

Topology influence on the radio communication range of sensor networks

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Abstract. The Internet of Things (IoT) applications use wireless technologies in order to establish Internet connection. Communication technologies such as Wi-Fi, cellular, ZigBee, Bluetooth, etc. are used to transfer data in IoT. The choice of the appropriate technology or combination of technologies depends on the type of application, its characteristics, user requirements, and other factors such as communication range, security requirements, battery life, etc. In our project, we will focus on Star, Cluster and Mesh wireless topologies, conduct comparative analysis between them, and testing different XBee devices with specialized software. The experiments are connected to the quality of the transferred data using different XBee devices and how this will affect the transmission range. The results of our research show that in terms of the range and quality of packet transmission, the cluster topology shows the best results.

1. Introduction

The Wireless Sensor Network (WSN) is made up of multiple nodes that communicate with each other [1]. Sensor nodes gather information for the environment and forward it to the base station for processing. Sensors in WSN, examine acceleration, blood sugar, kinematics and dynamics, pressure, angular rate of rotation, etc. WSNs are used in many areas such as agriculture, environmental monitoring, building automation, health, and many other areas.

ZigBee is a wireless personal area network (WPAN) protocol that is used in WSN. ZigBee transmits at a distance of 10 to 100 m [1], depending on the radio frequency environment and the output power. Despite its short communication scope, the ZigBee has many easy operating advantages, small size, low power consumption.

ZigBee is also able to maintain low-cost stable networks and is able to maintain a set of very vast number of nodes [2]. The end sensor nodes collect environmental data and, according to the topology type, transmit this information either to the coordinator, who transmits the data to the base station or, transmit the data first to the routers which in turn forward the data to the coordinator [3].

This project runs a range test comparing the quality of packet data transmission in cluster, star and mesh networks to check the difference in data transmission quality and use techniques to minimize errors, and therefore to optimize network performance [3].

The results of this study are used to show how reliable XBee devices are when they work with different topologies cluster, star and mesh, to make comparative analysis of the topologies that checks in which cases package loss is the smallest [4].

2. Related studies

For the survey we are building real wireless networks with ZigBee devices: coordinator node, router and different smart sensors as end devices. Wireless networks have three different topologies - star, cluster, and mesh topology [4].

In our study we implement ZigBee-based data transmission and monitor wireless smart sensor networks, (which are cost-efficient, energy-efficient) for monitoring and obtaining a quality data packets. The combination of hardware elements and an integrated software, used during our experimental range tests, allow us continuous monitoring and measurement of sensor data flow [4, 5].

The wireless network model we use, conduct experimental research, which can be practically used to build any sensor network. In the course of the study consistently build intelligent sensor networks with different topologies through specialized software XCTU which we use for range test investigation on quality of the transmitted data packets, in different topologies [7].

In this research we compared the three network topologies - cluster, star and mesh to see after what distance between nodes, the percentage of received packets decreases when the nodes play role of ZigBee coordinator (ZC), ZigBee router (ZR) and ZigBee end device (ZED) [9].

➤ ZigBee modules and network.

ZigBee is a protocol for low power, low range wireless devices, based on the IEEE 802.15.4 standard for Personal Area Network (PAN) [9].

ZigBee has the capabilities of communications like peer-to-peer, multipoint and mesh. They offer flexible wireless methods for embedded systems. The ZigBee network consists of three different types of ZigBee devices: coordinator, router, end device. A PAN ID is attached to all devices on the ZigBee network [9].

➤ Device Types used for the experiments.

- ZigBee Coordinator (ZC): This device defines network characteristics and can be used as a bridge to other networks. There can be only one coordinator per ZigBee network. Coordinator defines a PAN, by selecting RF channel and PAN ID. ZC also connects routers and end devices to the PAN [9].

- ZigBee Router (ZR): This device transmit data from other devices. The router starts working only when it is connected to ZC [9].

