A Low Power Routing and Topology Control Protocol for cluster-based Environmental Wireless Sensor Networks: The FLORA Project Case

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***Abstract*— Environmental monitoring is one of the most classic applications of Wireless Sensor Networks (WSN). Itaipu hydroelectric dam creates a unique scenario for the development of this type of WSN with more than 200 square kilometers of natural forests. In this context, FLORA project is aimed at developing a habitat monitoring WSN to be deployed in the Zoo of Itaipu and in the Tati Yupi Biological Refuge. The deployment includes more that 50 nodes. The paper describes the two scenarios of this ambitious and challenging application and presents the routing and topology control protocol developed in the framework of FLORA. The protocol was designed to fulfil the requirements of the application, extend the lifetime of the network, and to adapt to continuous nodes deployment and potential failures. It is based in several protocols already reported in the literature. The novel proposal is a reliable and lightweight routing protocol for wireless sensor network based on vector distance, collection tree, and energy aware distance vector protocols. The main idea is that each node of the network finds the shortest path to the sink with the best link quality, in order to guarantee the delivery of data to the sink despite the dynamic and lossy nature of wireless transmissions. The functionality of this novel protocol is presented as well as the results based on a TinyOS implementation and traditional WSN nodes (motes) including a CC2420 radio.**

I. INTRODUCTION

Wireless Sensor Networks (WSN) is one technology that attracted the interest of Itaipu. In general, WSN received the attention of researchers over the last years, [1], as being identified as one of the most promising technologies of the new century. Main advances in WSN are driven by constant improvements in modern micro-electronics, energy management systems, wireless communications and sensing technologies. However, the scientific community still faces many open research challenges regarding node architecture and hardware, energy efficient communication protocols, and gathered information management [2].

One of the most classic applications of WSN is environmental monitoring. The main idea is to deploy several low-cost sensor motes in an area to monitor variables such as temperature, humidity, light level, and gases, among others [3]. In line with these concepts, FLORA project [1] was conceived as a result of the interest of Itaipu in forest monitoring. FLORA project is aimed at developing wireless sensor networks for habitat monitoring and assessment of the environmental impact of these biological reserves. The sensor nodes of the FLORA WSN will be equipped with light, humidity, temperature and CO2 sensors, depending on the application and requirements of the specific deployment area. The proposed platform will allow the early detection of fires and presence of poachers, or simply to measure the quality of air and other environmental variables.

The sensor motes deployed in the framework of FLORA are based on traditional architectures. Each mote includes a microcontroller to process the information, and a radio to transmit the gathered information and communicate with other nodes. All the measurements obtained from the sensor are sent to a central node, referred as sink. This node will be connected to a base station as a PC, in which all the data generated by the network is saved. Although the location of every node is known in advance, not all the motes can directly communicate with the sink node. To solve this problem a multihop communication protocol is developed, allowing the motes out of the transmission range to transmit the collected information or packet to another node, and these repeat the operation. In this way the packet travels along the network until reaching the sink.

II. FLORA PROJECT SCENARIO

The FLORA project is a first step in environmental monitoring in the area of influence of Itaipu. At a first stage, two WSN will de be deployed. Each WSN is considered as a cluster of the complete FLORA system.

The first cluster is deployed in the Zoo of Itaipú in Paraguay. This cluster is aimed at monitoring the environmental variables, including temperature, relative humidity and light intensity of animal yards and cages. This will allow the veterinarians and biologists of the Zoo to control the captivity conditions of the animals. The network also includes some sensors to detect the human presence and moving objects in the border of the Zoo. The Zoo is located on the border of the Acaray Lake, being exposed to poachers during the nights.

