UDC 681
DOI: 10.15587/1729-4061.2022.266990

INVESTIGATING THE IMPACT OF NETWORK TOPOLOGIES ON THE IOT-BASED WSN IN SMART HOME MONITORING SYSTEM

Shayma W. Nourildean
Corresponding author
Master of Engineering, Lecturer*
E-mail: Shayma.w.nourildean@uotechnology.edu.iq
Yousra A. Mohammed
Master of Engineering, Lecturer*
May T. Abdulhadi
Master of Science, Assistant Teacher
Iraqi Commission for Computers and Informatics
Almansour str., Baghdad, Iraq, 00964
*Department of Communication Engineering
University of Technology
Alsinaa str., Baghdad, Iraq, 00964

The object of this research is to present IoT WSN-based smart home monitoring system, which allows users to monitor and manage all of their appliances and home equipment via the Internet using established protocols. IoT is described as the connection of equipment and appliances to the Internet in order to monitor, report, and perform certain tasks. Wireless Sensor Networks (WSN) are considered as a key component in the IoT model's implementation. This research presented the IoT WSN platform using Riverbed Modeler Simulation Program in order to examine the network performance for different Wireless Sensor topologies (Star, Tree and Mesh). This platform consists of a number of scenarios with a number of sensors in each scenario. Each sensor is represented by the ZigBee end device, which sensed and collected data about the smart home and sent the collected data to the controller, which is represented by the ZigBee coordinator. The controller sends the data to the server to be monitored by the users through any gateway (Wi-Fi) after logging in using a specific application with three routing topologies on the controller. The results showed that IoT WSN tree topology is the best topology if the throughput is considered for improvement at the expense of data dropped with acceptable delay. Star topology improves the network performance in terms of data dropped and throughput when the number of sensors was increased. Mesh topology achieved the smallest data dropped with low throughput. Due to their features, these results were effective because they indicated that the selection of suitable routing topology played an important role in improving the degradation of IoT WSN performance due to the interference of Wi-Fi and ZigBee network since they utilized the same frequency band (2.4 GHz)

Keywords: IoT, Riverbed, smart, Star, Tree, Mesh, ZigBee, throughput, delay, Wi-Fi

Received date 29.08.2022
Accepted date 08.11.2022
Published date 30.12.2022

***How to Cite:** Nourildean, S. W, Mohammed, Y. A., Abdulhadi, M. T. (2022). Investigating the impact of network topologies on the IoT-based WSN in smart home monitoring system. Eastern-European Journal of Enterprise Technologies, 6 (9 (120)), 6–14. doi: https://doi.org/10.15587/1729-4061.2022.266990*

1. Introduction

In the Internet of Things (IoT), electrical gadgets and sensors connect with each other over the Internet in order to make our lives more convenient and efficient. Businesses, governments, and public/private sectors throughout the world are benefiting from IoT's usage of smart devices and the Internet to solve a range of problems and issues. Our daily lives are becoming deeply integrated with the IoT in a variety of areas, including industrial, environmental, transportation, medical and so on [1]. A Smart Home is a secure, networked, and intelligent home control system that combines network connection and IoT technology. The IoT-based Smart Home collects interior environmental parameter information such as temperature, humidity, as well as information on different household equipment, through the use of sensors. After logging in, users can monitor the operation of each subsystem of the Smart Home via the IoT gateway's transmission of the data to an Internet server. The WSN is a major component of the IoT [2, 3]. WSN is the basis of IoT, IoT relies on WSN as a foundational technology [4]. In this paper, an IoT WSN-based smart home monitoring system platform had been developed using a Riverbed modeler (OPNET) simulation program to study the role of routing topologies of WSN in the performance of the network because this performance had been affected by the interference of Wi-Fi, which acts as a gateway to the Internet. IoT WSN consists of a number of sensors so that each sensor is represented by Zigbee end devices. These sensors sense the monitoring parameters from the smart home and send the collected data to the controller. This controller is represented by the ZigBee controller, which is connected through the Wi-Fi gateway to the server so the user can monitor the smart home parameters by using a specific application via the Internet. Three routing WSN topologies were taken in order to indicate which topology is the best to improve the network performance since Wi-Fi and Zigbee utilize the same frequency band in terms of the number of QoS parameters for different applications. Therefore, research on the selection of an appropriate routing topology is relevant and important. Because the object of any network is performance improvement and this research is one of the techniques used to improve network performance.

2. Literature review and problem statement

The paper [5] presented the adoption of WSN-based IoT in precision agriculture. The basic physical characteristics of weather have been observed. The advantage of this study is that the IoT allows data to be transferred to any location but this approach highlighted the limitation of IoT. The advantage of the approach in [6] is that it had developed an IoT-based WSN framework for smart agriculture, which includes several design levels for monitoring yields and automating agriculture precision utilizing various sensors but it is costly in practice, which makes the corresponding research inexpedient. The paper [7] offers a precision farming application prototype based on a wireless sensor network and an IoT cloud, which supports platforms that enable the creation of web services appropriate for Internet-connected products. An option to overcome the relevant difficulties of the previous study can be found in [8], which presents the essential features and experimental research of flood monitoring utilizing an IoT-based wireless sensor network by collecting data on environmental parameters and transmitting them in real time to a server over 3G and Wi-Fi networks but it has disadvantages of the interference of WSN and Wi-Fi since they utilize the same frequency band. The approach in [3] showed a WSN IoT prototype for use in water pipelines. To arrive at a final suitable design, experimental and comparative research for the various node components was performed but it was costly.

