Multi-Hop Protocol to Extend Signal Coverage

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***Abstract*—This paper describes the tests carried out with a Wireless Sensor Network in order to examine the radio coverage in the large space of a university food court. Due to the challenging environment, the development of a multi-hop protocol was necessary. The protocol deems a sensor node as a repeater to extend the signal reach. We used the Radiuino open-source platform to develop the protocol with the flexibility to design an address strategy in the packet. The preliminary results indicate that the protocol developed is feasible, stable and robust.**

Keywords-WSN; multi-hop topology; routing protocol.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) play an important role in Internet of Things (IoT) applications, having low-power sensors and easy installation. Indoor WSNs will be essential in smart homes, monitoring appliances and systems, such as closing the windows automatically based on the weather forecast [1].

Usually, a WSN consists of sensing nodes that report their results to a base station node. The base station node can process the data and monitor the network [2]. If a WSN needs to cover a wide area and the sensing nodes can not communicate directly with the base station node, a change in the topology of the nodes can be a solution.

In this project, the sensing nodes were placed inside the food court of the Pontifícia Universidade Católica of Campinas in Brazil, and the base station node was placed in a laboratory. The distance between the base station node and the repeater node was 200 meters. Although is a small distance, it is in non-line-of-sight (NLOS), making the direct communication impossible.

To extend the range of the signal, a multi-hop protocol was created, using protocol stacks with five layers, akin to the Transmission Control Protocol/Internet Protocol (TCP/IP) concept.

The rest of the paper is structured as follows. In Section II, we discuss the state-of-the-art. In Section III, we present the payout of the WSN. Section IV shows preliminary results and we conclude in Section V with the outcome of the experiment.

II. STATE OF THE ART

WSNs can have a distributed or a centralized routing protocol. The majority of articles found in literature use a distributed routing protocol, such as [3], [4], [5], in which the protocol runs in a peer-to-peer mode, requiring all the nodes to possess processing power. Another used protocol is the Routing Protocol for Low Power and Lossy Networks (RPL), but it is also a distributed protocol [6], being different from the protocol shown in this project.

Although, by using the distributed protocol, the system does not depend on a centralized process unit. It also uses more energy, decreasing the equipment's lifetime. The base station node, in both cases, always needs to be connected to the Internet and to have processing power.

Another advantage of centralized routing is the simplicity of the network nodes. Only the base station node demands more complex processing capabilities. It also allows the development of the multi-hop protocol, that would not be possible with a distributed routing management.

That simplicity makes it easier to meet the Quality of Service (QoS) parameters, like changing the routing path, changing radio attributes, such as power and channel. This ability is important for WSN operators, as seen in [7]. Without a centralized routing protocol, this operator can not attest to the QoS parameters.

Further, it is possible to change priorities, for example, the information importance of the nodes can change over time. Considering those aspects, the WSN of this paper has a centralized routing protocol.

III. MATERIAL AND METHODS

In this setup, we employed seven sensor nodes using the open *Radiuino* [8] platform, a library of Arduino that allows the user to work in five layers. This platform was chosen because it allows a change of network topology, differently from other platforms like *ZigBee* [9].

The logical view of the network is shown in Fig. 1. The base station node uses the first three layers (PHY, MAC and Net) while the sensors nodes use five layers (PHY, MAC, Net, Transp and App).

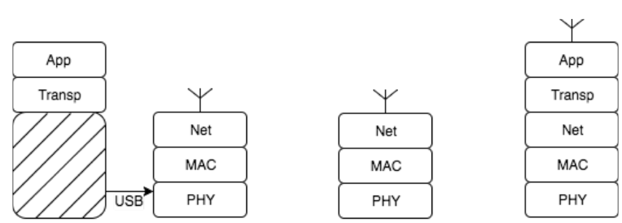

Figure 1. Logical view of the WSN layers.

The communication modules used in the set up were BE990 and BE900, both homologated by the Brazilian National Telecommunications Agency (ANATEL). These modules carry an ATMega328 processor and a CC1101 RF transceiver with a bandwidth filter, operating in the Industrial, Scientific and Medical (ISM) frequency of 915 MHz. The BE990 module also has a CC1190 that integrates a power amplifier (PA) with a low-noise amplifier (LNA) for improved wireless performance [10].

The communication module BE900 can reach up to 100 meters indoors and 500 meters outdoors. The communication module BE990 can reach up to 1000 meters indoors and 8000 meters outdoors. Those distances are considering it is in line-of-sight (LOS), which we did not have in this project.

One sensor node was programmed to work only as a repeater, receiving data from the base station node and forwarding the packet to the other five sensor nodes. For a better performance, the base station node, the repeater node and the sensor 5 node used the BE990 (16dBm) module, while sensors nodes from 1 to 4 used BE900 (10dBm).

In the layout of the system, the base station node is B, the repeater node R and the sensors are S1, S2, …, Sn. Fig. 2 shows this layout.

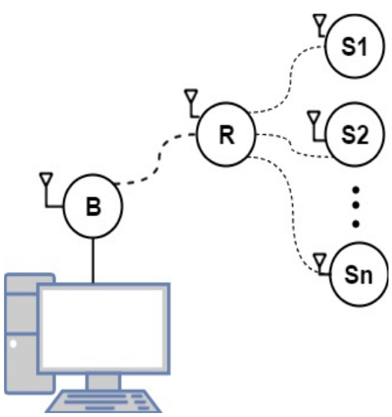

Figure 2. Layout of the system.

