

## A Wireless Sensor Networks Management Strategy for the Small and Medium Sized Manufacturing Enterprises

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**Abstract:** The demand for Wireless Sensor Networks (WSN) applied to industrial process monitoring and control is increasing as the forth industrial revolution (Industry 4.0) gathers pace. Flexibility and low cost make WSN the perfect choice for these modern 21<sup>st</sup> century manufacturing plants. Small and Medium Sized Enterprises (SMEs) have an important role in the growth of developing economies as they account for approximately 60 % of all private sector employment, but are currently finding it difficult to take advantage of new sensor technologies. This paper describes the tests carried out with a WSN in order to ascertain the relationship between the Received Signal Strength Indicator (RSSI) and the Packet Error Rate (PER). Subsequently, a new RSSI based network management strategy is presented; it includes two RSSI tracking indices that guarantee an early warning in case of radio signal deterioration. Both indices are generated in real time; the first estimates the RSSI tendency allowing for the mapping of a sample position in the set and its value, while the second compares the current RSSI to a preconfigured reference value. This article ends with the implementation and testing of the strategy on the ScadaBR Supervisory System.

**Keywords:** Wireless sensor networks, WSN, PER, RSSI, Network management.

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### 1. Introduction

Small and Medium Sized Enterprises (SMEs) contribute decisively for the advancement of developing countries. Worldwide, SMEs account for about 52 % of private sector value added, varying from 16 % of the gross domestic product (GDP) in low-income countries to 51 % of GDP in high-income ones. SMEs dominate the world business stage; estimates suggest that more than 95 % of enterprises across the world are SMEs, accounting for approximately 60 % of all private sector employment [1].

With the advent of the fourth industrial revolution (Industry 4.0), automation with the use of industrial WSN should intensify since one of the main characteristics of these networks is their great flexibility in terms of installation, which meets the needs of the modern 21<sup>st</sup> century manufacturing plants, regarding the flexibilization of the general arrangement of equipment [2]. Due to its inherent flexibility, it would be natural for control and not just process monitoring to be done with the use of WSN [3].

Smart factories will allow machines and materials to communicate while on the assembly line. At the

beginning of the process, each product will bring with it a chip with the necessary information for its assembly, and, as it advances in the line, it will communicate with the equipment by means of Identification by Frequency of Radio (RFID).

If compared to wired networks, WSN offer substantial advantages in terms of installation, commissioning and maintenance [4]. They can cover areas that were previously out of physical or economic reach, thus allowing the improvement of processes. Remote areas and physical obstructions are no longer a barrier.

The signal tends to be degraded by the type of processes executed in the area and by the infrastructure density, which can be estimated by mapping the areas where the sensor nodes will be installed, classifying them as low, medium and high.

A WSN is composed of a group of transceivers that monitor processes and environments and control

actuators. Commonly monitored parameters include temperature, humidity, pressure, flow, liquid level, luminosity, vibrations, voltage and concentration of pollutants. These networks are composed of several monitoring stations called sensor nodes that should be small, light and portable, a sink node and a central with enough processing power to receive and handle the data. Each sensor node should be equipped with a transducer, a microprocessor, a transceiver, a power source and, optionally, an actuator. The transducer generates an electrical signal based on physical effects, the microprocessor processes and saves the data while the transceiver sends and receives it to the monitoring centre.

Fig. 1 shows a diagram of a WSN. The Subsystem A can be considered as the client and is characterized by databases and network managers that request information from the Subsystem B.