However, for all of the previous WSN studies, the important goal is to improve the network performance for any WSN for different applications so that the problem statement of this study, which differs from the previous work, is the role of selection of an appropriate WSN routing topology in an IoT WSN based smart home monitoring system. This platform had been developed using a Riverbed modeler (OPNET) simulation program to investigate which routing topology improved the network performance in terms of delay, data dropped and throughput, as they are the most important efficiency parameters of any network.

3. The aim and objectives of the study

The aim of the study is to select an appropriate routing topology from the three WSN routing topologies (Tree, Mesh and Star) in order to improve the network performance.

To achieve this aim, the following objectives are accomplished:

– to measure delay, data dropped and throughput where the number of sensors is 30 in three cases (IoT WSN Mesh Routing 15 nodes, IoT WSN Star Routing 15 nodes and IoT WSN Tree Routing 15 nodes);

– to measure delay, data dropped and throughput where the number of sensors is 30 in three cases (IoT WSN Mesh Routing 30 nodes, IoT WSN Star Routing 30 nodes and IoT WSN Tree Routing 30 nodes);

– to measure delay, data dropped and throughput where the number of sensors is 60 in three cases (IoT WSN Mesh Routing 60 nodes, IoT WSN Star Routing 60 nodes and IoT WSN Tree Routing 60 nodes).

4. Materials and methods of research

4. 1. Object and hypothesis of the study

The object of this study is to improve the network efficiency of any IoT WSN system in terms of some of Quality of Service parameters (delay, data dropped and throughput). The assumptions are that a number of sensors sense the environmental data and send the collected data to the controller to be monitored by the users through any gateway.

The main hypothesis of the study is that three WSN routing topologies were applied to select which one improved the network efficiency from the delay, throughput or data dropped point of view. Riverbed Modeler v17.5 was utilized in this study because it is an active program to simulate various kinds of networks, devices and protocols in an efficient and flexible way.

4. 2. The Theoretical Basis

The theoretical basis of this research had been presented in terms of:

a) Internet of Things (IoT). Definition: The Internet of Things (IoT) is made up of two terms: “Internet” and “things”. It is simply described as the connection of equipment and appliances to the internet in order to monitor, report, and perform certain tasks. Sensors, actuators, and RFID tags are types of IoT devices. The majority of IoT devices should have low power consumption [1]. The Internet of Things (IoT) will connect a wide range of devices, enabling automated (human-to-machine) machine (M2M) communication. With visual, auditory, and optical sensors, all of the IoT hardware and software had been provided [4]. It is possible to alter our relationship to the physical world and the way we perceive it using the Internet of Things (IoT). Connecting real-world items to the information network would improve apps’ efficiency and intelligence, as well as their ability to be more accurate. In this technology, wireless sensor networks (WSNs) play a significant role in shaping the physical environment to human perception [3]. In addition, many scholars have explained the Internet of Things in different ways, depending on their particular areas of expertise and research interests [9]. Sensor nodes are used in the Internet of Things (IoT) to provide multi-hop transmission, collision-free transmission, and great energy efficiency in automated systems [1].

b) Smart Home. In a “smart home”, all of the household appliances and equipment can be managed and controlled remotely and automatically, making it possible to live in a “smart” environment. Smart homes allow users to monitor and manage all of their appliances and home equipment via the Internet using established protocols and a predetermined network architecture [10]. When we talk about a “smart home”, we’re not referring to a building that uses solar power or recycles waste water since that would be a “smart house”. Instead, we’re talking about a building that uses interactive technology. A smart house is described as “intelligent” since its computer systems can monitor many aspects of everyday life. The smart home concept is a potential and cost-effective solution to improve home monitoring. House appliances, actuators, sensors, analyzers and data processors are part of a smart home, which can be wired or wireless [11]. Home security, visual intercom, remote video surveillance, telemedicine diagnosis and care systems, remote monitoring of home appliances and online education systems are all examples of smart home systems [12].

c) WSN IoT. The advancement of IoT technology enables communication between billions of items, applications, data and people. Since most IoT devices communicate wirelessly with one another and/or the base station (BS), WSN had been considered as a key component in the IoT model’s implementation. A smart home monitoring system is one of many potential breakthroughs enabled by the incorporation of WSN devices with other IoT enabling technologies [13]. The WSN serves as a bridge to the Internet of Things. A wireless sensor network is a collection of sensor nodes with a restricted power source and limited computing and transmission capabilities. It is simpler to monitor the challenging environments that are difficult to monitor normally because sensor nodes perceive, analyze, and transmit the observed data to the destination. Routing algorithms can assist to preserve resources and prolong the life of a node by making intelligent decisions based on a realistic lifespan prediction [14, 15].

