EVALUATION OF A WIRELESS SENSOR NETWORK APPLIED TO PRECISION AGRICULTURE UNDER ADVERSE WEATHER CONDITIONS

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Abstract: *Wireless Sensor Networks (WSNs) need to be efficient in communication and power management. In order to achieve these requirements, there are technical obstacles to be overcome, highlighting those that enable mobility and portability combined with a lower power consumption, low latency and, in particular, the reliability of the data gathered by sensor nodes. Based on these principles, this paper presents the evaluation of a WSN applied to the measurement of soil moisture in irrigated crop area. The focus of this study is to present and discuss the factors that affect network stability and quality of data measurements under adverse weather conditions.*

Keywords: *Wireless Sensor Networks (WSNs), protocols.*

1. INTRODUCTION

Within the context of a WSN, we have the hardware and software associated to a range of values being collected across the network. However, ensuring continuity in sensor readings and obtain consistent values is still a challenge, especially under adverse weather conditions.

The most active weather systems in the central-southern Brazil, associated with air masses and fronts are causing severe local storms. These are characterized by localized torrential rains and accompanied, in general, by thunder, lightning, hail, strong winds, sudden changes in temperature and even tornadoes (Mendonça, 2010).

Considering the challenges in this environment, this paper proposes a review of WSN solutions that address the problems associated with network operation, having as reference a project in Precision Agriculture. This project is a quantitative approach, using methodologies such as field and experimental research. Regarding the techniques, those involve observation, literature review and analysis of content collected by the WSN. The quantitative method is, in principle, intended to ensure accurate results, avoiding distortions of analysis and interpretation, and allowing, therefore, a degree of certainty regarding the inferences [Lakatos & Marconi 1991].

2. BIBLIOGRAPHICAL REVISION

The Wireless Sensor Network has the task of collecting, monitoring and processing data in different environments [Oliveira, 2006]. The use of sensors to monitor expands the possibilities for increasing productivity and optimal results in the field.

A WSN is defined as a large number of equipment consisting of resources of sensoring, communication, storage, power supply and processing [Akyildiz and Wang, 2005]. According to Lamb and Agrawal [Agrawal & Lamb 2002], a WSN has the following characteristics:

Dynamic Topology - The sensors of a WSN can move in a dynamic and unpredictable way, continuously or in sparse movements, constantly changing network topology and establishing symmetric and asymmetric communication links. These changes must be identified by the other sensors in the network;

Limited bandwidth - Comparatively, wireless networks have a limited bandwidth compared to wired networks. Moreover, the range of ability of communication links, the effects from sharing access to the means of transmission, and interferences affect, significantly, the maximum rate of transmission of radio-transmitters;

Energy Limited Capacity - Some sensors may be located in places difficult to access or inhospitable, where the only available energy source would be the batteries, in which the power consumption becomes a major focus points for protocols;

Security - Sensors are exposed or the sign of the external network can reach external areas, making wireless networks more vulnerable than wired networks;

Decentralized Network - the provision of decentralized devices can enable multiple paths between the communicating entities, increasing the robustness of the network in case of failures in sensors.

Communications networks are classified into several types, highlighting that the applicability of each is defined by the proposed application. Directly related to the WSN, one can highlight the data communication networks of personal area of low transmission rate (Low-Rate Personal Area Network - LR-PAN), with the basic layers defined in the IEEE 802.15.4 [IEEE 802.15 .4]. These networks are used to provide wireless connectivity, having low complexity, low power consumption and low cost, besides simplifying the network control signaling.

There are several problems related to efficiency in reading, collection and data transmission in WSN. These problems can be data flow, routing, interference between channels of communication or excessive energy consumption. In our project, we highlight the consequences of electrical discharges which can disrupt the operation of sensors or "paralyze" the entire network for a period of time beyond the tolerated.

According to Casone (2007), difficulties related to network bottlenecks can be solved with algorithms that make the congestion control implemented on the IEEE 802.15.4. Regarding energy consumption, several studies are highlighted and, in particular, those which propose routing protocols derived from the Ad hoc On-demand Distance Vector (AODV) and Dynamic MANET On-demand (DYMO) [Raghuvansh & Tiwari, 2010].