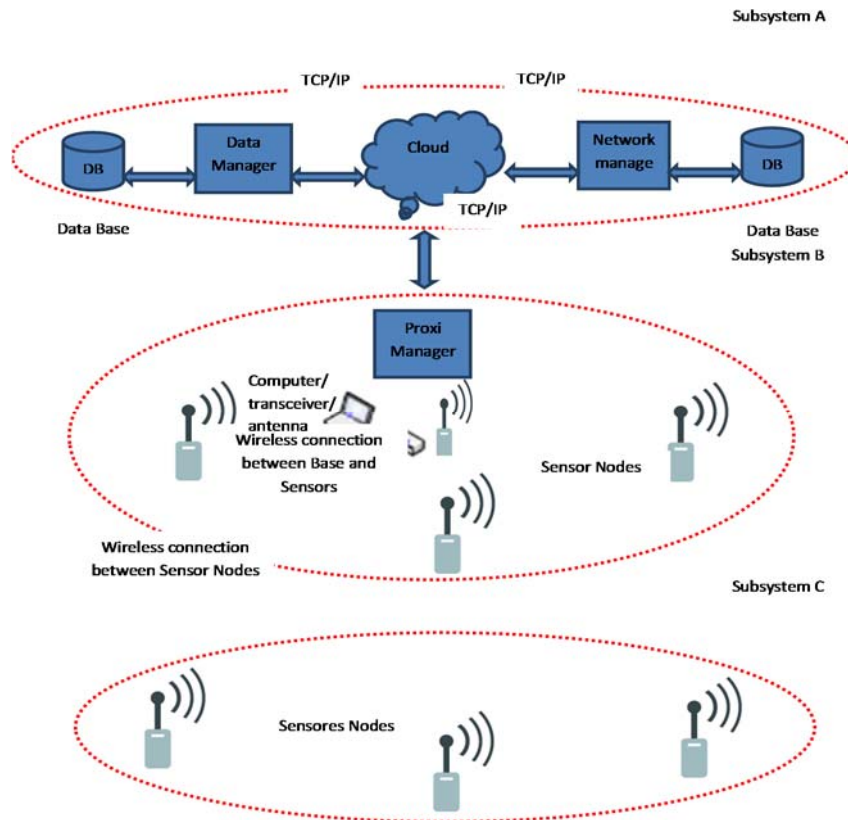


Fig. 1. Typical WSN Diagram.

The Subsystem B consists of a proxy manager, with the possibility of insertion of a database at this level. The proxy manager requests the data being monitored and converts it to the cloud protocol, Transmission Control Protocol/Internet Protocol (TCP/IP). This subsystem is complemented by the sink node (computer/transceiver/antenna) and sensor nodes (sensor/transceiver/antenna) which in turn, depending on the topology, route the packets to the sensor nodes of the Subsystem C.

The Subsystem C is composed primarily by the managed agents, sensor nodes that communicate wirelessly with the Subsystem B.

The *raison d'être* of a WSN is to monitor and control processes and environments [5], while a manufacturing process can be defined as a systematic series of operations executed to produce something. The management of a WSN must define a set of functions that will integrate configuration, monitoring, operation and maintenance of the network services and

devices [6]. Table 1 compiles the service classes for industrial environments, according to the International Society of Automation (ISA).

**Table 1.** Service Classes (ISA).

Use	Class	Description	Characteristic
Safety	0	Emergency Action	Always Critical
	1	Control	Usually Critical
Control	2	Supervision Control (Closed Loop)	Usually not Critical
	3	Open Control (Open Loop)	Human Action
Monitoring	4	Alert	Few Consequences
	5	Logging, up e download	No immediate Consequences

Currently in industrial environments, WSN are usually employed in monitoring processes, Classes 4 and 5, but not so commonly in control, Classes 1, 2 and 3 [4].

Network traffic, when used in monitoring and process control, includes continuous, asymmetric and spontaneous data transmission [7].

Some of the biggest challenges in the development of WSN are:

- Device limitations: battery capacity, size and weight;
- Topologies: Dynamic routing is subject to changes over time due to different processes and activities;
- Adverse conditions: problems with the propagation of radio waves, multipath, noise and interference caused by equipment and machines;
- Aggressive environment: environments with great thermal variation, vibrations, humidity, condensation and pollutants;
- Quality of service (QoS): WSN will attend processes with different demands;
- Security: WSN must have strategies to deal with internal and external attacks;
- Scalability: growth or changes in network topology;
- Integration: need to be compatible with existing infrastructure [8].

The transmissions of the process state readings (downlink) and the actuators control commands (uplink) use half-duplex as they occur in different time slots and must meet the requirements of the processes round trip times (RTT) [9].

For use in process control classes one, two, or three, timing is an essential parameter. The WSN must have low jitter and low delay. In [10] it is defended the use of the point-to-multipoint (star) topology, as this dispenses with routing between sensor nodes, reducing jitter and delay. This strategy, however, may limit the reach of WSN, a difficulty that can be minimized by the use of high-power transceivers.

Point-to-multipoint routing, if not well planned, can also cause reliability difficulties in the communication due to the lack of path redundancy between sink and sensor nodes.

A mesh topology with static or even dynamic multi-hop routing offers the possibility of path redundancy, but may compromise timing. Thus, the choice of network topology depends on the particularities of the project; distance between sensor nodes, density, processes criticality, equipment position, plant size, etc. [10], requiring careful planning.

