Lab-Based Learning on Wireless Network QoS Case Study: WSN for real time environmental monitoring

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*Abstract –***With a growing number of wireless applications for real time continuous event monitoring, the concept of Internet of Things (IoT) is becoming reality. However, in contrast to the fixed wired networks, the performances of wireless networks are much more unstable. In the scope of the advanced computer networks and wireless communication courses, the graduate computer science students are taught on network performance analytics and wireless sensor networks, respectively. This paper presents a project based approach of researching on both topics. Specifically, it brings up the synergic effects on multidisciplinary learning by evaluating the performance of a wireless network for environmental (greenhouse) monitoring. For this purpose, a typical wireless sensor network for medium-size greenhouse is simulated by using OPNET network modeller.**

While the educational effect was fully achieved, the simulations show satisfying network performance for the given purpose. The results also show the influence of the network settings (such as network topology, the wireless transmission distances, and the number of nodes) on Quality of Service (QoS) parameters.

*Keywords –***Greenhouse, WSN, ZigBee, QoS, environmental monitoring, learning.**

I. INTRODUCTION

The IoT involves various information and communication technologies towards enabling the efficient human interaction with the environment. An IoT module/network collects the information from the surrounding objects with the aim to further process it and/or visualize it to the users.

Wireless Sensor Network (WSN) is the technology of choice regarding the IoT data acquisition infrastructure. It is comprised of a number of small battery supplied nodes that sense the information, locally process it, and wirelessly transmit it to the user and/or data centre. The critical part of a WSN, i.e., its greatest power consumer, is the Radio Frequency (RF) transmission module. Hence, choosing the right wireless technology for long term power-autonomous monitoring system is of crucial importance. ZigBee, a personal-area communication technology, is becoming a standard for low power wireless transmission at the 2,4 GHz unlicensed ISM band. The ZigBee transceivers are designed to have low cost, low power consumption, high security, and low data rates.

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The technology supports for three topologies. Star and tree topologies are used in local, small to medium coverage networks, while mesh topology is used to cover greater areas in the multi hop manner. A ZigBee node can be a sensor, a router or a coordinator. Each of them contains microcontrollers and the RF transceivers, with some of them containing the sensing circuits as well. A sensor node transmits data from the sensors towards the router or the coordinator. A router simply routes the traffic, and is included only in tree and mesh topologies. The coordinator synchronizes the whole network and presents the central part of the topology.

An emerging WSN application area is the greenhouse monitoring systems. Previous systems of this purpose were based on the cable infrastructure, usually with a single sensing node at the centre of the greenhouse. The actual greenhouses are bigger in size and hence more measurement points are needed. With the development of the embedded systems and low power wireless technologies, the areas are now covered with the greater number of nodes and the bulky cabling has been replaced by wireless links. Depending on the various factors (such as sampling rate and transmitting/sleeping duty cycle, the used technologies and protocols, node-to-node distances etc.) today's wireless sensor nodes can last on batteries for weeks, or even years. As such, modern greenhouses use WSNs as a technology of choice for real time and continuous monitoring of the parameters such as air humidity and temperature, soil humidity and temperature, light intensity and concentration of the CO_2.

To meet the application requirements, the wireless networking infrastructure should enable for the timely, accurate and reliable transmission of the sensor data. An appropriate traffic analytics can lead to the improvement on the network settings. A number of efforts has been made towards the QoS parameter evaluation for the greenhouse networking scenarios [1]-[5].

The paper presents a lab-based QoS analysis of a WSN for greenhouse monitoring by using OPNET modeller [7]. The motivation for the study is two-folded:

a) The academic/engineering argumentation - traffic analytics of the greenhouse monitoring network can lead to a better understanding of the networking problems and, consequently, to the network performance improvement.

b) Synergic multidisciplinary education effect - the OPNET is a powerful tool for network performance analytics in education [6]. Even though its support for the WSN simulation might be considered as a bit complex and incomplete; learning it from a realistic scenario will help students applying the QoS analytics on the other networking technologies and topologies.

Accordingly, the primary objective of the study is the performance analysis of a typical mid-size real time greenhouse monitoring system. The study is conducted in scope of the project that envisions students to learn by research. As such, another objective of the study is in the domain of education. Namely, in a research-oriented environment, students learn on how to deploy and set up the WSN, and how to analyse the network performances. On top of that, they are also able to understand the importance of each parameter as well as the factors that influence them in a WSN setup.

