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6LoWPAN network analysis using simulations and experiments

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Abstract. The constant expansion of Internet consumption increases the communication traffic on the network both locally and globally. To meet the needs of such consumption, technologies such as 4G, 5G and the Internet of Things (IoT) are increasingly being developed. Remote monitoring of environmental parameters or the condition of patients in real time can be organised using the capabilities of IoT networks. This paper presents a study of end-to-end delay and throughput in a 6LoWPAN IoT network through real network construction and simulation.

1. Introduction

According to Ericsson mobility report from June 2020 [1], the coronavirus crisis has caused an unprecedented number of people to continue their work remotely via the Internet. Thus, the levels of traffic on the Internet have increased. New generation communications such as 4G, 5G [2, 3, 4] and the Internet of Things (IoT) can be relied upon to successfully maintain such levels of traffic on the global network [5]. Global pandemics such as coronavirus may require remote control and monitoring of various indicators of both patients and the environment. This can be achieved through new IoT technologies such as 6LoWPAN, which allows communication over an IP network to transmit data from sensor nodes such as temperature, atmospheric pressure, humidity, ambient light and more. Continuous monitoring of various parameters of sensor networks requires the provision of good values for indicators such as throughput, end-to-end delay, packet loss, latency, etc. This can be achieved by studying a real network infrastructure or by simulating to study the impact of environmental interference, implemented algorithms or mechanisms on the operation of the network.

This paper presents the physical deployment of 6LoWPAN network and the study of throughput and end-to-end delay indicators, which compared with the results obtained through the 6LoWPAN simulation product presented in [6].

2. Related works

The study at [7] examined the neighbor discovery model and IPv6 frame in 6LoWPAN using the Contiki (Cooja) simulator. The experiments performed with 3, 5 and 7 sensor nodes. The studied parameters are throughput and packet loss. The aim of the study is to predict performance and characterise the proposed real network topology for 6LoWPAN.

In [8] the aim is to form an open, interoperable, scalable, reliable and low power wireless sensor network stack for 6LoWPAN. This stack is simulated through Contiki's Cooja simulator to studying performance under various conditions such as noise, topology, traffic, etc. For validation the simulated



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stack, a physical 6LoWPAN network was built using the Raspberry Pi as a 6LoWPAN border router with T-mote sky sensor nodes. The performance study bases on the values for throughput, latency and packet loss. The studies were performed for a 6LoWPAN network with 1 coordinator and 5 sensor nodes.

In [9] evaluates the performance of the communication stack containing CoAP and 6LoWPAN over the IEEE 802.15.4 radio link. The research realised through Contiki's Cooja simulator for 6LoWPAN. The parameters throughput, packet loss and end-to-end delay studied. The simulations realised for a 6LoWPAN network with 1 coordinator and 5 sensor nodes.

Similar to the researches considered, this paper presents studies of the 6LoWPAN sensor network through simulation and real deployment. The simulations realised through the product proposed in [6]. To validate and compare the simulation results, the same tests were performed over a real 6LoWPAN network using a BeagleBone Black board for border router, Texas Instruments (TI) CC2531EMK transceiver and TI CC2650STK sensor nodes.

3. 6LoWPAN simulation scenario and results

The tests for throughput and end-to-end delay from the simulator were obtained after building a 6LoWPAN network by one coordinator and 6 6LoWPAN sensor nodes connected in a star topology (figure 1). The coordinator configured to work on channel 25. Up to 6 end 6LoWPAN sensor nodes can be connected to the coordinator. All end nodes are static, perform the same type of application and located at the same distance from the coordinator (from 1m to 5m). The tests for reporting the values for throughput and end-to-end delay were made with 2, 4 and 6 sensor nodes connected to the 6LoWPAN coordinator. Once the coordinator and end node information added, a simulation performed to send a certain number of packets (figure 2-1). After adding the packets to the send queue (figure 2-2), the calculated values (figure 2-3) for end-to-end delay and throughput displayed.