- ZigBee End Device (ZED): It only can to communicate with the parent node (coordinator or router); cannot retransmit data from other devices. The device has the ability to "sleep" most of the time, thus providing a long battery life. ZED join PAN through a router, so it can begin to send data. ZED finds the least amount of memory and is then cheaper to manufacture compared to ZR or ZC [9].

Parameters that we compared involve data transmission and delays. The results show that the amount of transmitted data to the ZC in the case of star topology is very small compared to the cluster and mesh topology, so it is unreliable for networks, that most have high results for

3. Methodology

3.1. Hardware Design

In the designed WSN, we use seven XBee modules that are divided into three groups, ZigBee, 802.15.4 and Mesh, according to the firmware they use. The settings for XBee was done with X-CTU software. This settings defines XBee modules as coordinator, router or end device in ZigBee firmware, router to router in mesh firmware and end device to end device/coordinator to end device in 802.15.4 firmware. The X-CTU software was used to obtain user interfaces for easy monitoring of communications [8]. Testing was done with star, mesh and cluster topology. Then a comparison was made between the three network topologies [8, 9, and 10].

3.2. Network Design

The test was performed by measuring the delay and packet loss parameters. The measurement and analysis used the scenario on star, mesh and cluster topologies to define network performance and reliability level of the proposed Xbee network [8, 9, 10, and 11].

3.2.1. Star network Design

In the study, we examine the star network to find out the communication efficiency between the XBee modules. In this test, we configured the first XBee module as coordinator to receive information from other devices, which were configured as end devices, so that they can send information to the coordinator directly. In this test, the distances between nodes were checked between coordinator - end device and end device-end device, to examine the quality level of the network, transmitted data, and lost packages [12]. Figure 1 shows the configuration of the created network, which is displayed by the software tool. The function, MAC addresses and operating mode of the devices are shown.



Fig. 1. Wireless network configuration with star topology



Fig. 2. Wireless network configuration with Mesh topology

3.2.2. Mesh network Design

In this study, we tested the mesh network in order to find out the communication performance between (to sends and receives data packages) the three XBee modules, for this purpose were configured them to use routing techniques (each- to- each) [9]. Figure 2 shows the configuration of the studied network topology mesh. Displayed are a function of the network, MAC addresses and modes.

3.2.3. Cluster network Design

In the study we use cluster network topology to find out the communication efficiency between Xbee modules. In the design of this test, we set up the first Xbee module as coordinator to obtain information from router and end devices [10, 11, and 12]. In the designed test, each device conducts a range test with the coordinator, and with each other, to check the quality level of communication between each of them. The distances between nodes were set within non-line of sight environment [10, 11, and 12]. Figure 3 shows the configuration of the studied cluster network topology. Displayed are a function of the network, MAC addresses and modes.

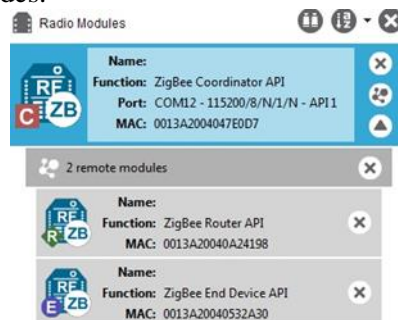


Fig. 3. Wireless network configuration with Cluster topology

3. Test and results

The test of transmitted data on WSN topology was carry out by using Xbee modules.

➤ *Range test tool*

A range test tool is a built-in tool that tests the actual radio frequency range and the quality of the connection between two radio modules on the same network. To run such test, we have to use at least one local radio module and a remote module on the same network [6].

➤ *Range Test Configuration*

For the conducted test is configure several different options from the XCTU software: range test type, packet payload, Rx Timeout (ms), Tx interval (ms), number of packets, loop infinitely, RSSI chart. [6].

