attenuation plus the system loss can be calculated by Equation 4.

$$L_{Tot} = 10\log\left(\frac{4\pi d_0}{\lambda}\right)^2 + L_S + 10\beta\log\left(\frac{d}{d_0}\right) \qquad (4)$$

The path loss β could be calculated with Equation 5.

$$\beta = \frac{P_{RX}(d_0) - P_{RX}(d)}{10\log\left(\frac{d}{d_0}\right)} \qquad (5)$$

When is not possible to measure the received power in the reference distance, and the system loss is known, the $P_{RX}(d_0)$ could be calculated with the Expression 2.

Shadowing Model

Using the model with obstacles, the signal attenuation calculations depend on the environment and use information such as constant power, antenna gains and attenuation factor. These are deterministic parameters that depend on the environment. However, there is an uncertainty degree in the signal level. The Equation 6 gives this uncertainty degree as a random variable X_{dB}.

$$P_r(d)[dBm] = P_r(d_o)[dB] - 10\beta\log\left(\frac{d}{d_o}\right) + X_{dB} \qquad (6)$$

Where X_{dB} is a log-normal random variable and the standard deviation σ is another factor that characterizes the environment.

Radiuino Platform

The experiment was conducted with the Radiuino open source platform specially designed to implement WSN. This platform was developed with a structured stack that simplifies the implementation of WSN. This approach is easy to use compared with others platforms like SimpliciTI (Texas Instruments), SMAC (Freescale) and MiWi (Microchip).

The differentiation is initially based on an easy firmware development environment. Unlike the conventional platforms, which use complex and extremely detail-oriented IDE's (Integrated Development Environment), Radiuino is based on Arduino, (MCROBERTS, 2010). This platform uses a simplified IDE and is easily adaptable, even for non-experts programmers.

Another interesting feature of this platform is its conceptual similarity with the TCP/IP stack. As in the Internet protocol stack, the Radiuino stack has five layers: Physical, Data Link, Network, Transport and Application. This distinction is very clear when designing and implementing the application, while maintaining the firmware modularity and maintainability. Figure 1 shows the structure of the protocol stack of Radiuino in its three main elements.

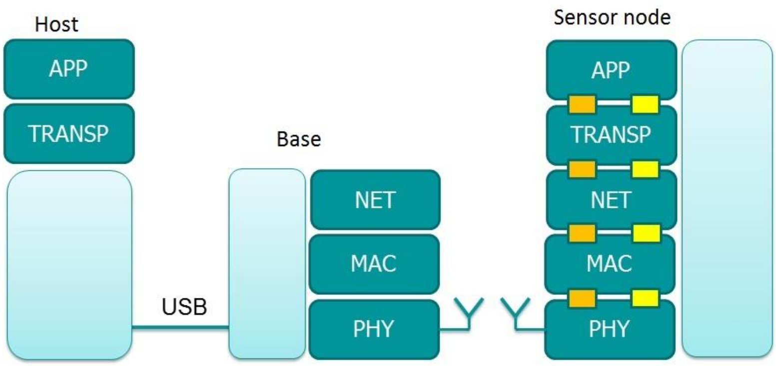

Figure 1: Protocol stacks in a Radiuino platform.

It can be seen that the sensor's protocol stack have all layers. In the computer and base the structure is:

- in the sink: physical, data link and network
- in the host: transport and application.

Thus, the communication and addressing characteristics are handled in a hardware base, leaving the host to control the transport layer and the application itself.

The Radiuino communication platform sketch is shown in Figure 2.

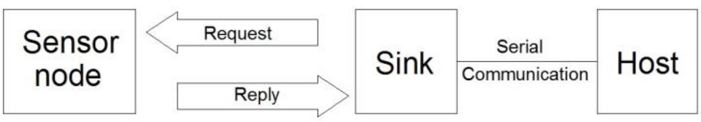

Figure 2: Radiuino communication platform.

The host is set with software to establish the communication with the sensors. The computer communicates through serial with the base, which sends a wireless requisition to the sensor. Then, the sensor executes the commands sent by the host and reads the data from the transducers. The sensor sends back to the base an answer to the requisition. Other information received by the base is the RSSI (Radio Signal Strength Indicator) with the signal received powers of the up and down link. The computer processes these data and let them available for manipulation.
Both the requisition and the answer packet have the same size (52 bytes) and the same format. The packet composition is:

- 4 bytes for the layers: physical, mac, net and transportation;
- 36 bytes for the payload.