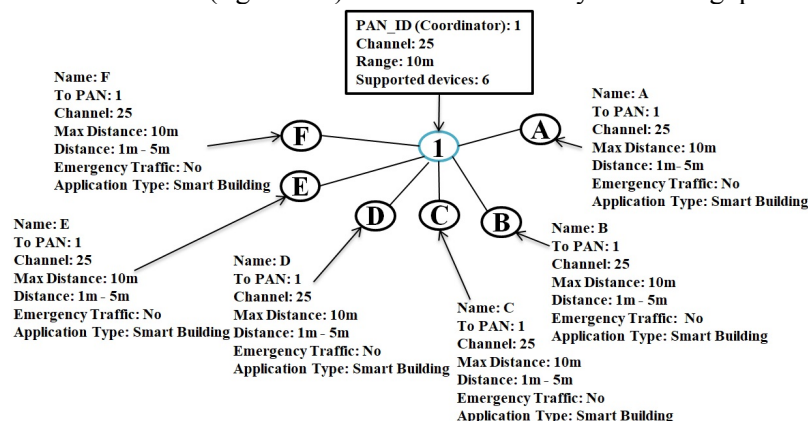


Figure 1. Used 6LoWPAN simulation topology.

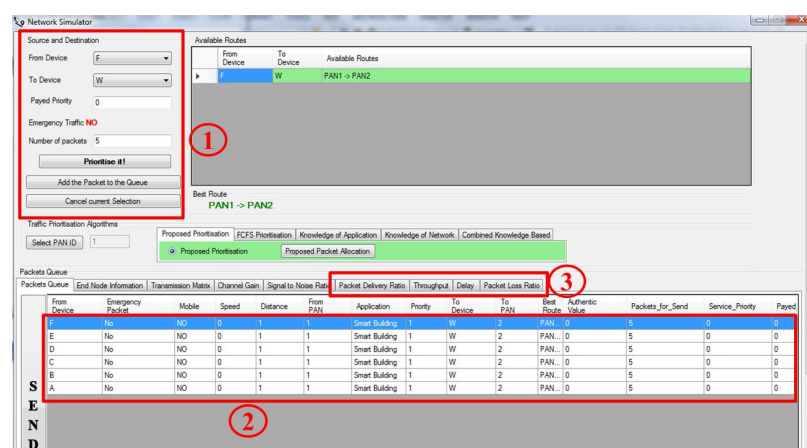
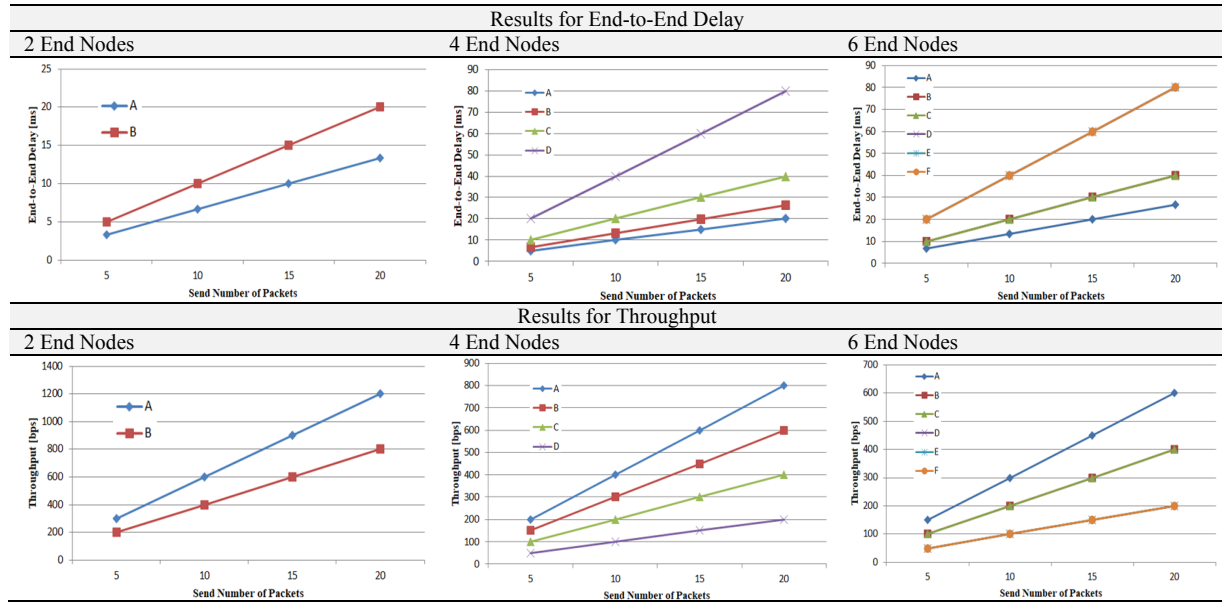