Radiuino packet has 52 bytes. The first 4 layers have 4 bytes each, forming a 16 bytes header. The rest of the packet belongs to the Application layer. The remaining 36 bytes are split into two halves, 18 bytes to measure proprieties and 18 bytes to control processes.

The WSNs have a centralized protocol where the base station node is responsible for the routing protocol. The routing protocol approach is hierarchical. The route is chosen trough the ID of the nodes.

The protocol algorithm uses the bytes from 8 to 11 (bytes of the Net layer header). In byte 8 is placed the address (ID) of the next node that is to receive the packet; in byte 9 goes the address of the final node in downlink; in byte 10 goes the ID of the sender in the hop and in byte 11 goes the address of the final node in uplink.

An example of the protocol where the base station node's ID is 0, the repeater node's ID is 20 and the sensor node's ID is 1 is shown in Fig. 3. The protocol was designed to work only with the message in the packet, so the node sensor reacts, changing the addresses for the next hop. The advantage of this strategy is that it allows the sensor nodes to be scalable.

The repeater node, which is predefined, works with bytes 8 and 10, it inputs the data of byte 8 in byte 10 (its address) and inputs the data of byte 9 in byte 8 (the sensor address). The sensor node swaps byte 8, for the data, in byte 10, and swaps byte 9, for the data, in byte 11. After that, it inputs its own address (ID = 1) in bytes 10 and 11.

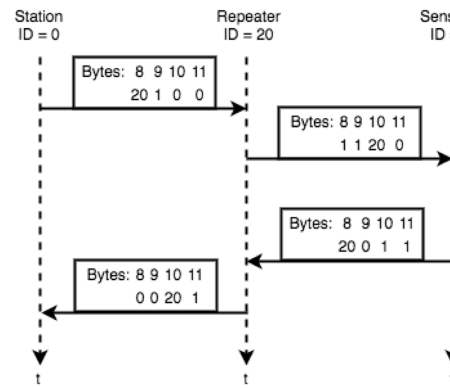

Figure 3. Sequence diagram of the packet.

IV. PRELIMINARY RESULTS

The first test lasted for six hours, from 1pm to 7pm, while the received signal strength indicator (RSSI) of down and uplink were measured. Fig. 4 shows the RSSI of sensor 3 node as a function of time. The solid line is the downlink RSSI, that is, the RSSI that the sensor is measuring. The dotted line is the uplink RSSI, that is, the RSSI measured by the repeater node.

The solid points showing in both lines are the errors, when the packet was lost in transmission.

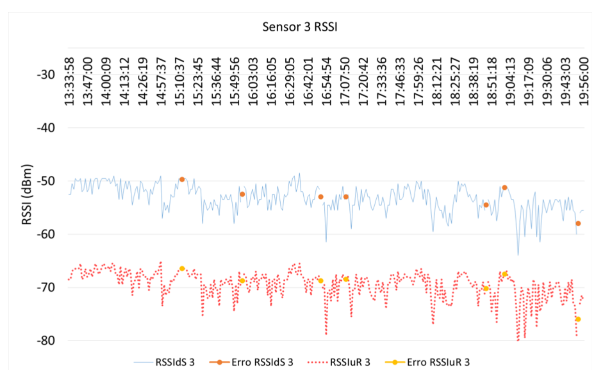

Figure 4. Chart of RSSI of Sensor 3.

The discrepancy shown is the result of different communication modules in the repeater node and in the sensor 3 node. The position of the sensor node also influences the RSSI stability. Sensor 3 node is not in the line of sight making it less susceptible to passers-by. The majority of packets lost are when the flux of people in the food court increases.

In Fig. 5, we show the RSSI for the sensor 5 node as a function of time. The downlink RSSI is overlapping the uplink RSSI.

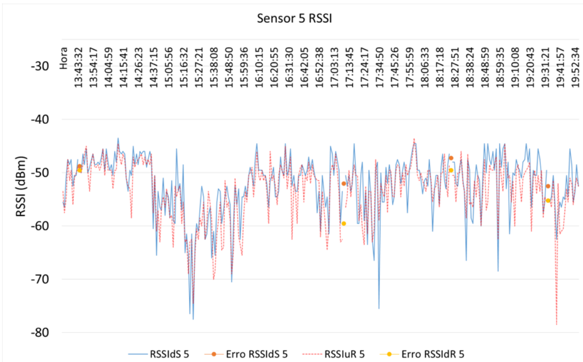

Figure 5. Chart of RSSI of Sensor 5.

The overlapping of RSSI happens because the same module BE990 was used in both the repeater node and the sensor 5 node. Its position was in LOS, making the RSSI more unstable as a result of passers-by interference.

V. CONCLUSION

The purpose of this project was to cover university's food court. A pretest was made trying the direct communication between sensor 3 node and the base station node, which was impossible due numerus obstacles between them.

After the development of the protocol and the placement of the repeater node, the communication was possible.

Sensor 3 node follows a Gaussian distribution, while sensor 5 node follows a Rayleigh distribution. This data is important to manage the WSN and take decisions about it.

The RSSI improvement that is shown in sensor 5 node can be attributed to the different location and to different communication modules.

In the future, some statistics will be compiled while the tests are running, estimating the average of the signal and its standard deviation.

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