The module with the radio and microcontroller used for the experiment is made in Brazil, called BE900, which contains an Atmega328 microcontroller from Atmel, and the transceiver CC1101 from Texas Instruments (Figure 3).

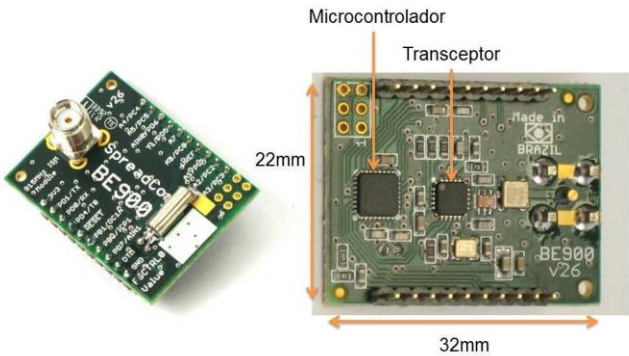

Figure 3: The Radio BE 900.

The connection with the antenna uses a SMA connector that provides a robust connection between the radio and the antenna.
To collect the results it was used a free Brazilian SCADA (Supervisory Control Acquisition Data Automation) called ScadaBR (Figure 4).

Figure 4: ScadaBR screen.

The graphical presents the RSSI of up and down link used to characterize the two situations. The ScadaBR has a data base that stores the data for off line processing.

Wireless Communication System

The wireless network project needs to consider the environment type and the system characteristics. Figure 5 illustrates the radio communication elements.

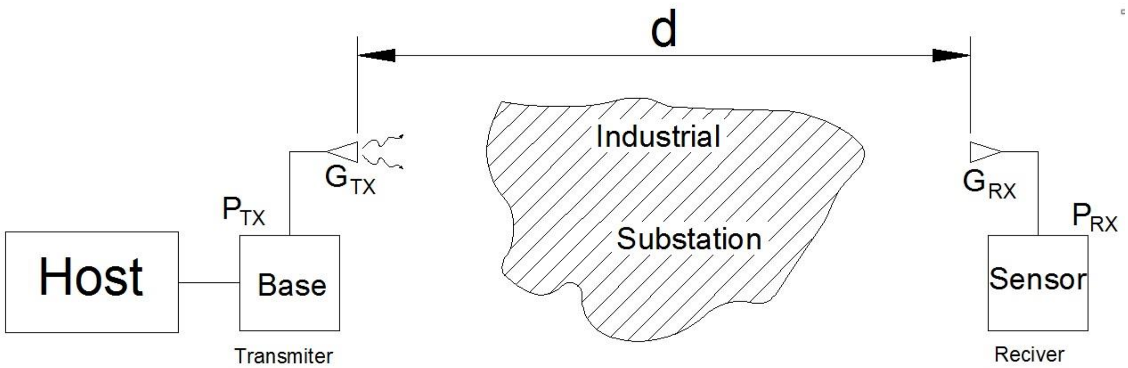

Figure 5: Wireless communication system.

System parameters:

- P_{TX} – transmission Power = 10 dBm;
- G_{base} – sectorial base antenna gain = 12 dBi;
- G_{sensor} – omnidirectional sensor antenna gain = 8 dBi;
- Sensibility – the lower receiving power needed to obtain an specific BER = -97 dBm;
- Modulation format = 2-FSK;
- Deviation = 177.734375 kHz;

- Base frequency = 915.999725 MHz;
- Carrier frequency = 915.999725 MHz;
- Sync word qualifier mode = 30/32 sync word bits detected;
- Preamble count = 4;
- Channel spacing = 405.456543 kHz;
- Data rate = 4.79794 bps;
- Rx filter BW = 541.666667 kHz.

Figures 6, 7 and 8 show the test bed photographs.

Figure 6: Base sectorial antenna.

Figure 7: View of substation and sectorial antenna.