The Internet of Things (IoT) and Wireless Sensor Networks (WSN) are going toward edge technologies. IoT-based wireless sensor networks include a wide range of considerations, including communication delay, throughput, security, cost and power consumption. Low-cost sensor nodes for transmission, data collection and remote monitoring are being performed with the rapid rise of IoT-based WSNs. In terms of energy, computational power, and storage capacity, IoT-enabled smart nodes had some limitations on resources. For further communication, IoT-based WSN sensor nodes sense the environment and send their data to the cluster head (CH), which in turn sends it to the sink or Base Station (BS) where it can be processed [16, 17].

Because of WSN limited resources with unreliable links between the nodes, it had been difficult in designing an effective routing algorithm due to the diverse requirements of different applications, therefore, the design of appropriate routing algorithms for varied applications has been a key concern. The design challenges of WSN in terms of data throughput, energy consumption, hardware constraints and scalability could be improved through the use of efficient routing protocols. Because of this, protocols and pathways are needed to transport data with a decreased latency, loss rate and minimal power consumption for various IoT applications [14, 18].

The most common use of WSNs is in smart home monitoring, where a variety of sensors are used to track a house's various activities. The introduction of IEEE 802.15.4 as a significant international standard for WSNs in 2003 was a breakthrough step for WSNs. The ZigBee Alliance then standardized the ZigBee communication protocol (IEEE 802.15 ZigBee protocol) [19]. ZigBee and IEEE 802.15.4 are two of the most widely utilized protocols in such monitoring contexts. Among the numerous advantages of ZigBee technology is its ability to conserve battery power, handle a large number of nodes in a network, and communicate over long distances. As a result, expanding the network is simple, and it offers high levels of security for its users [20]:

d) ZigBee (IEEE802.15.4). ZigBee is a low-power and low-cost wireless communication technology suitable for low data rate applications. ZigBee technology is used in a variety of controlling and monitoring applications and operates in 915/868 MHz bands or unlicensed 2.4 GHz [21].

The ZigBee protocol supports 3 node types [19, 22]:

– ZigBee Coordinator (ZC): It sets up the network, secures it, and creates the necessary control algorithms. The PAN coordinator works as ZR as soon as the network starts up. ZC is the device that is responsible for network configuration. The ZC stores network information;

– ZigBee Router (ZR): The router has the capability of routing observed data to the sink node. By having a preexisting relationship with ZC or any ZR, it performs a multiple node hopping function. The ZigBee routers (ZRs) are used in tree and mesh topologies to enhance the network coverage area for wireless communication;

– ZigBee End Device (ZED): They just function as regular nodes, with no routing capabilities. ZEDs are typically low-power and battery-powered devices. They send their information to the parent (ZC), which might be the coordinator or another router node. Data from other nodes cannot be relayed via the ZED. Nodes in the home's ZigBee network are distributed in various locations, and the data is sent to a central coordinator through the Internet.

e) ZigBee Routing Topologies. WSN topology represents how the nodes are interconnected. Where the routing protocol or algorithm will determine the route to send the data, e.g., LEACH, Proactive, Reactive. In this study, WSN-based ZigBee topologies describe the way the sensors were interconnected. ZigBee technology uses three basic topologies, including star, tree and mesh topologies [23] as shown in Fig. 1.

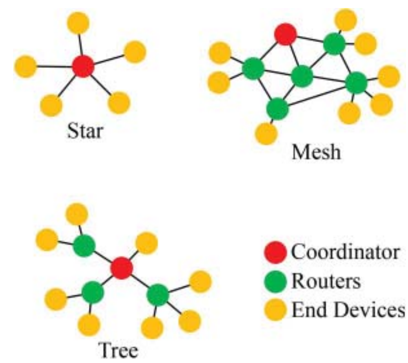

Fig. 1. ZigBee topologies [24]

The three topologies are [23]:

– the star topology: It is a centralized architecture in which a central node that functions as a ZC handles all management and communication with terminal nodes. Through its neighborhood, ZC employs a unique PAN identity. This topology has two main issues:

a) the node's centralization, where heavy workloads exhaust the node's energy and cause it to shut down the network;

b) the IEEE 802.15.4/ZigBee standard's constrained coverage area, which causes scaling issues;

– the mesh topology: This design enables each node to interact directly with other nodes within its range using one-hop or multi-hop approaches, overcoming the problem of node centralization. On the other hand, the complexity and estimated delay are increased by this cozy communication. The effectiveness of this topology's power consumption means that no node is likely to deplete its energy quickly, extending the network's lifespan;

– the tree topology: This kind of topology is ideal for networks with low costs and power consumption. They have numerous drawbacks, including a very high failure cost in terms of network lifetime or maintenance costs. Additionally, the blocking of several pathways routing results in a waste of bandwidth.

4. 3. Research Method (IoT-based WSN Simulation system)

Analyzing system behavior using the old approach has become increasingly difficult as communication networks have grown increasingly complicated. As a result, a model is needed to accurately describe the system's behavior. Before implementing a model or method in hardware, it is necessary to test a system's functioning and performance through the use of a computer simulation. Modeling and simulation frameworks for wireless sensor networks are used to validate and test the system under various operating situations [25, 26]. Riverbed (OPNET) Modeler Academic Edition 17.5 software program was utilized in this study because it provides extensive performance analysis of ZigBee networks in terms of service quality criteria. OPNET was bought by Riverbed (a technology business). In this simulation program, multiple system models are developed so that it allows communication between end devices, the administrator, routers and coordinator [27].