With the use of devices and paths redundancies, a WSN may have greater availability than a wired network, however to ensure system reliability, network availability and data reliability must be assured. In wireless communications, the received signal strength is medium dependent [6]. The signal, when crossing the environment, suffers fading, caused by the degradation, absorption and attenuation of the radio signal. Interference in the same frequency band as the WSN can corrupt or even disable the signal [7].

The processes criticality and the characterization of the signal and medium generate subsidies to the network management system. The more critical the process is, the more reliable the link needs to be [11]. The International Organization for Standardization (ISO) divides the network management into five distinct areas. This classification was developed for the Open System Interconnection (OSI) model:

- Configuration management - controls, identifies and collects data from and supplies data to managed objects;
- Performance management - evaluates the behavior of managed objects and the effectiveness of the communication;
- Fault management - enables the detection, isolation and correction of abnormal operation of the OSI environment;
- Security management - addresses aspects essential to the safe operation and protection of managed objects;
- Account management - enables charges to be established and costs to be identified [12].

A strategy that assists in estimating the Received Signal Strength Indicator (RSSI) tendency with relation to a threshold would be relevant to the performance and configuration managements, as actions could be taken before that threshold is reached.

Supervisory Data Acquisition and Control Systems (SCADA) are industrial control systems used in the monitoring and control of remote devices. These systems collect data from remote sensor nodes in real time in order to monitor and control communication networks, including alarm monitoring, data processing, and equipment and conditions control. Based on the information from remote sensor nodes, manual or automatic commands can be executed on remote devices [13].

The WSN solutions currently offered by large solution providers tend to be complex, non-centralized

and expensive [3] putting these solutions out of the reach of most SMEs, considering that, differently from large corporations, these companies have neither the capital to acquire nor the dedicated departments to manage these new communication technologies [13].

Big WSN suppliers tend to offer solutions for the needs of large enterprisers, with prices that can reach millions of dollars. These suppliers offer large, noncentralized networks that grant the routing decisions to the nodes [14-16], effectively rendering the network hostage of the topology, impacting in its control. This reality does not really attend the necessities of SMEs regarding cost, control and complexity. Usually, these plants are small in area, demanding cheaper, less complex network solutions. Centralized solutions also allow for full network control.

For the tests in this paper, we used a low cost, centralized WSN approach geared towards SMEs, where the network manager has total control over its running.

We also identified a shortage of low-complexity network summarization solutions that can be used by non-technical operators working in SMEs. For that reason, in this paper, we present a management strategy that uses the RSSI as the main metric.

This paper is organized into eleven sections: in Section 2 we compare different WSN solutions, in Section 3 we explain the relation between RSSI and Packet Error Rate (PER), in Section 4 we present the Radiumo Platform, in Section 5 we specify the testing set up, in Section 6 we show the benchmarking test results, in Section 7 we introduce the indices management strategy, in Section 8 we describe the tests done with the strategy, in Section 9 we show the strategy implementation on a supervisory system, in Section 10 we show the tests done and in Section 11 we present our conclusions and future work.

## 2. WSN in the Industry

Since WLANs, Bluetooth, Wi-Fi, Wireless Hart and ZigBee, to mention just some, were introduced, a lot of the effort was focused on the non-licensed Industrial, Scientific and Medical (ISM) band of 2.4 GHz as some systems can require higher data rates. However, in some cases, this band may get overcrowded, degrading the signal. There are, however, other non-licensed bands reserved for ISM applications that can be used for wireless communication [17].

The 915 MHz ISM band is narrow and limits the maximum data rates. Applications such as SCADA, where the data requirements are lower than applications found in the 2.4 GHz frequency band, can use the 915 MHz band.

In this paper, we use a platform which operates on the 915 MHz band as there are no restrictions for the use of this ISM band regarding the application type [17].

## 3. The RSSI-PER Relation

The RSSI was chosen as the main metric in this study since link quality monitoring methods based on hardware, e.g., Link Quality Indicator (LQI), Signal to Noise Ratio (SNR) and RSSI, make use of basic metrics provided by the chip that, if compared to software solutions, require far less overhead allowing for a better response to changes on the link [18].

As indicated by [19], for a given scenario, there is a clear relation between the RSSI and the PER as the latter tends to go up as the former goes down. In this paper, we propose a strategy that takes advantage of this relation.

## 4. The Radiumo Platform

All measurements in this work were done using the low cost, open software, open hardware Radiumo platform [20]. The firmware used in the transceivers was developed using the Radiumo Integrated Development Environment (IDE). The Radiumo platform is structured in layers of protocol akin to the TCP/IP.

