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Performance evaluation of an AODV-based routing protocol implementation by using a novel in-field WSN diagnosis tool

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ABSTRACT

The Wireless Sensor Network research field has been growing and becoming more mature during the last decade since novel technologies and research lines have emerged targeting its usability under different real scenarios. One of the key topics to assure the efficiency and effectiveness of these technologies in final applications is the quality of the service and the reliability of the whole system, which strongly depends on the communication/topology capabilities as well as routing strategies within the WSN. In this context, it is essential to evaluate the implementation of routing algorithms and network connectivity in actual deployments, as a support to theoretical simulation models that cannot predict certain constraints and limitations in the system behavior. These are the main reasons why a real implementation of a flexible AODV-based routing protocol using a modular HW-SW node platform is proposed in this work, in addition to its practical assessment under real conditions by using a novel in-situ WSN performance evaluation tool. This tool has been created as a support for users during the in-field deployment analysis and diagnosis in real environments, in order to correlate theoretical results with the operation of the network beyond the typical study of routing performance with WSN simulators.

1. Introduction and related work

During the last decade the Wireless Sensor Networks (WSNs) have emerged as a key and challenging topic for the research community due to the inherent integration of a wide range of different hardware and software technologies, protocols and new algorithms in order to maximize their performance and feasibility in final applications. One of the most relevant aspects to be considered to assure the efficiency and effectiveness of these technologies in real scenarios is not only the quality of the service of the whole implemented system, but also the robustness and reliability of the network performance, which strongly depends on the communication capabilities as well as topologies and routing strategies within the WSN. In this context, routing problems in WSNs have been studied from different perspectives, depending on the target application, topologies needed for specific scenarios and environments, network mobility and scalability, and data aggregation [1].

On one hand, from the point of view of the network structure to be adopted, three major groups of routing algorithms can be distinguished. The first one is the flat-based routing protocols [2], in which nodes have the same role in order to collaborate in achieving the goal of the wireless deployment in a reliable way. Flexibility is a key aspect covered in these types of protocols due to the possibility of having different alternatives to disseminate the sensor information, which is important in unstable environments where the quality of the links are prone to be affected. The second group is the hierarchical-based routing protocols, in which two main types of roles are defined. Sensor nodes are used to gather the target measurements whereas cluster nodes retransmit these data to the base station. Such configuration aims to reduce the power consumption of the sensor nodes, since they do not need to include routing capabilities and then special sleep modes can be adopted for the former type of device [3]. However, these routing protocols are mainly intended to be used in stable environments where the probability of communication failures is lower, and the redundancy criteria are not a critical network requirement. The third group is focused on location-based protocols, in which nodes find the routing alternatives by knowing their location (using signal-strength-based algorithms or adding GPS-based hardware to the sensor implementation) with respect to the surrounding neighbor nodes [4].

On the other hand, considering how routes are discovered and created, routing algorithms can also be classified in proactive, in which the mechanism periodically or continuously attempts to determine the routes even if they are not used, so that the corresponding path is already available whenever a node needs to send a packet to a destination point [5]. Although this schema reduces the time delay when a

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packet has to be transmitted, it has poor performance in unstable environments where the routes are prone to be changed or in network mobility, in which the frequency of the connectivity reconfiguration is much greater, in addition to its high energy and resource consumption to maintain the routes. In order to cope with these limitations, a second classification is included, the reactive protocols, in which the route determination is performed on demand [5]. This means that the first time a source node needs to send a packet to a destination node the route mechanism will attempt to discover a connection path and then keep such route for subsequent transmissions. Although this schema may increase the delay of the transmission process due to the route request procedure, it is more flexible and less resource consuming in those environments where the connectivity can be more unstable.

Most of the aforementioned mechanisms and the state-of-the-art routing protocols have been evaluated by using simulation tools and modeling process, or some of them by controlled testbeds, which give to some extent an idea of what the functionality of the mechanism will be. However, fewer works focus on implementing and integrating routing protocols in real hardware platforms and tested in actual scenarios in order to analyze the performance and the efficiency of those implementations under real and operational conditions of the deployment, as well as dealing with the resource limitations of sensor nodes. In this context, it is essential to evaluate and validate the implementation of routing algorithms and network connectivity in real deployments, as a support to theoretical simulation models that cannot predict certain constraints and limitations in the behavior of the system. These are the main reasons and motivations why a real implementation of a flexible AODV-based (Ad hoc On-Demand Distance Vector) routing protocol using a modular HW-SW platform has been deeply studied and is proposed in this work, as a support of the Cookie nodes [6] and their integration with an IEEE 802.15.4 based communication layer. AODV is a flat-based routing protocol, which provides Cookies with a greater flexibility that allows the use of any required topology by the target application. It is also within the reactive protocol classification, which is more suitable for reconfigurable and Ad-hoc network topologies, being one of the main targets to be covered by Cookie implementations. The proposed implementation, called CB-AODV (Cookie-Based AODV), aims to help developers to analyze different aspects, constrains and requirements in the use of reactive routing protocols in real WSN application scenarios.