The topology of the Zoo WSN cluster is shown in figure 1. Pins represent the location of wireless sensor nodes. They have been placed according to the requirements written by the authorities of the Zoo. The network architecture includes:

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[1] FLORA project website: http://flora.uca.edu.py

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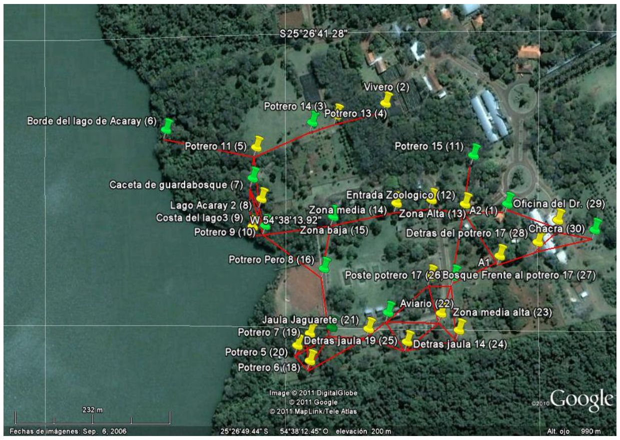

Fig. 1: Topology of the Zoo WSN. Yellow pins correspond to Telosb generic motes. Green pins correspond to long-range nodes.

Fig. 2: Topology of the Tati Yupi WSN. All pins correspond to long-range nodes.

- 1 indoor Base Station with sensors located at the office of the veterinarian (Node 29, yellow pin on the right of the figure 1).
- 31 outdoor nodes with sensors distributed across de Zoo.

The second cluster is deployed in the Biological Refuge Tati Yupi, also located in Paraguay. This Refuge has an extension over 2,200 hectares. The network deployment is shown in figure 2. In this case, the objectives of the network depend on the deployment area. The deployment in Tati Yupi is divided in three groups. They are handled in this way because in this scenario the distances are longer. The first sub-network includes the deployment of a line of nodes, see white pins in figure 2, in a natural grazing land. The aim of these nodes is to monitor and early detect potential fires. This ecosystem, very particular to the region, has a high probability of fires during dry seasons, especially in summer. The nodes includes movement detectors, and temperature and humidity sensors. The second group is identified with red pins in figure 2. These nodes are located in the Atlantic Forest of Alto Parana ecosystem of Tati Yupi. Some nodes are also located in a reforested area. The aim of this red group is to monitor and assess the environmental conditions of these high-value areas. These nodes are equipped with temperature, relative humidity and light sensors. Gas sensors are also included to measure the quality of air. The third group of nodes is depicted with purple pins. These nodes are also located in deep and close natural forest. The third group is also aimed to work as a backbone for future deployments. The distances between nodes of Tati are long as can be seen in figure 2. Summarizing, the Tati Yupi WSN includes:

- 2 indoor Base Stations with sensors (white and red groups) located at the reception office of the Refuge (TY9, white group) and at the barbecue shed (*"Quincho Central"*, red group).
- 18 outdoor nodes with sensors distributed across the Refuge.

III. Routing and topology control protocol of FLORA WSN

The protocol was designed for a specific WSN application consisting of a data sink and an arbitrary number of sensor nodes, as can be seen in the proposed topologies of FLORA project. These nodes periodically send their sensor samples to the sink.

Since the transmission power of a wireless radio is proportional to distance squared or even higher order in the presence of obstacles, multi-hop routing is a clear alternative to minimize the energy consumption comparing to direct communication [4]. The protocol proposed in this paper uses the neighbor's information to find a route to the sink. Each node selects the closer neighbor as part of the route to the sink based on the amount of hops to the sink and the quality of the wireless link. In this way, and in subsequent periods, a tree topology is established, in which the root of the tree is the sink node, e.g. the node at the office of the veterinarian in the Zoo scenario.

IV. TinyOS implementation

The protocol was implemented in TinyOS. Two components represent the core of the protocol: BuildTreeP and RoutingP. Figure 3 shows a block diagram of the TinyOS implementation. The functions of these components are:

BuildTreeP: It is responsible for the tree topology creation and further control, the component starts the network tasks. It is also responsible for the selection of the node's parent.

RoutingP: This component is responsible for providing *send* and *receive* interfaces to the high level application. As all packets generated by the nodes go to the same final node, the sink. In this way, this component provides a transparent interface to the application for sending packets using information provided by the component buildtreeP. It also makes the forwarding of packets, totally transparent to the application. The component controls that all the packets have reached the one-hop destination by means of the *ack* message, otherwise it sends the same packet again.