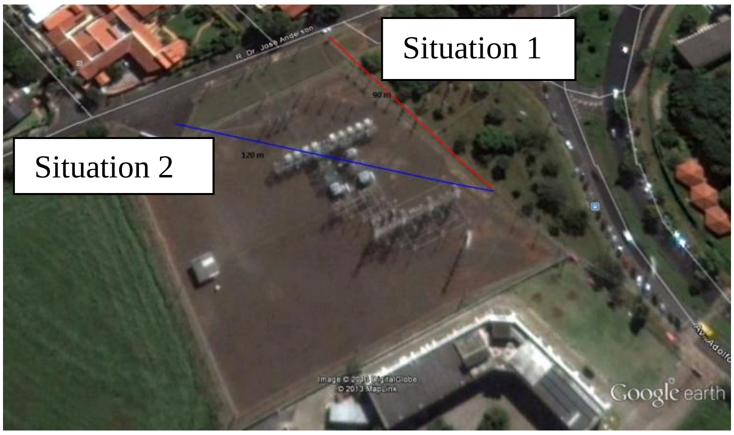

Figure 8: The two situations analyzed.

The sensor antenna was Omni-directional and the base antenna Panel Standalone 900-928 GHz, 12 dBi, which radiation diagram can be seen in Figure 9.

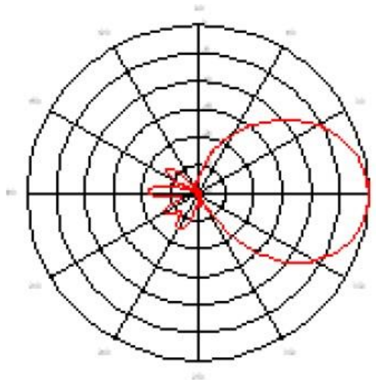

Figure 9: Base antenna with 60 degree of aperture angle.

RESULTS AND ANALYSIS

A - Test Characterization

Two data sets were collected considering the two situations showed in Figure 8:

1. Without the substation between the base and the sensor node;
2. the substation between the base and the node sensor.

The experiment aims to evaluate these two situations calculating the path loss β and the standard deviation σ. The signal is collected in *dBm* in a 2 seconds period. On Situation 1, 424 measurements were made and on situation 2, 824 measurements were made. The number of samples was sufficient to cognize a regularity of the data, as showed in Figure 4. The RSSI of up and down link as measured to verify a possible asymmetry in the two paths.

Firstly the data must be converted from dBm to Watt for the signal average calculation. Then, the results was converted to *dBm* again to determine the path loss *β*.

To determine the standard deviation *σ* the set of data was manipulated directly in *dB* (RAPPAPORT, 2009). First is calculated the average, which is subtract of each data point. The result is a random variable with zero average, as mentioned in Section II, where is determined the probability distribution and the standard deviation *σ*.

B - Path Loss β

The system loss (L_S) is 10dB measured in laboratory and the reference distance is considerate 1 meter to compare the two situations.

Considering the values of the parameters of system, and using Equation 2, is calculated the P_{RX} (d_0) = -11.68 dBm. Considering the average power of each situation is determined the values of *β*. Table 1 shows the path loss.

Table 1: The *β* value for the two situations.

	Down Link		Up Link	
	β	$\overline{P_{RX}(d)}$ [dBm]	*β*	$\overline{P_{RX}(d)}$ [dBm]
Situation 1	3.143	-73,1	3.189	-74,0
Situation 2	3.065	-75,4	3.094	-76,0

C - Statistics Analysis.

The Probability Mass Function (PMF) curve can be plotted. Figures 10 and 11 show the distribution curves for each situation, (BUSSAB, 2003), (DANTAS, 2000).

Figure 10: Probability function for the 1st situation.

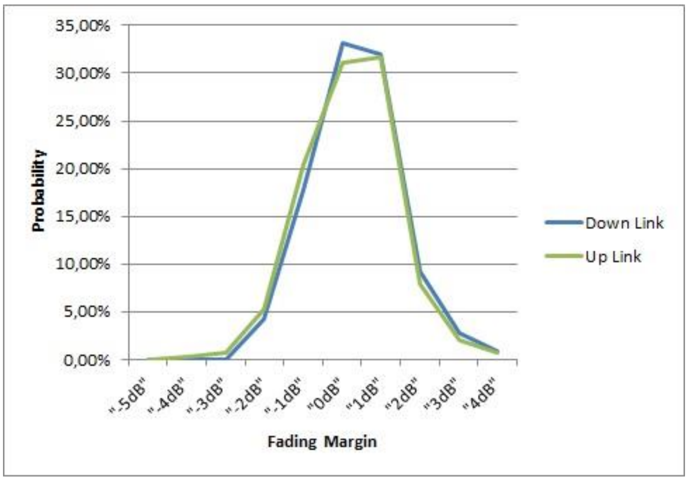

Figure 11: Probability function for the 2nd situation.