The RSSI and PER monitoring applications were developed in Python 2.6 [21] and the supervisory system used for the management was the open software ScadaBR [22].

The transceiver used was the BE990 radio module, with dimensions of 32.0 mm×24.4 mm×1.5 mm, as shown in the top of Fig. 2. It operates in the ISM band of 915 MHz and uses FSK modulation. The module was configured with a baud rate of 38.38 kbps. The BE990 complies with the regulations of the Brazilian National Telecommunications Agency (ANATEL), features an Atmega 328 micro controller, a Texas CC1101 transceiver and a Texas CC1190 RF amplifier [23].

At the sensor nodes, the module was mounted on the DK104 development board [20].



Fig. 2. BE990 and UartSBee.

This board has a voltage regulator that allows the use of power sources between 5 V and 14 V as shown in Fig. 3. The sensor nodes used in this study were always powered by 12-volt batteries.



Fig. 3. DK104 Development Board.

The DK104 does not have serial USB output for communication with the computer and therefore could not be used as the sink node. For this purpose, we employed the UartSBe module as it has a mini USB output, shown in bottom of Fig. 2.

The transceiver provides the parameter used in this study, the RSSI. It represents the signal strength observed at the transceiver at the time of reception in dBm [24]. The RSSI may suffer noise interference from other transmissions [25]. However [26] proves that the RSSI can be a good indicator of link quality, as long as this value is above the sensitivity limit of the device, which in the case of CC1190 is -112 dBm [23]. The RSSI is measured as an integer and then converted to dBm by subtracting a constant [25].

Through tests, it was validated that the BE990 presents up and downlink RSSI symmetry and for this reason, in this work, only the downlink RSSI values, that is to say, the perceived power in the sensor node, was used.

## 5. Benchmarking and Set Up

Benchmarking tests were carried out on all modules before any tests with the strategy were carried out.

For the benchmarking tests, the wireless communication link between the sink node and each remote sensor node was emulated using a coaxial cable.

To avoid saturation, Mini-Circuit attenuators were placed between the module in the sink node and the modules in each sensor node, as indicated in Fig. 4.

In turn, the modules of each sensor node were placed in a sealed RF test chamber, so to check their normalization and assess their PER and RSSI results with minimum electromagnetic interference (EMI).

## 6. Benchmarking and Correlation Tests

The results of the benchmarking tests are summarized in Table 2. It shows that all modules were conforming, returning very similar values of RSSI and

PER for the same attenuation scenario, in this case 90 dB. The highest standard deviation was just 0.13 dBm and the highest PER only 1.6 %, indicating good stability of all modules. The results indicated that the modules could be considered normalized and could be used in the correlation tests.

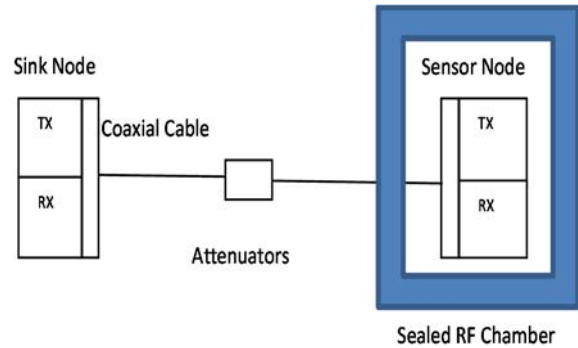


Fig. 4. Emulation Setup Diagram.

Table 2. Benchmarking results.

Sensor	SSI (average)	S.D. (dBm)	PER (%)
S1	- 42.50 dBm	0	0
S2	- 42.50 dBm	0.13	1.6
S3	- 42.00 dBm	0	0

The same set up shown in Fig. 4 was used again to collect the information that allowed correlating the RSSI to the PER. This time, the attenuation was gradually increased, thus reducing the RSSI level at the sensor node and consequently increasing the PER, so to find the RSSI level corresponding to the 5 % PER reference level ( $R_v$ ) suggested by [27]. To guarantee the reliability of the results, three series of 200 packets each were sent to each sensor node. The data presented in Table 3 shows the average results of the three-test series.

Table 3. Correlation RSSI – PER.

RSSI Average (dBm)	PER (%)	RSSI St. Dev. (dBm)
-45.0	0	0.11
-52.0	0	0.31
-63.0	0	0.38
-69.5	0	0.64
-70.0	2.0	0.57
-71.5	2.5	0.69
-72.0	4.5	0.76
-75.0	5.0	0.57
-77.5	12.5	1.15
-80.0	38	4.41

The results indicate that -72 dBm is the maximum RSSI before the PER reaches the 5 % reference level  $R_v$ .