Some studies suggest solutions to the problems of interference between multiple PAN's based on the IEEE 802.15.4 operating at various communication channels, which can cause noise and packet loss related to the frequency of operation of networks [Toscano & Bello, 2008] . Also related to packet loss, some studies provide analysis on the overlap of devices on networks and the problems associated to Packet Overlap [Subbu & Howitt, 2010].

3. METHODOLOGY

This project is being developed in partnership with Falke Agricultural Automation, located in Porto Alegre - RS. The company produces various devices for precision farming, and since October 2010, she is the sponsor of the equipment for the project's development, and promotes improvements to new product releases.

3.1 Used Software

The embedded software described here consists of the LNK2100 project, which proposes the development of a WSN to collect data on irrigated farming. The intention is to make use of components and interfaces already implemented in the operating system, making the most of its functionality.

3.1.1 LNK2100

The LNK2100 is a modular system based on the TinyOS operating system, which aims at establishing a WSN so that all the sensor nodes can participate in the routing of packets to a node data collector (ie, sink). For that, the Collection Tree Protocol (CTP) is employed already implemented in TinyOS. The system runs on TELOSB based platform that uses the MSP430F5418 processor [Pohren & Lange, 2010].

3.1.2 TinyOS Operating System

TinyOS is a simple operating system (OS) simple, considering as well a development environment. This OS was especially developed for applications in wireless sensor networks, based on components, a set of interfaces and the programming language nesC.

3.1.3 NesC

The nesC is an extension of C language. It allows to separate construction of composition. Applications written in nesC consist of components that can be constructed and combined to form an application, increasing the modularity and reusability of code [Pohren & Lange, 2010].

3.1.4 Collection Tree Protocol (CTP)

This is the network protocol used to make the messages routed to a collector node, using the most appropriate way. Its operation is based on creating a routing table using the information in the packets received from other nodes. Each node elects from among its neighboring nodes, a parent node that is the router of its messages. If, over time, the link with the parent node becomes weakened, the node will choose another neighbor [Pohren & Lange, 2010].

3.1.5 Dissemination Protocol

The purpose of the Dissemination protocol is to distribute small amounts of reliable data to all nodes in the network. This protocol allows different nodes to share a given variable, which may be a data structure containing the current network configuration.

When it becomes necessary to change this variable, the node that originated the change "spread" the new information for the other stations. Its working principle consists in, periodically, transmitting a data packet containing a sequence number that represents the current version of the variable data disseminated. Whenever any node notices that other nodes at hand have an older version of the information, it will send packets containing the latest version of the parameter to update the others [Pohren & Lange, 2010].

3.1.6 IEEE 802.15.4

The IEEE 802.15.4 offers the basis for developing a network mode of wireless personal area (WPAN) focused on low cost, low speed and ubiquitous communication among devices [Li-Chi F. C & Hsin-Yang, et.al, 2010].The IEEE 802.15.4 defines only the two lower layers of the OSI architecture: the physical layer and the layer of medium access control (MAC). The ZigBee is a standard that is based on IEEE 802.15.4, also considering the upper layers offering a complete solution for personal networks.

3.2 Used Hardware

Figure 1 shows the hardware devices used to build the WSN. In the first picture we have the image of an antenna and sensor already positioned on the ground; the second table presents only part of the device that is attached to the top of the shaft; the third includes a frame image of the data concentrator.

Figure 1 – Used Hardware

3.2.1 Sensors

Sensors are devices that receive and respond to stimuli or signals from the place where they are installed. There is a wide range of sensors that allow, for example, the light sensing, temperature, humidity, sound, motion, radiation and pressure. In this project, sensor nodes are being used from models HidroFarm HFM1010. In total, there are six sensors covering an area of 33 hectares, containing at its center an irrigation pivot with a radius of 300 m [Falk, 2010].

3.2.2 Data Concentrators

The data collection devices are computer systems composed of processor, memory, static and dynamic memory, entrance and exit bus connectors which and can be mobile or fixed, performing the function of acquiring the data collected by sensor nodes. In this project, the model data concentrator DBX1330 is being used, based on PIC18 series processors. Alternatively, we intend to employ Netbooks with Intel x86 architecture.

3.2.3 Antennas

The antennas are the beginning and end of the line of communication. They can add gains or losses for his guidance, both in transmission and reception. Its angle of elevation is based on its type, on the height from the soil and on the terrain around them (Caro, 2004). They can be divided into multi-band or narrowband, directional or omnidirectional, individual or joint antennas, with or without reflector, among others. In this project, omnidirectional antennas are used.