The simulation setup of the proposed IoT WSN is composed of nine different Riverbed Modeler scenarios. The steps of the methodology are:

1. Each scenario consists of a number of sensors sending data to the controller.

2. Each smart sensor is represented by ZigBee end device. These sensors sense and collect the smart home data and send it to the controller. The parameters of each ZigBee sensor are shown in Fig. 2.

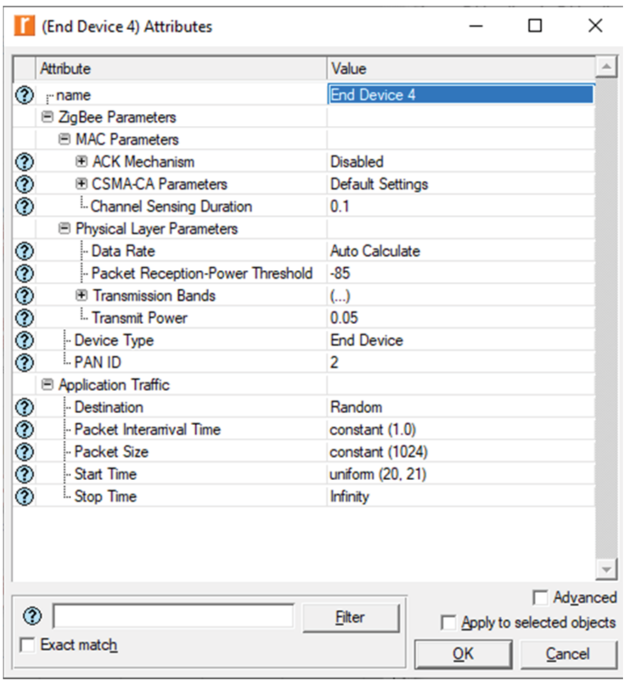

Fig. 2. ZigBee Sensor Parameters

3. The controller is represented by ZigBee Coordinator, which sends the collected data from the sensors to the Wi-Fi workstation (PC and server) so that any user could monitor the data via peer-to-peer file sharing application in this study or any applications. The ZigBee attributes are shown in Fig. 3.

Wi-Fi attributes are shown in Fig. 4.

4. Assign Application and Profile Configuration in each scenario specifies the applications for any network so that the profile of each WLAN is assigned to the specific application. In this paper, peer-to-peer file sharing application is installed so that each workstation and the server are configured for this application. The modeled network in each scenario of the first three scenarios is shown in Fig. 5.

5. The three topologies (Star, Tree and Mesh topologies) were applied to the ZigBee network to obtain three scenarios: 15 sensor nodes (IoT WSN Mesh Routing 15 nodes, IoT WSN Star Routing 15 nodes, IoT WSN Tree Routing 15 nodes) by setting the attributes of the coordinator in each scenario and select one of the three topologies as shown in Fig. 3.