Figure 2. Simulation of 6LoWPAN communication.

The results of the conducted experimental studies are in large numbers, so they are summarised and presented in table 1. Since the simulation product considers tests in ideal conditions, at different distances the values obtained are identical. The difference in the experiments performed is manifested in relation to the different number of sent packets.

Table 1. Results for end-to-end delay and throughput according test by the 6LoWPAN simulator.



4. 6LoWPAN physical deployment, experimental scenario and results

The physical building of the 6LoWPAN network is done with BeagleBone Black – BBB01-SC-505 [10] board with Bone-Debian-9.9 operating system working as 6LoWPAN Gateway, TI transceiver - CC2531EMK [11] and TI multi-standard sensor nodes – CC2650STK [12]. The 6LoWPAN Gateway configured using Contiki Cetic-6lbr version 1.4.0 [13, 14]. The CC2531EMK board configured to operate as a 6LoWPAN transceiver and sensor nodes to operate in 6LoWPAN network using CC-DEVPACK-DEBUG of TI. The data transfer and the receipt number of bits from the end sensor nodes in the already built 6LoWPAN network can be tracked, when a second CC2531EMK transceiver configured to work as a 6LoWPAN sniffer. This can be done on a Linux machine using Sensniff program for 6LoWPAN [15]. The program is downloaded and installed, and at startup a traffic flow is created that can be visualised through Wireshark (figure 3). Packet source, destination and number of bits send performed by the IEEE address of the source and destination from the Wireshark output.

To ensure comparability of the results obtained by the simulator with those of the real network, the tests performed with the same topologies. According to figure 4, physical star topology realised, where 1 is 6LoWPAN coordinator and transceiver, and 2 are 6LoWPAN sensor nodes. Table 2 shows the results for end-to-end delay and throughput obtained through realised 6LoWPAN network. The results calculated based on the size of the sent and received packets between the sensor nodes and the coordinator in number of bits, as well as the delays received when transmitting 5, 10, 15 and 20 ICMPv6 packets. Situations with 2, 4 and 6 simultaneously connected in a 6LoWPAN network end sensor nodes were studied. The tests were performed by simultaneously sending ICMP packets to the end sensors. The values for end-to-end delay (1) and throughput (2) calculated similarly to [8].