➤ *Perform a range test*

Because communication between Xbee RF modules is carried out over the air, the wireless signal quality can be influenced by many factors: absorption, wave reflection, visibility issues, location, etc. The range test display the real radio frequency range and quality of the connection/ link between two Xbee modules on the same network. During a range test, XCTU dispatch data packets from the local Xbee module to the remote one and waits for the echo to return. The local module most work in AT (transparent) mode [12, 13]. XCTU counts the number of transmitted packets and evaluate the signal strength on both sides via RSSI (Received Signal Indicator) value [12, 13, and 14].

3.1. The Xbee Configuration was performed in three stages

3.1.1. Xbee Configuration as End Device

Xbee connected to XCTU software through COM port serial setting, then we set up some parameter, such as; Baud: 9600, Flow Control: none, Data Bits: 8, Parity: none and Stop Bits: 1. Xbee configuration as end device was done via firmware update, as shown in Fig. 4 and the parameters used were; Firmware Xbee: End Device Mode AT, PAN ID: 3099 and Baud Rate: 9600.

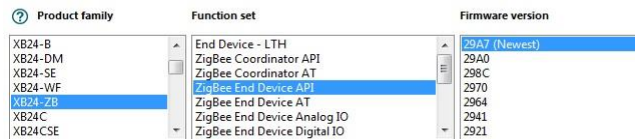


Fig. 4. Firmware Xbee Configuration as End Device

3.1.2. Xbee Configuration as Router

The Xbee configuration parameters used were: Firmware Xbee: Router Mode AT, PAN ID: 3099, Baud Rate: 9600. The Xbee configuration as router was done via firmware update, as shown in Fig. 5.

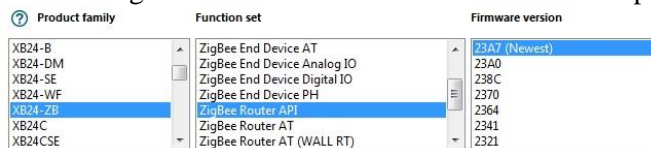


Fig. 5. Firmware Xbee Configuration as Router

3.1.3. Xbee Configuration as Coordinator

The Xbee configuration parameters used were: Firmware Xbee: Coordinator Mode API, PAN ID: 3099, Baud Rate: 9600 / 115200. The Xbee configuration as coordinator was done via firmware update as shown in Fig. 6.

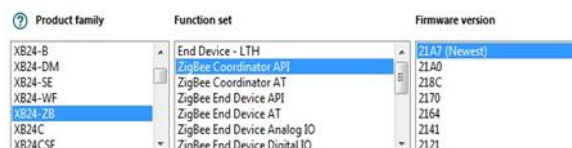


Fig. 6. Firmware Xbee Configuration as Coordinator

3.2. Tests

3.2.1. The Test from End Device to Coordinator in Cluster

As shown in Fig.7, the range test shows the percentage of packets received / lost, delay errors, RSSI chart, etc, for End Device to Coordinator in Cluster.

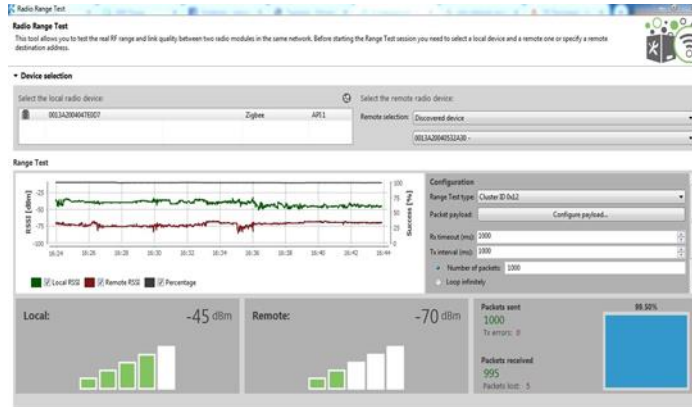


Fig. 7. Test from End Device to Coordinator in Cluster

3.2.2. The Test from End Device to Router in Cluster

As shown in Fig.8, the range test shows the percentage of packets received, packets lost, delay errors, RSSI chart, etc., for End Device to Router in Cluster.