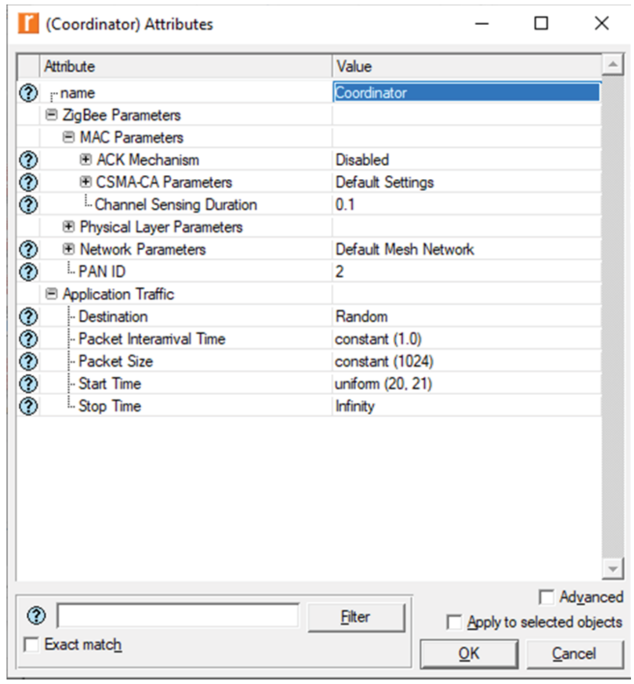

Fig. 3. ZigBee Coordinator attributes

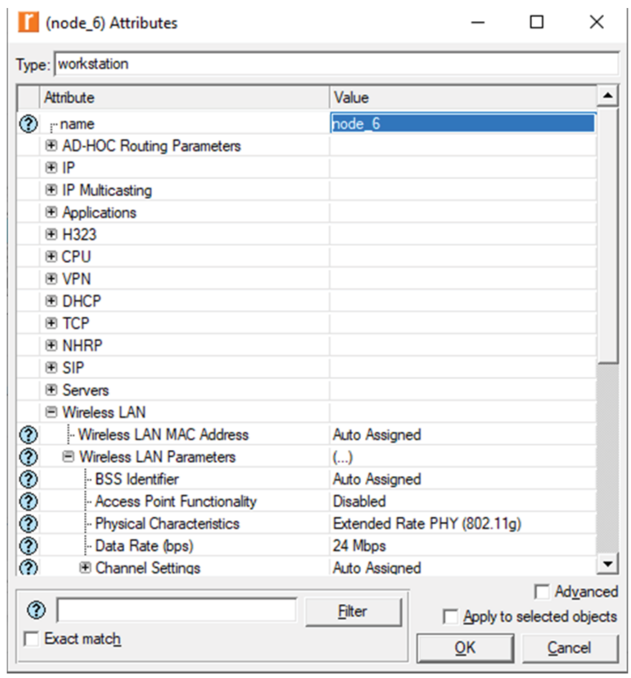

Fig. 4. Wi-Fi attributes

6. The next three different scenarios are IoT WSN Mesh Routing 30 nodes, IoT WSN Star Routing 30 nodes, IoT WSN Tree Routing 30 nodes, and the same three routing topologies were applied with 30 sensors. The modeled network in each scenario with 30 sensors is shown in Fig. 6.

7. The next three different scenarios are IoT WSN Mesh Routing 60 nodes, IoT WSN Star Routing 60 nodes, IoT WSN Tree Routing 60 nodes, and the same three routing topologies were applied with 60 sensors. The modeled network in each scenario with 60 sensors is shown in Fig. 7.

Each scenario contains the following objects in Table 1.

Table 1

Network Objects

Parameter	Value
No. of ZigBee nodes	1 coordinator, 7 routers, 15 end devices in three scenarios and 1 coordinator, 7 routers, 30 end devices in the next three scenarios and 1 coordinator, 7 routers, 60 end devices in the next three scenarios
ZigBee Routing Topology	Mesh, Star and tree Routing
WLAN	Two
Wireless Server	One
Transmission Band	2.4 GHz
Wi-Fi Data transfer	24 Mbps
Transmission Power	0.05 Watt
Simulation Duration	1,800 sec
Applications of the profile	Peer-to-peer File Sharing, Data Access with File transfer
QoS measured Parameters	Throughput, Delay and Data dropped

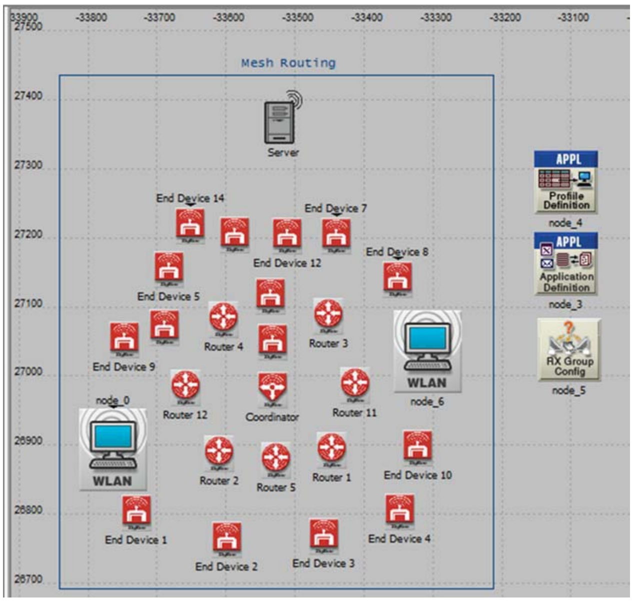

Fig. 5. Wireless Sensor Network scenarios (15 sensors)

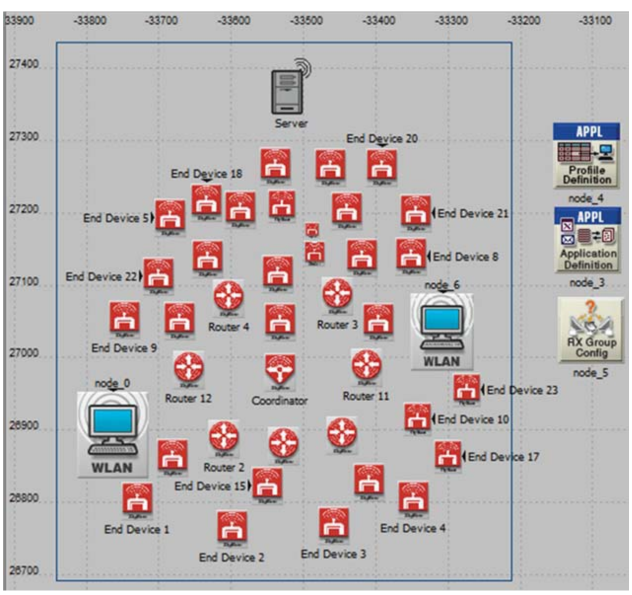

Fig. 6. Wireless Sensor Network scenarios (30 sensors)