## 7. Indices Zr and Zt

Indices aid in the monitoring work since they simplify the comparison of a current state with a past or predefined one.

This paper presents a management strategy that includes two indices, both generated in real time. The first estimates the trend of RSSI allowing for the mapping of a sample position in the set and its value, while the second compares the current RSSI to a preconfigured reference one.

These indices are loosely based on the Box Plot diagram and therefore present benefits such as the low complexity calculations required to obtain them, thus ensuring their easy implementation in supervisory systems.

In order to evaluate the trend of the RSSI based on the signal dispersion, we propose the index Zr that is composed by the ratio of the average RSSI values of a large, configurable, sliding time window (Zb) expressed by (1), that can also be understood as the historical average, by the average of the RSSI values of a small, configurable, sliding time window (Zs) expressed by (2).

$$Z_b = \bar{x} = \frac{x_1 + x_2 + \dots + x_m}{m}, \quad (1)$$

$$Z_s = \bar{x} = \frac{x_1 + x_2 + \dots + x_n}{n}, \quad (2)$$

where  $m > n$ .

The index Zr, expressed by (3), shows how far Zs departs from the historical average Zb indicating the dispersion and, more importantly, the RSSI trend, with the advantage of returning values around 1. This index is independent of the signal strength in which the sensor node operates. This feature allows for its easy implementation in the monitoring of wireless sensor networks; since these sensor nodes are usually positioned in different areas, they tend to present different RSSI levels.

The index Zr will tend to 1 as Zs approaches Zb.

$$Z_r = Z_b / Z_s \quad (3)$$

The second index, Zt, expressed by (4) tracks the value of Zs in relation to a reference level Rv value correlated to a PER threshold and tends to 1 as Zs approaches this reference value. This index is dependent on the signal strength at which the sensor node operates.

$$Z_t = R_v / Z_s \quad (4)$$

The observation of these two indices gives the operative in charge of the network a clear vision of the sensor nodes current situation with respect to the RSSI and, consequently, the PER.

## 8. Indices Testing

For the preliminary tests of the strategy, a WSN as specified in Section 5, comprising a sink node and a single sensor node was setup with the sensor node operating with a RSSI level above the reference level Rv of -72 dBm, as established in Section 6, allowing for the mapping of the RSSI variation to the increase of the PER. From this data, the indices Zr and Zt were extracted and compared to the RSSI behavior. The choice of the sliding time window for the tests was based on the Quality of Service (QoS) we expect industrial processes will demand from a WSN, so the sliding time window used for Zb was 60 minutes, and for Zs, it was 1 minute. However, these values are still subject of research. To validate the results, graphical comparisons between the variation of the RSSI and Zr, RSSI and Zt and Zr and PER were done.

Fig. 5 shows the RSSI with values in dBm on the primary vertical axis against the index Zr with values on the secondary vertical axis and the number of packets on the horizontal axis.

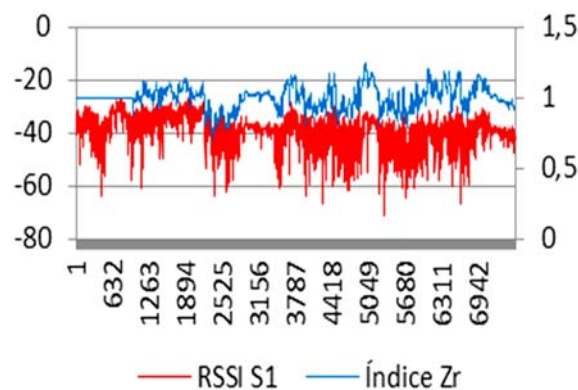


Fig. 5. RSSI x Index Zr.

The graph shows that the index Zr was equal to 1 up to approximately the packet 1000, which is equivalent to the 60 minutes required for Zb to be established. From that point on, the index tracks the variation of RSSI, always centered on 1 and differs from the RSSI as it considers the averages of the last 1 and 60 minutes sliding windows. This feature dilutes the impact of possible extreme and discrepant samples.

The graphs in Fig. 6 show the RSSI with values in dBm on the primary vertical axis against the index Zt with values on the secondary vertical axis, and the number of packets on the horizontal axis. The index Zt tracked the RSSI variation with respect to the reference level of -72 dBm that was never reached.

The index Zt acts as an alarm that is triggered whenever the RSSI reaches the pre-defined reference value, since its permanence at or below this threshold indicates an increase in the PER.