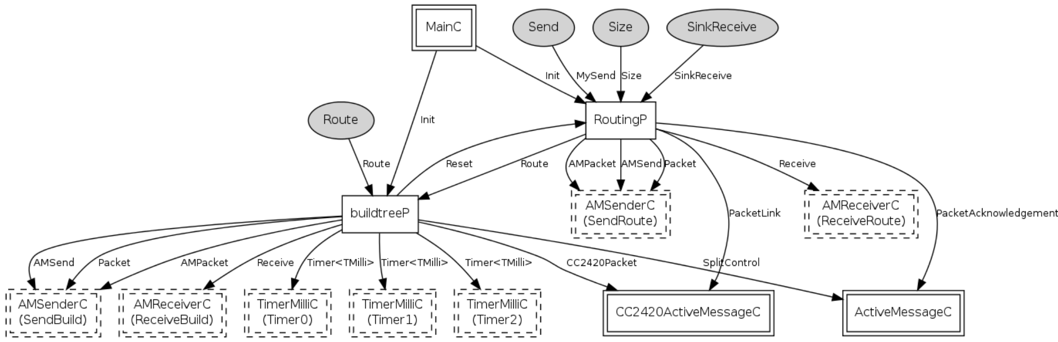

Fig. 3: Block diagram of TinyOS components and interfaces of the proposed protocol.

The transmitted message has an 11 bytes long header. For further details on these fields see [5]. The specific protocol payload consists of a sequence number (1 byte), data source ID (2 bytes), the hop counter (1 byte), the maximum hops number (1 byte) and data payload (up to 112 bytes).

V. Simulations and Empirical Results

To test the proposed protocol, it was first simulated with TOSSIM simulator (TinyOS 2.1.1 and CC2420 radio model). First results helped to debug the logic of the protocol. Afterwards, a network with nine nodes (Telosb) was deployed in a tree topology (1-2-2-3-1). Each node transmitted a packet every 5 minutes until completing a total of 1000 packets. A total of 9000 packages should be received at the sink. In this scenario, the protocol produced a delivery rate of 97%. This result is considered acceptable for FLORA applications.

The implementation of the protocol required 2376 bytes in RAM. This means around 23.76% of total RAM of the platform, and 17206 bytes in ROM, which mean around 35.85% of total program memory available in the Telosb mote.

Another important result of the design is the flexibility of the protocol and therefore of the network. The protocol allows the continuous deployment of nodes, the adjustment of the data rates and the dynamic self-reconfiguration of the networks. All these features have been tested empirically. Power consumption tests to predict lifetime of the network will be conducted in the future.

VI. Conclusions

FLORA project represents a unique scenario for WSN application. Two networks were presented, located in the Zoo of Itaipu and the Tati Yupi Biological Refuge. These networks include over 50 sensor nodes in total located on preplanned places.

The paper presents a lightweight routing and topology control protocol. This protocol was designed considering some design principles and constraints, and the particular application requirements. In these regards, the protocol supports the addition of new sensors and it is robust since the topology is updated periodically to avoid disconnection caused by node failures. He protocol is lightweight in terms of hardware and firmware needs. This was important considering that the FLORA project looks forward to including the IEEEE 1451 protocol for smart sensors in the newtwork. Overheading is also avoided. Only a few fields (bytes) are included in the payload to ensure the functionality of the protocol.

VII. Future Work

The application of FLORA requires the reconfiguration of nodes. e.g. alarm's threshold, node's sample frequency, sensors on/off, among others. The network protocol must be able to transmit these control messages to specific nodes. Future work in this regard will include the development of a bidirectional communication protocol.

Finally, the last already identified work regarding the communication protocols consist in the possibility of a full network reconfiguration. For instance, in case of a failure of the sink node or a very critical node close to the sink, the complete network can be affected. Special nodes with sleeping hardware could actuate once a network fault is detected. How this global failure is detected and how it handles the network data using this emergency hardware, e.g. a GPRS modem, should be considered in the protocol stack.

Al these presented developments are being intensively tested within a local testbed replicating the explained topologies. The aim is to have a full tested WSN before deploying in the real scenarios.

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