3.2.4 Radio Frequency

The transmission of data via radio frequency (RF) occurs by means of electromagnetic radiation in space via satellite. The propagation of electromagnetic waves can occur in line of sight or on the horizon, aided by refraction in the ionosphere. The behavior of wave propagation is directly related to the frequencies used. At low frequencies (ie, 30 Hz to 3 MHz), the waves propagate at greater distance, following the curvature of the earth waveguide formed between the Earth and the ionosphere. In these cases, there is great influence of climatic factors, both terrestrial and special (Caro, 2004). Otherwise, higher frequencies suffer less from these factors, but its range is more limited. The frequency bands are divided into bands, eg, Very Hight Frequency (VHF), Ultra Hight Frequency (UHF) and Super High Frequency (SHF). In this project, the selected devices are operating in the frequency range of 915 MHz

4. RESULTS

The installation of WSN took place on 12/09/2011, following an arrangement as shown in Figure 1, showing the monitored area and also the points of installation of each sensor node. Each node has its reference number identified with decimal digits. The arrangement of the nodes was defined following the limit range of the irrigation pivot, which is, in this case, 320 m range, following a tree topology in which the node 2 is set as root. The nodes 34, 36, and 38 were placed at a distance of 200 m from the center. However, the nodes 27 and 33 (one replaced the other in the period) were at 9 m from the center.

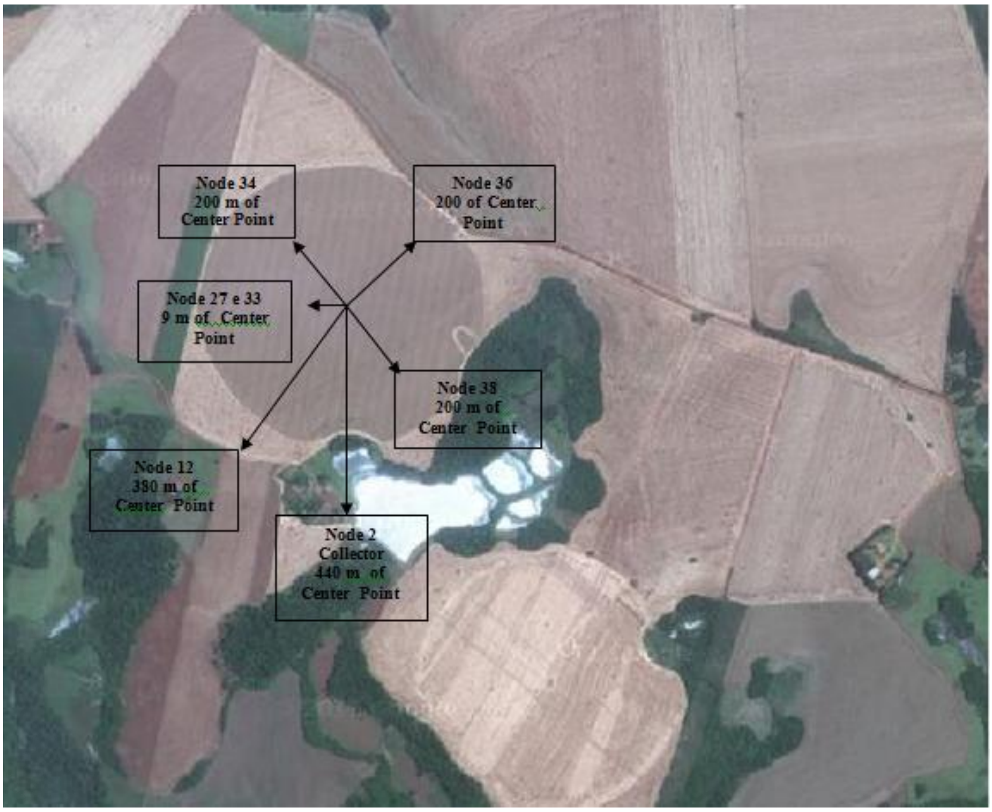

Figure 2 - Agricultural monitored area

The node 12 is positioned outside the coverage area of the irrigation pivot and has the function of collecting the moisture data to serve as a parameter to the readings from other sensors of the same value. Thus, it measures soil moisture under normal conditions, without forced irrigation, and its data are compared with others. The soil moisture data are not presented in this work.