In order for the goals to be achieved, the theoretical background on WSNs, ZigBee, OPNET simulation framework and QoS are priory presented to the students in scope of the advanced computer networks and wireless communications courses.

The paper is organized as follows. After introducing the topic and the problem, Section II presents the simulation setup and details. The results are presented in Section III, while the Section IV concludes the paper.

II. THE SIMULATION ENVIRONMENT AND SETUP

A. The rationale behind OPNET for WSN in education

OPNET is a commercial general-purpose network simulator which is recently re-branded as a Riverbed Modeller by Riverbed Technologies [7]. In this paper, OPNET Modeller Academic Edition 17.5 was used. It supports design and modelling of communication systems as well as end-to-end system performance assessment by discrete event simulations. In addition to a wide range of ready to use models and functions, it provides a user with a Graphical User Interface (GUI) for node and network configuration, as well as for defining the underlying processes. Its graphical presentation capabilities make it easier to practice the network quality parameters, hence it is considered to be a more attractive and user friendly tool for students. It allows them to focus on results and understanding of performance evaluation metrics for WSN systems.

Other state of the art tools for simulation and QoS analysis of WSNs used by researchers and educators include ns-2 [8], OMNET++ [9] and TOSSIM [10]. However, ns-2 and OMNET++ require additional add-ons and modifications to provide reliable results for different WSN applications. Also, code in ns-2 is relatively difficult to manipulate with a poor graphical presentation capability. TOSSIM offers scalability and is specifically designed for WSNs prototyping, but it is limited to simulations of TinyOS applications. Simulations of protocols require writing TinyOS application, making it hard to troubleshoot and abstract for laboratory exercises. A comprehensive comparison of limitations together with advantages of WSN simulators is given in [11], revisited by a recent work in [12].

With the rapid increase of WSN applications and demand for hands-one skills in job market on the one hand, and laboratory equipment costs and space limitations on the other

hand, OPNET provides an ideal tool to bridge the gap between theory and practice for teachers, practitioners and higher education institutions in general. The authors in [13] describe the effect of hands-on teaching using OPNET in a wireless communications undergrad class. By designing five simulation laboratories, they show how easy and beneficial to students is designing, deploying and assessing performance of complex and ever-changing wireless infrastructures. Based on surveys and student feedback, the authors in [14] claim the effectiveness of using OPNET simulation tool for teaching networking concepts. Participated students in this study show a significant increase in gaining both theoretical as well as practical skills in creating and analysing different networking scenarios.

We complement previous work by providing researchers and teachers a baseline of ZigBee implementation and performance analysis in OPNET. Thus, it can be easily replicated and extended to other case studies. Consequently, enabling students to practically understand other Low-Power Wide Area Network (LPWAN) technologies, its applications and last yet important appropriate QoS evaluation techniques one should choose.

B. The simulation scenario and setup

In order to observe the network QoS parameters, students consider a realistic environmental monitoring scenario, precisely a medium size 150mx200m rectangular greenhouse area. Although there are lots of ZigBee products in the market that are declared to cover much greater ranges (such as, for example, XBP24-API-001), we have adopted the theoretical limitations of the low power technology regarding the indoor and outdoor ranges. Therefore, the number of nodes is chosen accordingly to the field dimensions and general ZigBee range specifications (that claim the outdoor range of few tens of meters to 100m). Students set up the network by configuring one coordinator, two routers and 4 sensor nodes. The network topology is shown in Figure 1.
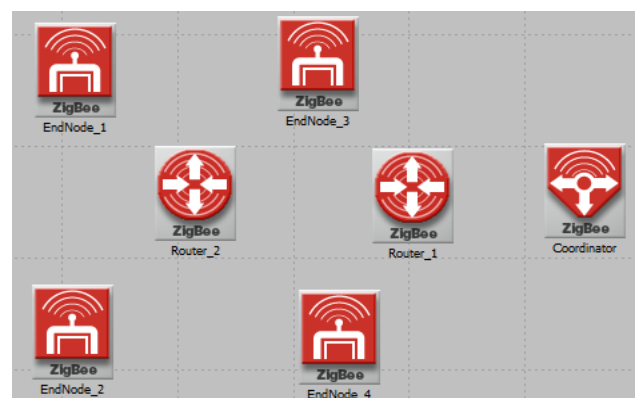

Fig. 1: Simulation setup

The coordinator is set to be data centre or to send data further through the Internet towards the end user. It sets the network in mesh-routing mode. The end-nodes are configured

to send data to the coordinator, i.e., with the coordinator set as the destination node. The routers are configured for the ad-hoc random connection manner. As such, the end nodes 1 and 2 are connected to the Router 2, while end nodes 3 and 4 are connected to the Router 1. Router 2 transmits data through Router 1 towards the coordinator.