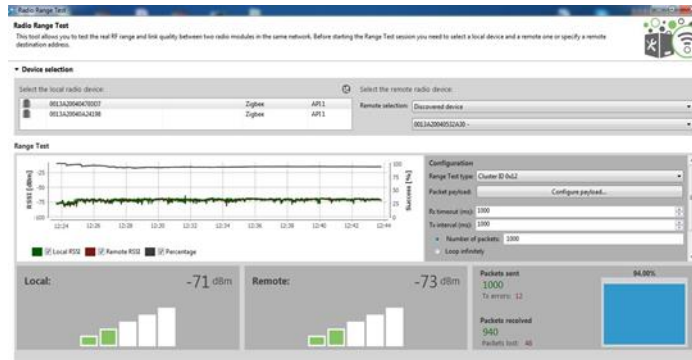


Fig. 8. Test from End Device to Router in Cluster

3.2.3. The Test from Router to Coordinator in Cluster

As shown in Fig.9, the range test shows the percentage of packets received, packets lost, delay errors, RSSI chart, etc., for Router to Coordinator in Cluster.

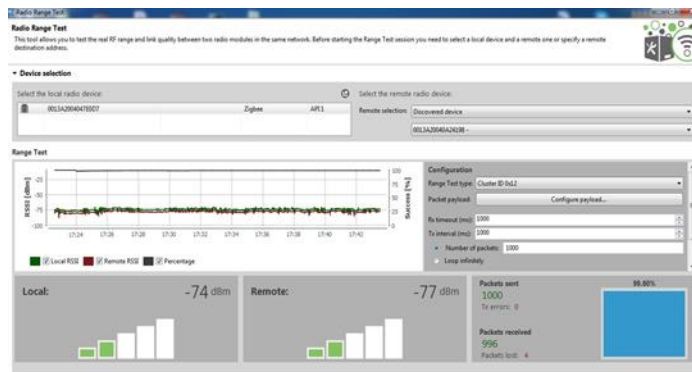


Fig. 9. Test from Router to Coordinator in Cluster

3.2.4. The Test from End Device to Coordinator in Star

As shown in Fig.10, the range test shows the percentage of packets received, packets lost, delay errors, RSSI chart, etc., for End Device to Coordinator in Star.

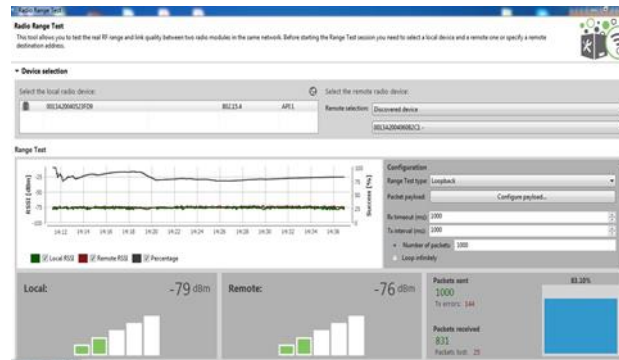


Fig. 10. Test from End Device to Coordinator in Star

3.2.5. The Test from End Device to End Device in Star

As shown in Fig.11, the range test shows the percentage of packets received, packets lost, delay errors, RSSI chart, etc., for End Device to End Device to in Star.

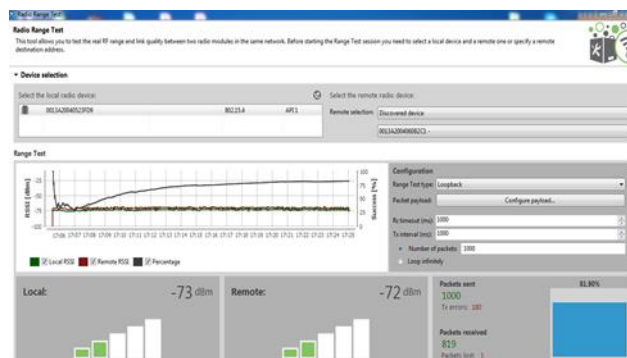


Fig. 11. Test from End Device to End Device in Star

3.2.6. The Test from Router to Router in Mesh

As shown in Fig.12, the range test shows the percentage of packets received, packets lost, delay errors, RSSI chart, etc., for Router to Router in Mesh.