The two curves present a symmetrical behavior, which demonstrate that the Gaussian function shape can be considerate. But, the standard deviation and average have differences as showed in Table 2.

Table 2: The σ value for two situations.

	Down Link	Up Link
	σ [dB]	σ [dB]
Situation 1	2.62	2.39
Situation 2	1.10	1.15

Figures 12 and 13 show the Cumulative Distribution Function for the two situations.

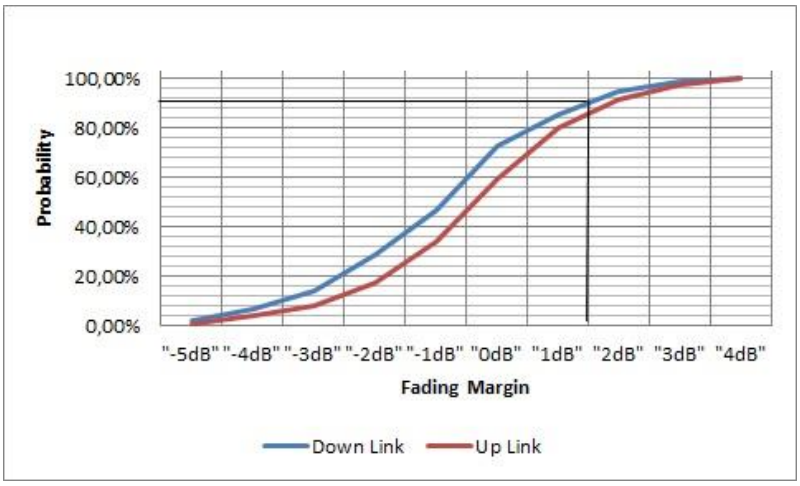

Figure 12: CDF for the 1st situation.

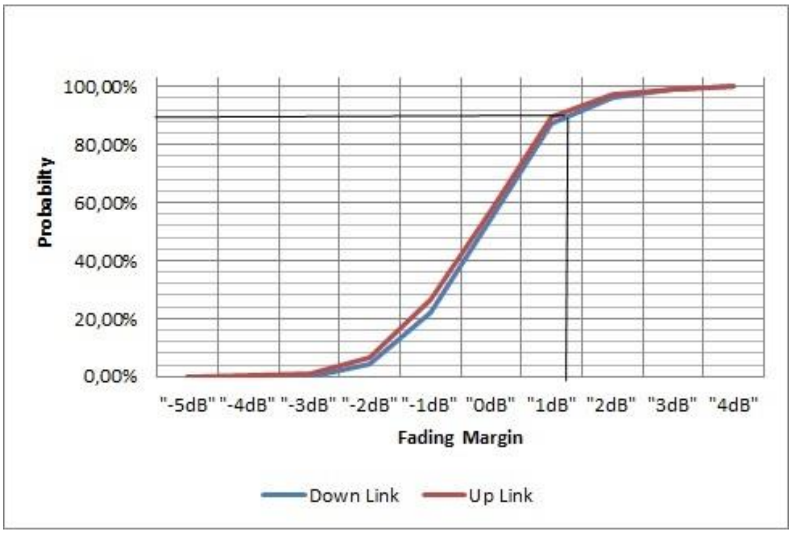

Figure 13: CDF for the 2nd situation

Comparing the two analyzed cases, it is possible to see the difference of 1.7 dB. This is a small difference that indicates that the two situations are similar.

The data analyzed show that the use of 915 MHz sensors networks did not commit the quality and reliability, when operating in a substation environment. For the two cases studied, the standard deviation, lower for the 2nd situation, occurred due to the fact that the measurements made inside the substation did not suffer the effects of the vehicles transit nearby the antennas as showed in Figure 8; for the 1st situation, the cars and buses traffic caused higher standard deviation. Therefore, it can be noticed through this experiment that, the power transformer operation in 60 Hz did not cause any radio link reliability loss or damage.

CONCLUSION

The work shows that an electrical equipment's monitoring and/or controlling system, using 915 MHz sensors networks, are not influenced anyhow by high power electrical devices operating nearby. Its reliability depends only of the design accuracy, considering the environment where the sensors network is going to operate.

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