III. THE SIMULATION RESULTS

The network parameter analytics were conducted at the end nodes 1 and 4, since they transfer through the different routers and number of hops to the destination. The simulation shows results for 20 minutes of the data transmission. To show the ad-hoc connection nature of the ZigBee network from the given topology, based on the nodes' distances, the numbers of hops towards the destination were firstly evaluated. The results were obtained from the network layer simulation interface. The results are shown in Figure 2.
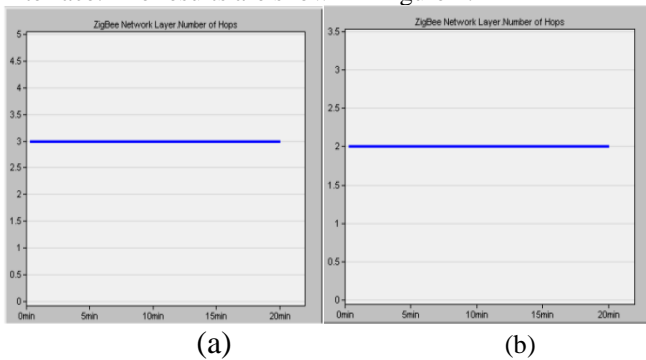

(a)   (b)

Fig.2: Number of hops for: (a) EndNode_1 and (b) EndNode_2

The average end-to-end delay were measured from the application point of view, i.e., from the application simulation interface. The results for end nodes 1 and 4, are shown in Figures 3 and 4, respectively.
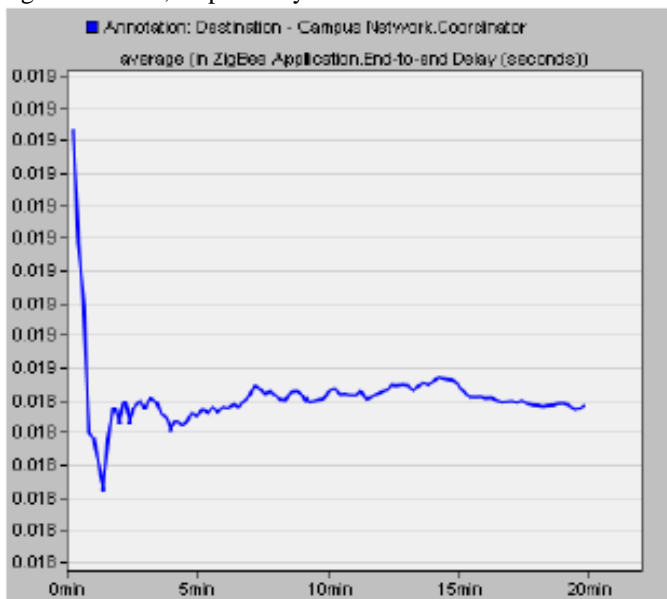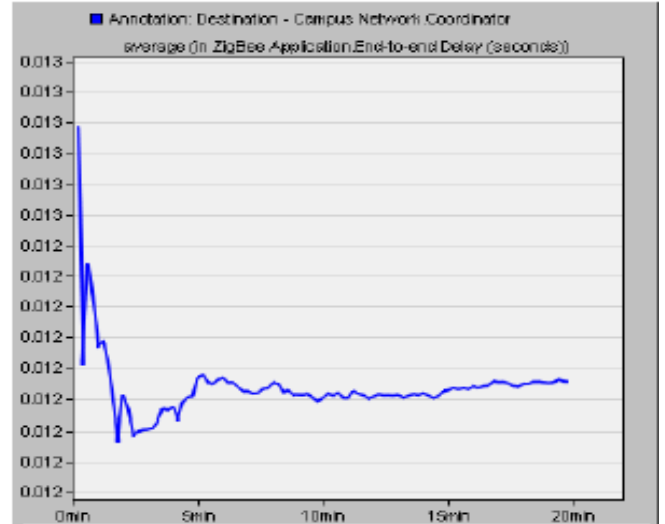

Fig. 3: End-to-end delay at EndNode_1

Fig. 4: End-to-end delay at EndNode_4

The results show that the average delay is higher at the beginning of the nodes' transmission. This can be explained by the on-demand nature of the routing protocol, and the initial route learning that happens at the beginning of the transmission. Also, as expected, when the delays get stabilized, the average delay of the EndNode_4 is lower than the average delay of the EndNode_1. But, this difference is not crucial.