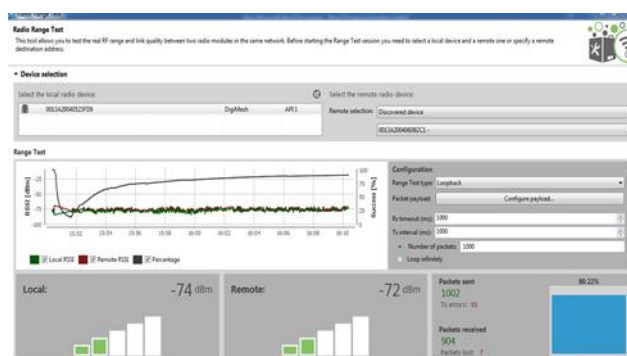


Fig. 12. Test from Router to Router in Mesh

3.3. Analyze of Test Topology Results

This test conducted to check the communication efficiency of Xbee in terms of distance in transmitting data using cluster, mesh and star topologies.

3.3.1. Star Topology

In the results from the test on star topology shows, the data sent by end device nodes to coordinator don't have packet loss from a distance under 10 m. So the communication between Xbee modules could run flowingly and all of the data packets sent by the end device should be received well by the coordinator node [18]. However, the data sent by end device to coordinator have packet loss from a distance above 10 m. Tests were performed using 1000 transmission packages. The received packages are average 82% of these 1000, which resulted in the decreasing quality of a network. This topology shows the lowest level of results in terms of range distance, received packets, and delays.

3.3.2. Mesh Topology

The results of the mesh network topology test show that as distance increases, so does the value of packet loss and delay in data transmission, since long- distance communication takes time in the process of data transmission through the router node. Tests were performed using 1000 transmission packages. The received packages are 90, 22% of these 1000, which also could result in the decreased quality of a network. This topology shows slightly better quality level of results in terms of range distance and received packets, compared to star, but still the percentage can lead to decreased quality of network performance.

3.3.2. Cluster Topology

Tests were done using three different types of devices - coordinator, router and end device. Sequentially, tests between the coordinator-router, coordinator-end device and router-end device were performed. The results show that the greatest success rate is with coordinator-router, followed by coordinator-end device and router-end device. Tests were performed using 1000 transmission packages. The received packages are average 97, 30% of these 1000, which don't lead to decreased quality of a network. The results of the test on ZigBee topology showed that the cluster topology has a significantly higher success rate than the other two topologies, in terms of range distance, received packets and delays. From the observation, we can see that the results of the percentage of success of data package received in cluster topology are bigger than in mesh.

4. Conclusions

We present the results of our study on the impact of different topologies such as star, cluster and mesh radio communication range and the quality of the transmitted data on a sensor network using ZigBee devices. Testing and configuration of the modules is performed with specialized software X-CTU. The room-to-room experiment is designed to examine the modules ability to transmit through walls, the results indicate that the module requires a clear line of sight for optimal transmissions. According to the tests done on the wireless sensor network data transmission using different topology scenario for measuring average packet loss, the conclusions are:

- Star topology had the biggest average packet transfer, don't have packet loss from a distance under 10 m and the biggest loss percentage packets in the biggest distance between notes, because the ZED nodes have the smallest communication range, therefore they are suitable for small networks.
- Mesh topology shows slightly better quality level of results, mainly because they use routing technique, in terms of range distance, received packets, compared to star, but still, the percentage can lead to decreased quality of network performance.
- Cluster topology has a significantly higher success rate than the other two topologies. Cluster topology had the smallest average packet loss value since they have the biggest communication range distance.
- Mesh and cluster topologies had an advantage that the data delivery could go through more distances than in star and they easy can add more nodes.