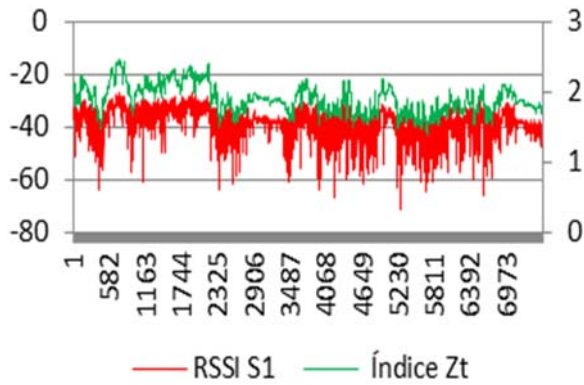


Fig. 6. R SSI x Index Zt.

Fig. 7 presents the index Zr with values on the primary vertical axis against the PER with values on the secondary vertical axis and the number of packets on the horizontal axis.

The graphs show that although the PER was consistently very low, it was higher at the times when the index Zr was below 1, that is, when the RSSI was below its historical average. It is important to observe that the graph of the PER is shown as the hourly average of its values.

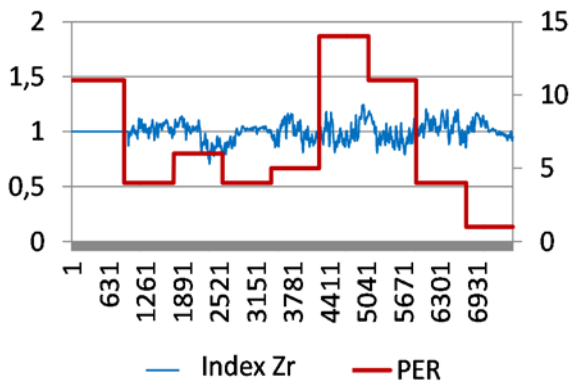


Fig. 7. Index Zr x PER.

The results shown on the graphs confirm the robustness of the indices Zr and Zt and their applicability as a wireless network management strategy.

### 9. Implementation on Supervisory

The strategy was implemented on the ScadaBR Supervisory System. For the tests, a WSN as specified in Section 5, consisting of a sink node and three sensor nodes using a point-to-multipoint topology was set up, as shown in Fig. 8. The supervisory system was configured to collect the downlink RSSI data from each sensor node, calculate Zs for the last minute and Zb for the last 60 minutes.

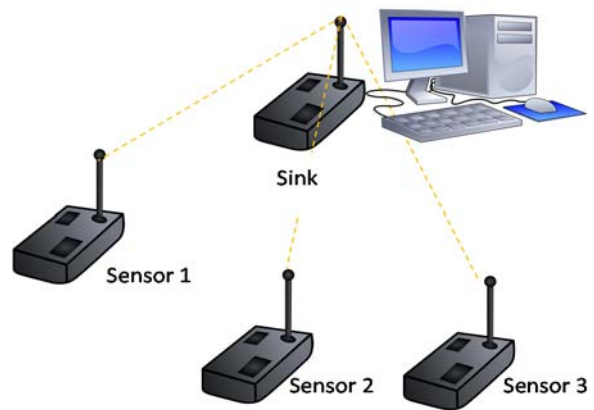


Fig. 8. Point-to-Multipoint Topology.

Monitoring via supervisory system allows the construction of graphical interfaces in which different levels of information can be presented, contemplating different levels of knowledge [5]. Figs. 9, 10, 11 and 12 show the ScadaBR screen. In each figure, the bottom chart on the right, "RSSI Sensors 1, 2 and 3" brings information that will be appreciated by a technically qualified person, the network manager, for example. The upper chart on the right, "Indices Sensors 1, 2 and 3" will be of great value for a person that is interested in the network but not necessarily technical, such as the production manager. The most concise information appears on the left side of the dashboard, with the Limit and Tendency light emitting diodes (LEDs) that are intended to alert a person that is not necessarily interested in the network, but dependent on it, such as a machine operator. Fig. 9 shows a snapshot of the graphs obtained with sensor nodes 1, 2 and 3.