Same as the delay, throughput depends on many parameters such as number of nodes, the network topology, the collision occurrence, etc. Throughput at the end nodes 1 and 4 were evaluated through the link layer simulation interface. The results are shown in figures 5 and 6.
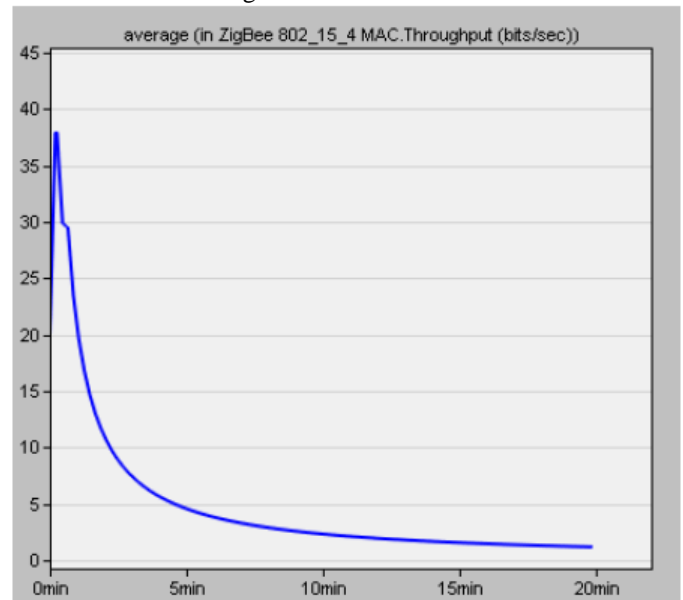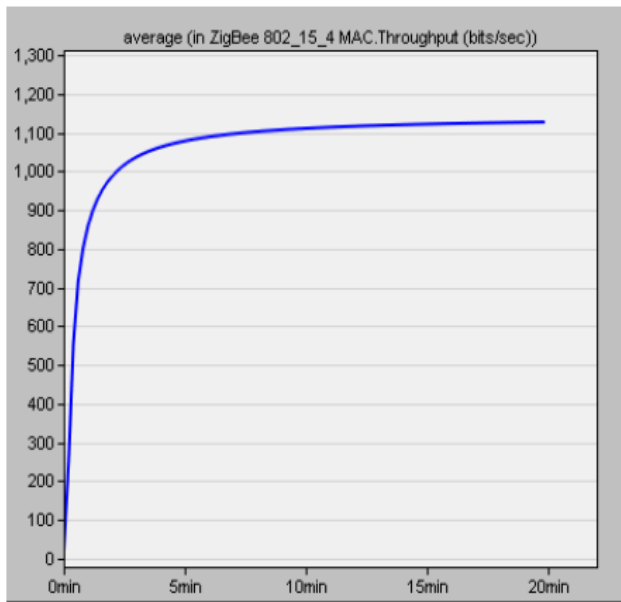

Fig. 5: Throughput at the EndNode_1

Fig. 6: Throughput at the EndNode_4

It can be noted that the number of hops, the position of the node in the topology, and the physical distance of the node from the destination, greatly influence throughput. The EndNode_4, which is much closer to the destination, reaching it with 2 hops, shows much greater throughput as compared to the EndNode_1. For the purpose of experimenting, the EndNode_3 and EndNode_4 were temporarily removed from the network. In this case, the throughput at EndNode_1 has improved significantly, but still hasn't reached the values of the EndNode_4.

IV. CONCLUSIONS AND FUTURE WORK

The paper presents a QoS analysis of the WSN-based greenhouse monitoring system. Its workflow and methodology follows the concept of learning through the research projects. The work has few main outcomes. From the educational point of view, based on the tests and the research goals' fulfillment measure, the educational effect can be considered as fully achieved. On the other hand, from the simulation results, it can be observed that the number of nodes and the node-to-node distance greatly impact throughput while they don't influence the average delay that much. However, it can be concluded that the given QoS parameters would meet the network requirements for the purpose of a greenhouse monitoring system.

Future work will be focused on QoS analytics for intermediate nodes (routers) as well as on the real implementation of the WSN for greenhouse monitoring by using off-the-shelf components.

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