- Generally, according to performance analysis, the XBee modules are more suitable for low-level data applications that have no reliability and very high real-time deadlines. The next research will examine the environmental impact on communication range, throughput and other parameters, in order to determine the effects the surrounding environment connected to quality of the signals.

References

- [1] Tsvetanov F and Pandurski M 2018, Some aspects for the integration of sensor networks in cloud structures, *Proceedings of International conference on High Technology for Sustainable Development (HiTech 2018)*, p.p.249-253
- [2] Tsvetanov F, Tsvetanov K and Georgieva I 2014, Modelling and Simulation of Communication Efficiency in Low-Speed Networks, *Proceedings of the International conference, TELFOR'2014* p.p. 178-182
- [3] Tsvetanov F, Georgieva I, Radeva S, and Radev D, 2013 Modeling of Low-Rate Sensor Network Access, *Proceedings of the International conference, TELFOR'2013*, Belgrade, p.p 78-82
- [4] ZigBee Alliance, ZigBee.org, 2017, [Online]. Available: <http://www.zigbee.org/>
- [5] IEEE 802.15.4. IEEE Standard for Low-Rate Wireless Networks, [Online]. Available: <http://standards.ieee.org/getieee802/download/802.15.4-2015.pdf>
- [6] Configure the XBee modules for a range test - Digi International". [Online]. Available: https://www.digi.com/resources/documentation/digidocs/90001526/tasks/t_configure_the_xbee_modules_for_a_range_test.htm
- [7] Wireless Communication Range Testing with Digi XCTU - Digi International". [Online]. Available: <https://www.digi.com/blog/wireless-communication-range-testing-with-digi-xctu/>
- [8] XCTU -Next Gen Configuration Platform for XBee/RF Solutions -Digi International", Digi.com, 2017. [Online]. Available: <http://www.digi.com/products/xbee-rf-solutions/xctu-software/xctu>
- [9] Exploring XBees and XCTU -learn.sparkfun.com", Learn.sparkfun.com, 2017. [Online]. Available: <https://learn.sparkfun.com/tutorials/exploring-xbees-and-xctu>
- [10] Many-to-one routing - Digi International". [Online]. Available: https://www.digi.com/resources/documentation/Digidocs/90001942-13/concepts/c_many_to_one_routing.htm
- [11] Kuzminykh I 2017, Testing of communication range in ZigBee technology, *Proceeding14th International Conference The Experience of Designing and Application of CAD Systems in Microelectronics (CADSM)*.
- [12] Hill R Szewczyk A Woo S Hollar D Culler and K. Pister, 2000, System architecture directions for networked sensors, *ASPLOS*
- [13] Punitha R Priya M Banu Vijayalakshmi B., and Kumar, C. Ram, 2014 Adoptive parent based framework for ZigBee cluster tree networks, *International Journal of Engineering and Technical Research (IJETR)*, Vol. 2, Issue 2
- [14] Ki-II Kim 2019, Wireless Sensor Networks for Big Data Systems, Published online <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6480280/>
- [15] Panchard J 2008, Wireless Sensor Networks For Marginal Farming in India“, Thesis, Ecole Polytechnique Federale, De Lausanne
- [16] Gutierrez J 2007 On The Use Of IEEE 802.15.4 To Enable Wireless Sensor Network in Building Automation, *International Journal of Wireless Information Networks, Volume 14*, Number 4
- [17] Kumbhar H 2016, Wireless sensor network using Xbee on Arduino Platform: An experimental study, *Proceedings of International Conference on Computing Communication Control and Automation (ICCUBEA)*, DOI:10.1109/iccubea.2016.7860081
- [18] Yun D and Cho S 2008, A Data Transmission Method in ZigBee Networks Using Power Efficient Device, *Int. Conf. on Advanced Technologies for Communications*, pp.162-165