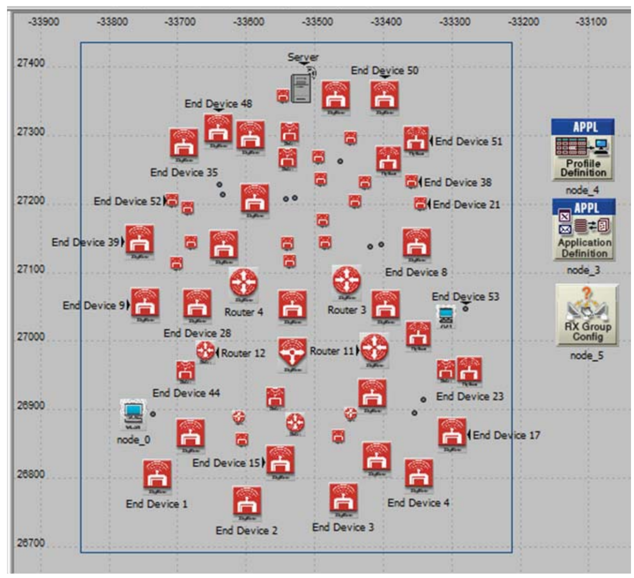

Fig. 7. Wireless Sensor Network scenarios (60 sensors)

After Discrete Event Simulation Statistics were selected for the nine scenarios by clicking right on each scenario and selecting Choose Individual DES statistics, which represent the QoS parameters (Throughput, Data Dropped and Delay) for peer-to-peer file sharing and data access applications. The simulation was run for 1800 seconds. The results are presented in the following section.

5. Results of IoT Wireless Sensor Network Study

5. 1. QoS parameters with 15 sensor nodes

The simulation was run and the results were collected by clicking right on each scenario and selecting View the results as follows: Throughput (bps), data dropped (bits/sec) and delay (sec) for the three scenarios named IoT WSN Mesh Routing 15 nodes, IoT WSN Star Routing 15 nodes and IoT WSN Tree Routing 15 nodes with 15 sensor nodes (ZigBee end devices) are collected and shown in Fig. 8–10, respectively.

Then the number of sensors is increased to 30 ZigBee end devices.

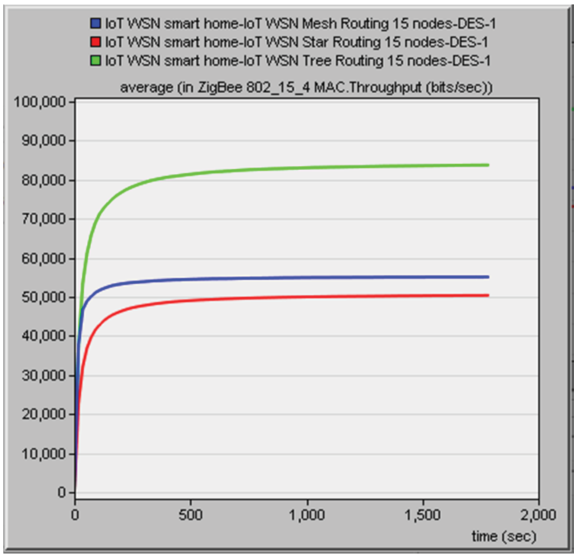

Fig. 8. Throughput (15 sensors)

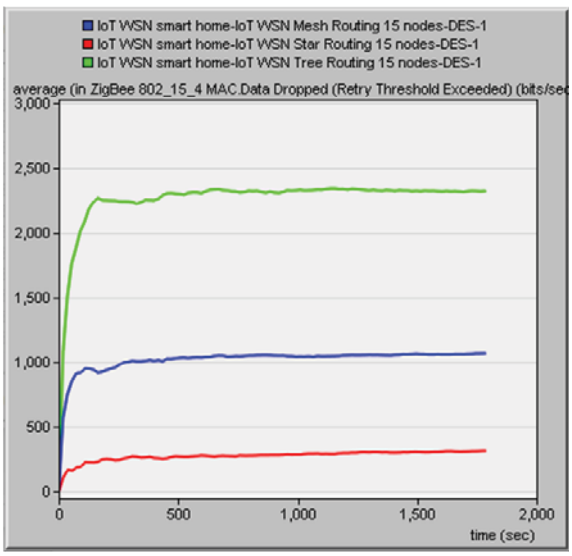

Fig. 9. Data Dropped (15 sensors)

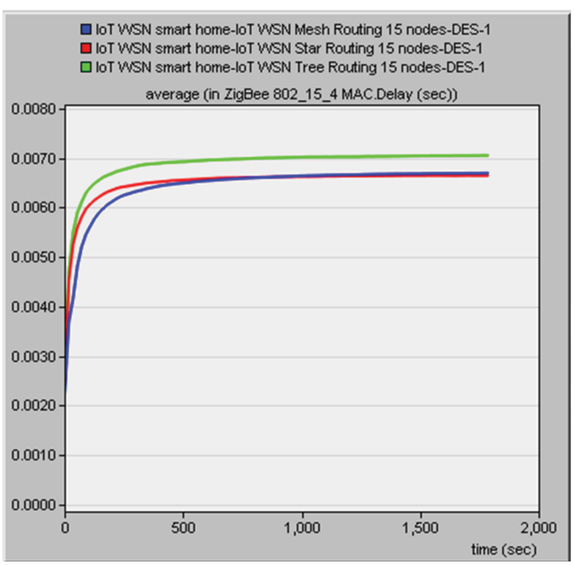

Fig. 10. Delay (15 sensors)

5. 2. QoS parameters with 30 sensor nodes

Throughput (bps), data dropped (bits/sec) and delay (sec) for the next three scenarios named IoT WSN Mesh Routing 30 nodes, IoT WSN Star Routing 30 nodes and IoT WSN Tree Routing 30 nodes with 30 sensor nodes (ZigBee end devices) are collected and shown in Fig. 11–13, respectively.