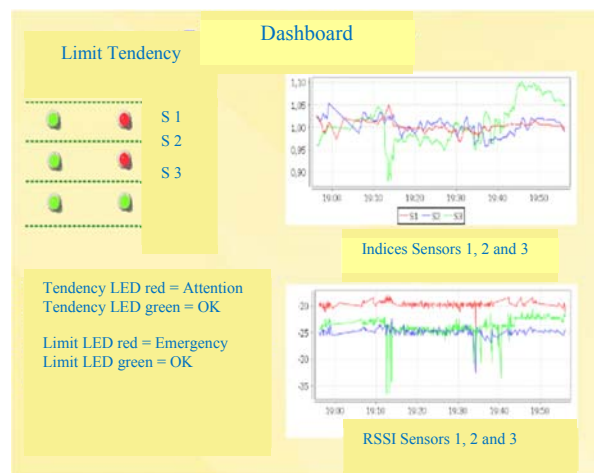


Fig. 9. Supervisory System Dashboard.

The chart "Indices Sensors 1, 2 and 3" shows the variation of the index Zr for each sensor node while the chart "RSSI Sensors 1, 2 and 3" brings the variation of RSSI.

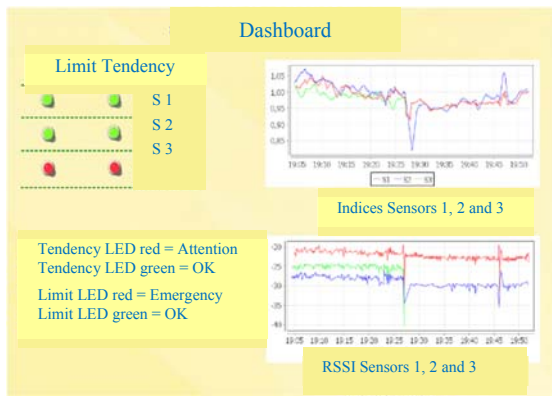


Fig. 10. Supervisory System Dashboard – First Test.

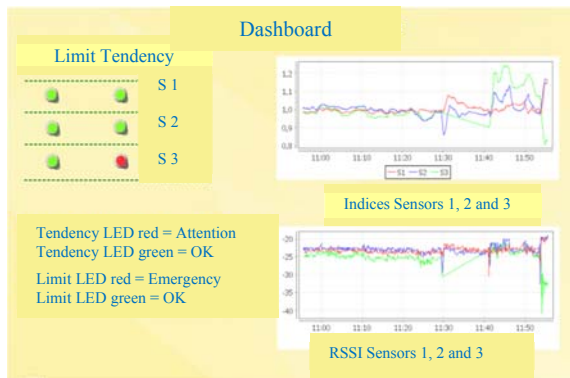


Fig. 11. Supervisory System Dashboard – Second Test.

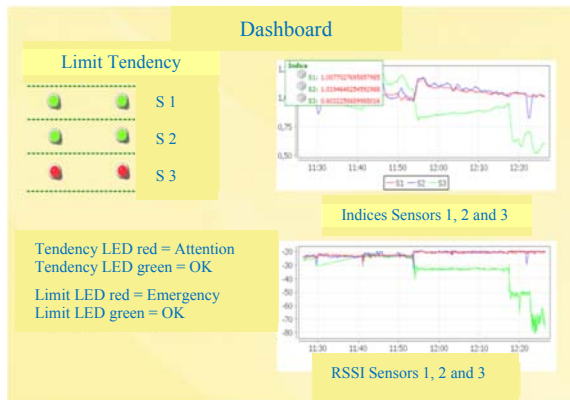


Fig. 12. Supervisory System Dashboard – Third Test.

On the left, the Limit LEDs flash green while the index  $Z_t$  is above the reference value, in this case  $-72$  dBm, and red when  $Z_t$  is at or below it, and the Tendency LEDs that indicate the position of the index  $Z_r$ , flashing green while it is above 1 or red when it's below. For the sake of screen simplicity, we chose not to present graphs with the  $Z_t$  index variation. It can be seen that the Tendency LEDs for sensor nodes 1 and 2 were red indicating that RSSI on these two nodes were in a downward trend. This fact can be confirmed by the graph "Indices Sensor nodes 1, 2 and 3" as the trend lines for sensor nodes 1 and 2 (red and blue lines) end below 1.

## 10. Stress Testing

To validate the use of the indices strategy on the ScadaBR Supervisory System, we extended the use of the test setup described in Section 8. Tests introducing unexpected situations of use were carried out. These tests were useful to reveal any potential problems with the strategy on the supervisory system, such as performance or behavior issues, errors on startup, shutdown or on the interface.

The first test, shown in Fig. 10, was done in order to ascertain what would be the supervisory system behavior in case one of the sensor nodes became unavailable.