To install the network, in addition to mapping the position of the sensors, operating parameters and data transmission were set, which are presented in Table 1.

Table 1 - Parameters of the network configuration.

Parameters	Default Configuration
Type of antenna	Measurement antenna
Radio channel	A
Reporting period	900 s (15 minutes)
Uptime radio	4 s (for collection)
Enabled sensors	• Battery Level • Sensor temperature • Soil Moisture

With these parameters adjusted and positioned in the area, the next step was to make the monitoring of variables that indicate the operating conditions of the network. These variables are presented in Table 2, listing the meaning of each one and the acceptable values, representing the ideal conditions of the network operation.

Table 2 - Variables related to the operating conditions of the network.

Variable	Description
Cycles	Time interval defined by the network administrator for data collection. A cycle corresponds to the reporting period of 15 minutes.
Energy	Level (%) of remaining energy in the node.
RSSI	Received signal strength in the first jump. It ranges from -128 (weak signal) to +127 (strong signal).
LQI	Signal quality in the first jump. Ranges from 0 (low quality signal) to 255 (signal quality).

The evaluation of the network occurred in the period between 12/09/2011 and 11/11/2011, and as the data has been collected, it was realized that the network had moments of instability in its operation, in which some of the nodes did not work and restarted after a period of time. To determine the cause of network failures, the days of the occurrence of instabilities were crossed with the ranges of values collected. With that realization, it was necessary to choose days of atmospheric instability to observe the network behavior.

Through *on-site observations* on days of unstable and rainy weather, we identified a break in the functioning of the nodes during periods of lightning. At a time when a node crashes, the routing protocol goes into action to restore the routes until the unstable node is working again.

After identifying the main source of instability of the network, the next step was to group the data collected from the entire period. Once grouped, the complete count of the total cycles of 15 minutes that the network produced. This total number of cycles was provided by the node 2 which is the root of the network and its operation was never interrupted.

Table 3 – Total cycles of operation per node.

COLLECTION PERIOD	Node 2	NODE 12	NODE 27	NODE 33	NODE 34	NODE 36	NODE 38
1st COLLECTION TO 12/09 23/09	2074	1883	1159	1511	1551	1450	199
2nd COLLECTION 23 / 9 TO 29 / 9	552	552	552	0	552	552	0
3rd GATHERING 29 / 9 15/10 TO	1502	1407	0	1132	1497	1486	1128
4th COLLECTION TO 15/10 31/10	1523	1345	1521	0	1475	1418	1516
5th COLLECTION TO 31/10 11/11	1046	1042	0	981	125	592	991
TOTAL CYCLES	6697	6229	3232	3624	5200	5498	3834
TOTAL FAILURE	**0**	**468**	**3465**	**3073**	**1497**	**1199**	**2863**

To make a detailed analysis of that behavior, we created a quantification of cycles, including periods of startup of the network. The analysis of each node over the total run time is shown in Table 3 and also illustrated in Figure 3. It is noteworthy that the node 2 is the benchmark on the run.

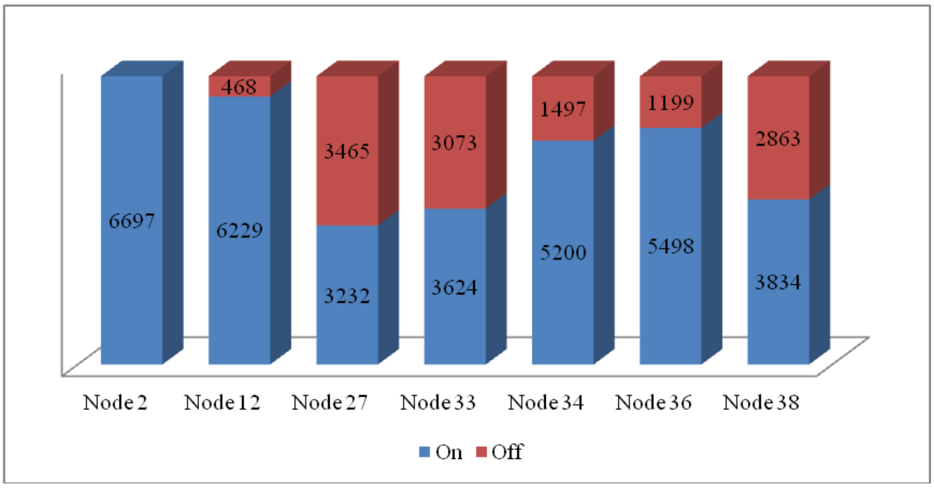

Figure 3 - Quantification of operating cycles.