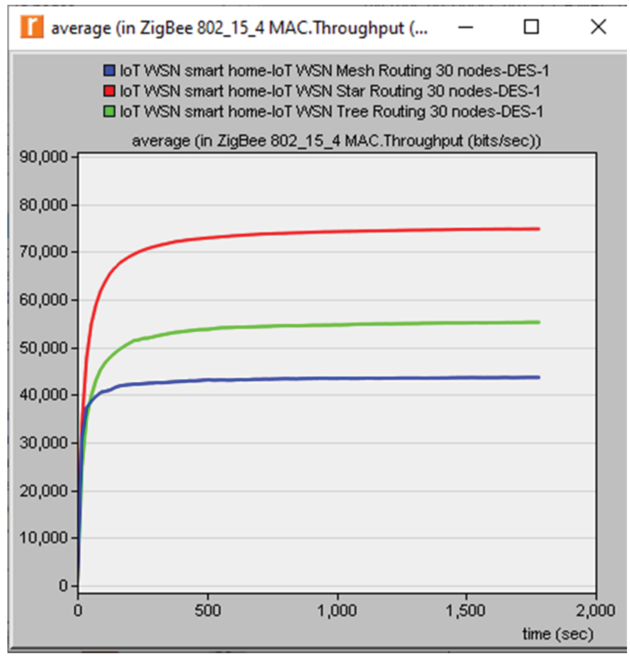

Fig. 11. Throughput (30 sensors)

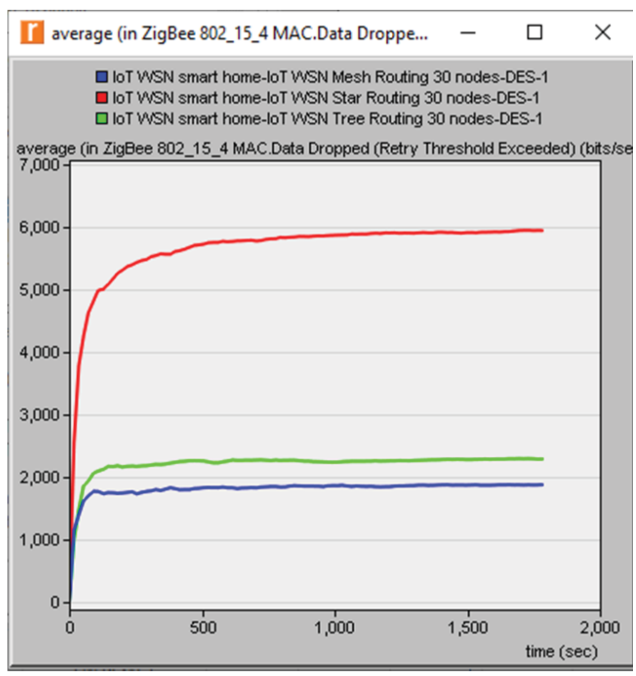

Fig. 12. Data Dropped (30 sensors)

Then the number of sensors is increased to 30 ZigBee end devices.

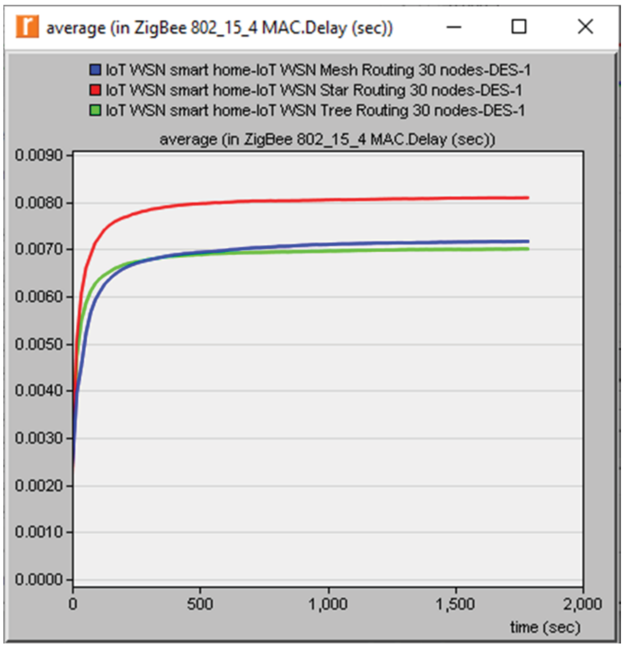

Fig. 13. Delay (30 sensors)

5. 3. QoS parameters with 60 sensor nodes

Throughput (bps), data dropped (bits/sec) and delay (sec) for the next three scenarios named IoT WSN Mesh Routing 60 nodes, IoT WSN Star Routing 60 nodes and IoT WSN Tree Routing 60 nodes with 60 sensor nodes (ZigBee end devices) are collected and shown in Fig. 14–16, respectively.