The network was started, and the 60 minutes needed for Zb to be established were observed. To simulate unavailability, the sensor node 3 was purposely disconnected from power.

The Limit and Tendency LEDs for the sensor node 3 immediately lit up in red and the green trend lines for the sensor node 3 on graphs "Indices Sensors 1, 2 and 3" and "RSSI Sensors 1, 2 and 3" disappeared. We conclude that the strategy in the supervisory system behaved as expected.

The second test, shown in Fig. 11, investigated the behavior of the indices strategy on a supervisory system in case of sudden signal deterioration. For this test, the sensor node 3 was distanced from the sink node, simulating signal deterioration. Again, it can be seen that the Tendency LED for sensor node 3 lights up in red and the green line in the "RSSI Sensors 1, 2 and 3" graph reaches values below  $-40$  dBm, reflecting accurately the node situation.

The third test, shown in Fig. 12, investigated the supervisory system behavior in case of acute signal deterioration.

For this test, the sensor node 3 was moved even further away from the sink node to a point where the RSSI reached and exceeded the reference value  $R_v$  of  $-72$  dBm, established in Section 6.

In this test, the dashboard shows the sensor node 3 Limit LED in red, indicating that the RSSI on that sensor node was below the reference value, which can lead to a PER above 5%. This condition was confirmed by the graph "RSSI Sensors 1, 2 and 3" as the green trend line for sensor node 3 reaches values below  $-80$  dBm. The Tendency LED for that node also lights up in red indicating a RSSI deterioration which can be confirmed by the graph "Indices Sensors 1, 2 and 3" where the sensor node 3 green trend line shows the drop of the index  $Z_r$ .

In order to carry out the last and most extensive test, all nodes were connected to mains power, in order to guarantee the uninterrupted supply of power. The test consisted of a continuous and uninterrupted use of the indices strategy on the ScadaBR for a whole week, in order to ascertain any possible system locking. At the end of that period, the tests pointed out that the system did not present any faults. The tests results with the indices strategy on the ScadaBR Supervisory System confirm the robustness of the solution.

## 11. Conclusions and Future Work

This paper objective was to demonstrate the feasibility of employing a new network management strategy based on indices that use the RSSI as the only metric, as this solution requires far less overhead allowing for a better response to changes on the link. For that, a testing set up using the Radiuino platform was assembled so data could be collected.

The preliminary tests with the indices strategy indicated that, when compared to the RSSI readings, the strategy presents an easier interpretation of the data as the impact of extreme and discrepant samples were diluted by it.

The strategy was also implemented on the ScadaBR Supervisory System where an interface that attended the needs of different levels of network expertise was created. The stress tests carried out then returned results that also confirmed that the strategy was stable and robust enough to be employed in the monitoring of WSN in SMEs and thus help these companies to take full advantage of the Industry 4.0 possibilities.

There are still a number of topics following from our findings that would benefit from more research, including the further development of the supervisory system, as other open source network and application monitoring software like the Zabbix could be tested and evaluated, and the development of a methodology for the choice of the sliding time window for the indices Zb and Zs, according to the different industrial plant environments and requirement settings.

Also, the deployment of the indices strategy in a real SME environment with sensors distributed across the plant, where adverse conditions like propagation issues and interferences in the spectrum are the norm, would allow for a better understanding of the real capabilities of the strategy

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## Online Experimentation: Emerging Technologies and IoT

Maria Teresa Restivo, Alberto Cardoso, António Mendes Lopes (Editors)

*Online Experimentation: Emerging Technologies and IoT* describes online experimentation, using fundamentally emergent technologies to build the resources and considering the context of IoT.

In this context, each online experimentation (OE) resource can be viewed as a "thing" in IoT, uniquely identifiable through its embedded computing system, and considered as an object to be sensed and controlled or remotely operated across the existing network infrastructure, allowing a more effective integration between the experiments and computer-based systems.

The various examples of OE can involve experiments of different type (remote, virtual or hybrid) but all are IoT devices connected to the Internet, sending information about the experiments (e.g. information sensed by connected sensors or cameras) over a network, to other devices or servers, or allowing remote actuation upon physical instruments or their virtual representations.

The contributions of this book show the effectiveness of the use of emergent technologies to develop and build a wide range of experiments and to make them available online, integrating the universe of the IoT, spreading its application in different academic and training contexts, offering an opportunity to break barriers and overcome differences in development all over the world.

*Online Experimentation: Emerging Technologies and IoT* is suitable for all who is involved in the development design and building of the domain of remote experiments.

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