$$\text{End_to_End Delay [ms]} = P + 2 * (L_{rq} + L_{rs}) \quad (1)$$

$$\text{Throughput [Kbps]} = \frac{N * (L_{rq} + L_{rs})}{T} \quad (2)$$

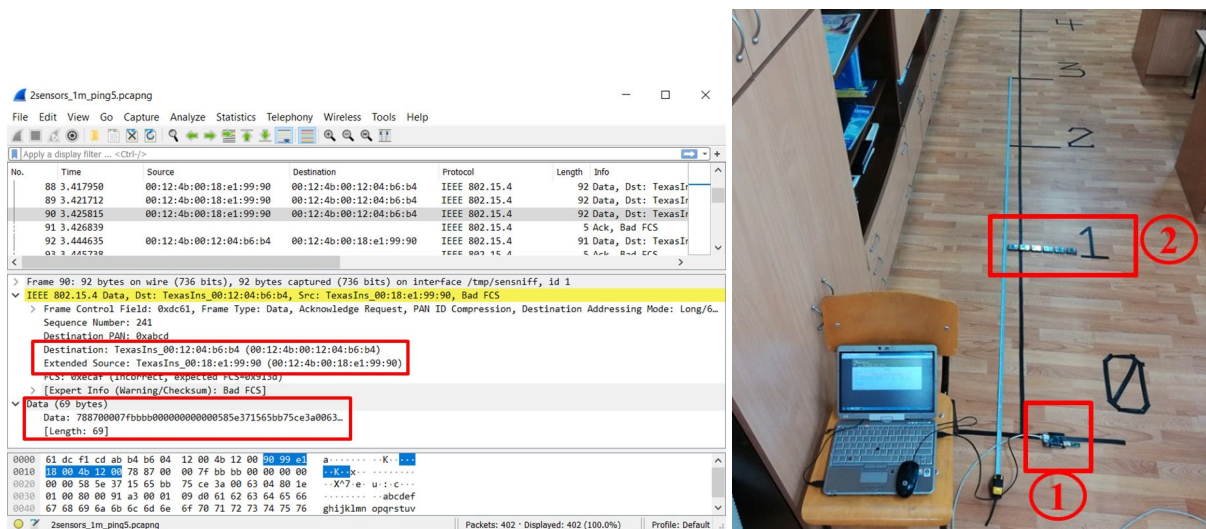


Figure 3. Captured 6LoWPAN packets through Wireshark. **Figure 4.** 6LoWPAN physical topology.

Where P is all processing delay, L_{rq} is length of request, L_{rs} is length of response, N is number of successful ICMP request/response pairs and T is total time of simulation. Throughput values converted from Kbps to bps.

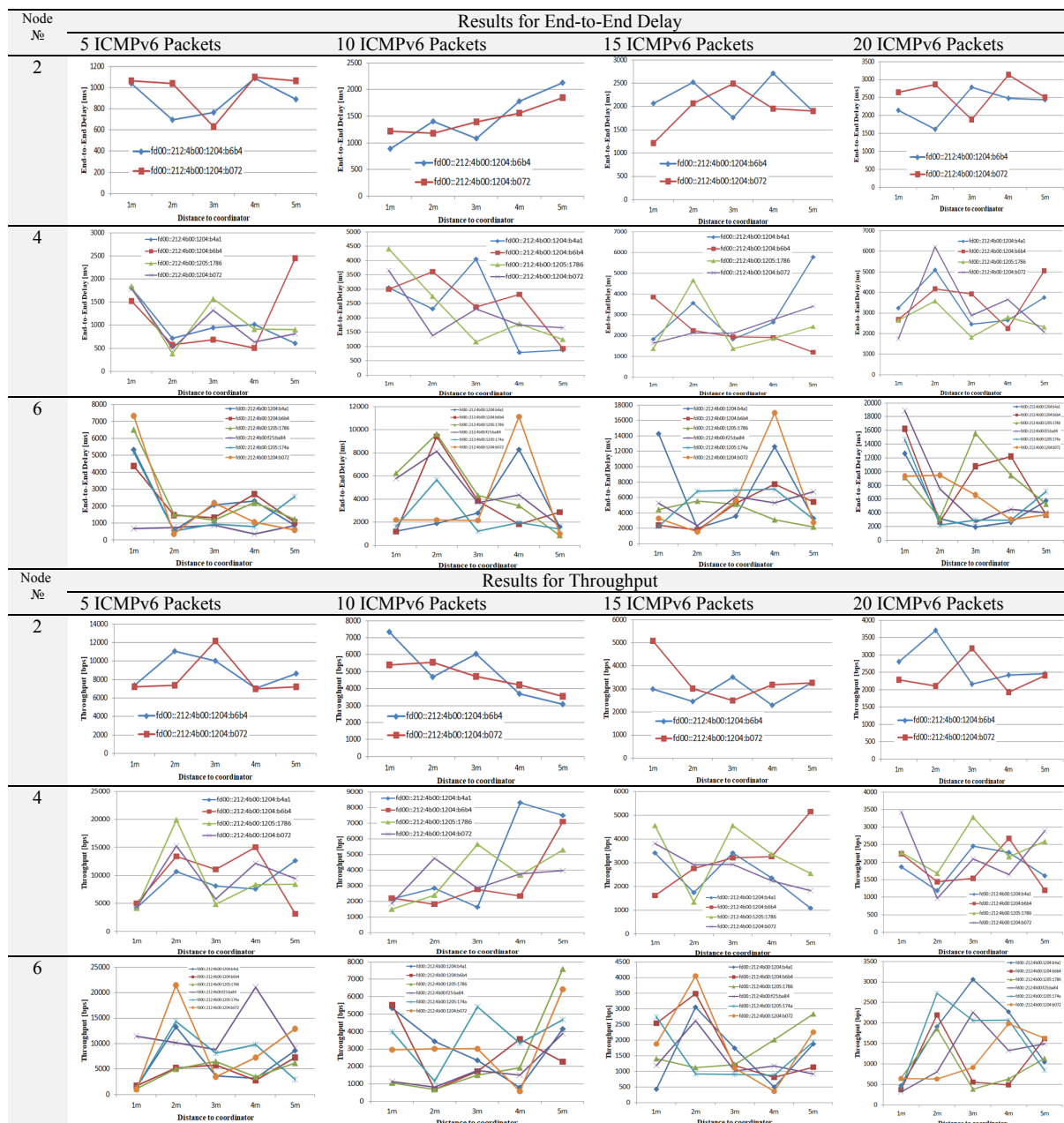
According to the results of simulation with 2 sensors, the values for end-to-end delay and throughput are the best, as the resources from one IEEE 802.15.4 frame are distributed only between two devices. As the number of sent packets increases, there is a deterioration of the studied parameters. This is because more resources are needed to send more packets. The deviation of the results for end-to-end delay in simulation from the real ones is average 99% for 5, 10, 15 and 20 sent packets, and in the values for throughput for 5 sent packets is 97%, for 10 packets is 90%, for 15 packages is 80% and 20 packages is 71%.