Such an approach brings another important issue for the success of the implementation of routing algorithms along with the network operation. Nowadays there is a lack of well-defined practical tools to analyze and evaluate the implementation of routing protocols and communication topologies in WSNs within their real operational environments and final application scenarios. Most previous works regarding the optimization process of WSN deployments targeted simulation and modeling techniques at the planning stage [7,8], so that the output models serve as a starting point for experts to carry out the commissioning activities following pre-deployment guidelines, which has been studied from a simulation perspective and considering some assumptions at system low-level implementation.

Furthermore, the behavior of routing protocols running in actual hardware platforms might be far from the expected simulation results or even from the testbed scenarios with respect to the final operability of the system, specially in terms of communication performance, due to limitations concerning the core and memory architecture on which routing algorithms are to be implemented, as well as computational and processing limitations that are not taken into account during the modeling process. In this work, a practical assessment of routing protocols (and specially for the CB-AODV implementation) under real conditions is also proposed as another major contribution, by means of creating a novel in-situ WSN evaluation tool (I-DPEs, In-situ Diagnosis & Performance Evaluation System). This tool is proposed to support users during the in-field deployment configuration, analysis and diagnosis in order to correlate theoretical results with the operation of the network in real environments and under actual conditions, beyond the typical study of routing performance through WSN simulators. Moreover, the aim of this support tool is to provide deployers with the possibility of considering and analyzing in runtime different abstraction levels of the target system implementation to enrich the on-site analysis and assessment. There are works focused on coping with the evaluation of routing protocols from a simulation perspective, such as the framework presented in [8], or the performance analysis of Ad Hoc networks proposed in [9]. However, fewer proposals try to address practical assessment of network connectivity and in-field analysis of routing mechanisms, such as the work presented in [10], or general approaches for evaluating node functionalities [11]. In [12], authors proposed a toolkit for evaluating collection tree protocols from a simulation perspective as well as translating their TinyOS implementation to a controlled testbed, where nodes are connected to PCs to gather data and statistics, which is more focused on a laboratory approach for pre-deployment analysis, similar to the approach proposed in [13], where the network testing information is collected through a sink node which then retransmits the data to a remote performance analysis system, by means of using a wired connection or Wi-Fi. Yet, these types of implementations are more focused on pre-deployment infrastructures where a controlled/rigid network is used, specially targeting the remote analysis of applications' behavior.

The rest of the paper is organized as follows, starting with the CB-AODV implementation and its integration with the HW-SW platform in Section 2. In Section 3 a discussion regarding the proposed in-situ Evaluation Tool together with its main designed capabilities are presented, whereas in Section 4 experimental results and comparisons are analyzed in detail. Finally, conclusions and contributions are provided.

2. CB-AODV design and development

As previously remarked, routing protocols in WSNs are a fundamental part to assure the success and the effectiveness of the target application as well as the quality of the provided service. Since the IEEE 802.15.4 standard [14] (which is the most common communication standard used in WSNs) only includes the PHY and MAC layers and not the upper levels, it is necessary to implement a routing protocol that allows using different network topologies and not only the star topology (where the coordinator has full coverage with the rest of the nodes, and the communication is only possible between a node and the coordinator). Therefore, the routing protocol allows multihop-based networks where the messages hop between different intermediate nodes until they arrive at the final destination.

In this way, the modularity of the Cookie platform [6] allows an easy integration of different communication modules to establish the wireless connection among the deployed nodes, such as the already implemented Bluetooth and ZigBee layers. Thus, in order to deeply analyze network connectivity issues in WSNs from different abstraction levels and specially targeting the study of real implementations of routing protocols, a new communication layer has been designed and implemented based on the IEEE 802.15.4 standard, taking advantage of the ease of prototyping in the Cookie platform, as shown in Fig. 1. The selected module is the well-known CC2420 from Texas Instruments [15], which has been widely used in different node platforms.

This communication layer has been designed to be managed from the processing layers of the Cookie platform, which means that the main processing element (the 8051-based microcontroller) hosts the controllers of the module (such as the RAM managing and configuration command), and the co-processor (the FPGA) allows hardware debugging issues and power mode's triggering. These controllers have been implemented following the HW-SW integration framework [16]