Considering the total operating cycles, we highlight the node 12 which has the lowest failure rate, staying inactive for 6.9% of the time, and node 27, with the highest failure rate, with a total of 51.7% in the interval of 60 days.

With the quantified cycles values, the next step the details the behavior of each of the network nodes, the periods being dropped from the network boot. It should be noted that the cycle has a startup time of 10 seconds, unlike the collection cycles, which are of every 15 minutes. Objectively, the total cycles computation including the boots is 6697 and, without initialization, is 5720, which is the value used as a reference to the results reported in Table 4.

Table 4 – Operating Statistics of network nodes.

NODE	NUMBER OF CYCLES	AVERAGE ENERGY	RSSI AVERAGE	AVERAGE LQI	MEDIAN ENERGY	MEDIAN RSSI	MEDIAN LQI	ENERGY VARIANCE	VARIANCE RSSI	VARIANCE LQI	ENERGY STANDARD DEVIATION	STANDARD DEVIATION RSSI	STANDARD DEVIATION LQI	INT.RELIANCE ENERGY	INT.TRUST RSSI	INT.TRUST LQI
2	5720	100.00	- 63.85	179.37	100	127	255	100	127	255	0.00	96.37	115.43	ND	2.50	2.99
12	5443	71.72	-60.07	20.69	87	-72	0	88	-71	0	27.33	54.09	67.47	0.73	1.44	1.79
27	1649	99.99	-81.73	0.35	100	-82	0	100	-81	0	0.18	2.83	2.23	0.01	0.14	0.11
33	4539	90.10	-66.24	24.96	89	-85	0	100	-84	0	6.81	60.80	72.42	0.20	1.77	2.11
34	4745	92.67	-77.18	19.61	92	-89	4	100	-89	0	5.49	48.97	56.68	0.16	1.39	1.61
36	5146	39.81	-75.25	19.94	37	-90	3	0	-90	0	23.49	50.83	59.25	0.64	1.39	1.62
38	3635	49.45	-64.93	21.42	58	-79	0	59	-80	0	20.85	55.94	67.96	0.68	1.82	2.21

These variables indicate the quality of communication among network nodes, always using the parametric values set out in Table 2. It is noteworthy that the values in analyzed in Table 4 refer, of course, to the cycles of activity of each node.

It appears that none of the nodes, while active, suffers from the loss of signal quality (LQI) or has its signal strength (RSSI) significantly affected. That reinforces the thesis that keeping the network stable as long as possible under environmental adverse conditions is the main objective to be achieved.

5. FUTURE WORK

The findings and analysis presented define, clearly, the actual conditions of operation of a WSN installed in an irrigated farming. The impairment of reading the sensors directly affects the necessary analysis and decision-making on irrigation systems. As a future proposal, it is being prepared a mapping of network behavior in relation to the establishment of routes during outages, packet loss and energy consumption associated to each network node.

That way, it is possible to get a quality operation of the WSN and to minimize energy consumption at each node. Another point to note is the possibility of expanding the number of nodes and the number of monitored irrigated areas, as highlighted in Figure 2.

6. CONCLUSION

The study of WSN is extremely important, regardless of where they are installed. The focus of this paper is on an area of irrigated farming in the context of precision agriculture, where to collect consistent data is a major goal, since nowadays, the decision-making to drive the irrigation systems comes from meteorological stations far away from crops. Each precipitated or behind touch related to the correct time can mean a great waste of water and electricity or compromising the quality of the plant and profit of planted crops.

We know that the cycle that begins with data collection through construction of information, knowledge and ultimately the decision making needs to be achieved. Applying techniques that improve the operating conditions of the WSN is a determining factor, and this study demonstrates that there are still adjustments to be made at the hardware and software used. The deficiencies have been pointed out to the partner company, and adjustments are being made, which will allow more detailed future assessments.

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