The results for 4 sensor devices in the simulation show better values for the devices whose requests have a higher priority. This is due to the algorithm used to prioritise traffic and the mechanism for allocating resources to service requests. The tendency for deterioration of the studied parameters with increasing number of request is maintained. The deviation of the simulation results for end-to-end delay from the real ones at 4 end devices is average 99% for 5 and 10 sent packets and 98% for 10 and 15 packets, and in the values for throughput for 5 packets it is 98%, at 10 packages is 93%, 15 packages is 88% and 20 packages is 80%.

The results for 6 sensors in simulation show the highest values for the devices with the highest priority requests, and lower for the others. Some of the devices with lower priority requests have the same values for the studied parameters. As the number of sent packets increases, the values for the examined parameters deteriorate. The deviation in the simulated results with 6 sensors from the real ones for end-to-end delay is average 99% for 5, 10, 15 and 20 sent packets, and for throughput is 98% for 5 packets, 94% for 10 packets, 86% for 15 packets and 79% at 20 packets.

The results for end-to-end delay from the simulation differ by a very large percentage from the actual ones, regardless of the number of packets sent. In the results for throughput it is observed that with the increase of the number of sent packets the results obtained from the simulation are getting closer to the real ones, but nevertheless there is a large difference. This is because the simulation product does not take into account the presence of different noise effects in the communication environment and interference between nodes in the network.

The trend in the results of simulation and tests in a real network show that when the network is loaded, the studied parameters deteriorate.

Table 2. Results for end-to-end delay and throughput according test by the 6LoWPAN network.

5. Conclusions

This paper compares end-to-end delay and throughput results reported in the simulation and the actual 6LoWPAN sensor network. The experimental results obtained from the simulation are low compared to the real ones. At different simulation distances, identical results are obtained, as the operation is performed under ideal conditions. The difference in the simulated results is manifested in the different number of packets sent in the simulation and in real conditions. The results of real network tests are variable because the communication between the sensors and the coordinator is influenced by environmental factors such as electromagnetic interference, radio interference, packet transmission errors, other sources operating on the same frequency, interference between sensors, etc. The obtained trend in the simulation results and real conditions are approaching, which gives reason to allege that the simulation product is suitable for purposes of education.

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