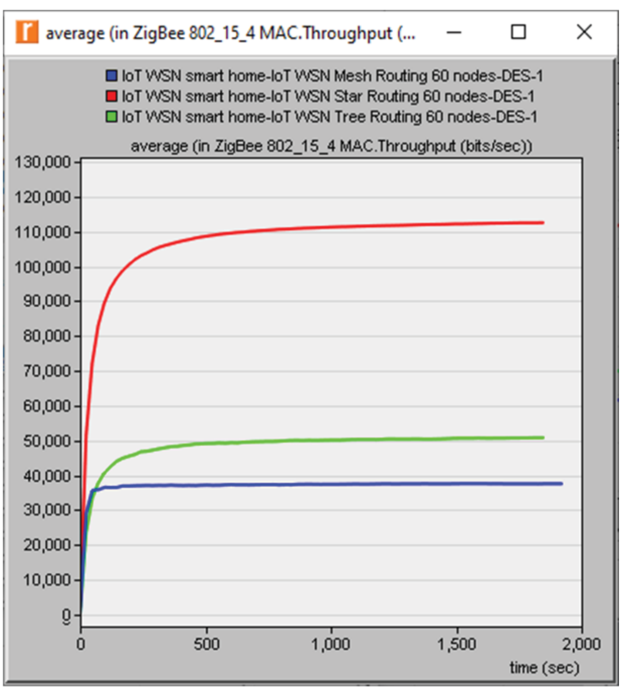

Fig. 14. Throughput (60 sensors)

Table 2 shows the network parameters (throughput, data dropped and delay).

A discussion of the results is given in the following section.

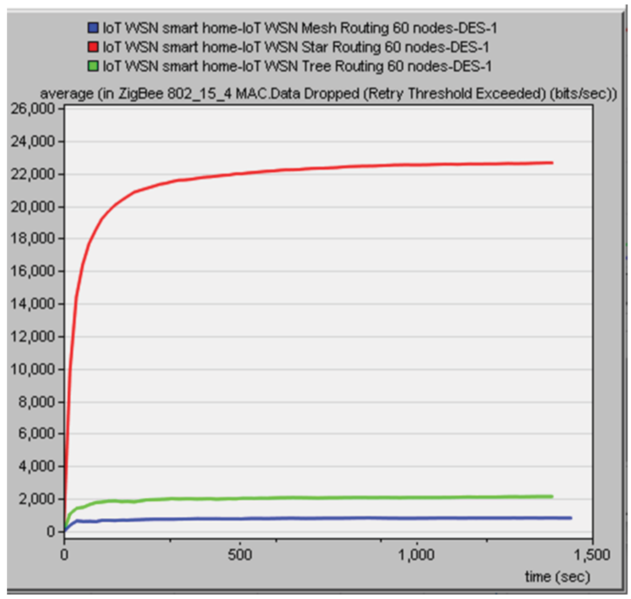

Fig. 15. Data Dropped (60 sensors)

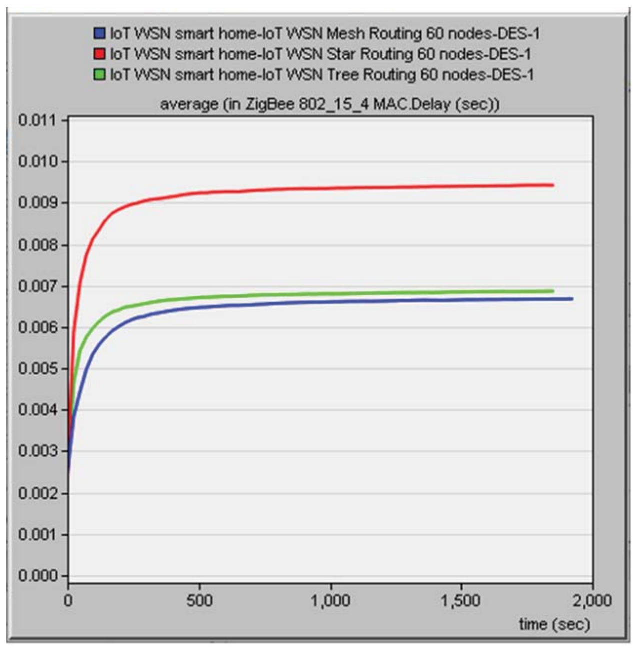

Fig. 16. Delay (60 sensors)

Table 2

Network parameters

No. of sensors	Network Scenario Parameter	IoT WSN Mesh Routing	IoT WSN Star Routing	IoT WSN Tree Routing
15 Sensors	Throughput	55,073	50,375	83,743
	Data Dropped	1,068.8	315.36	2,323.44
	Delay	0.00669	0.00664	0.00705
30 Sensors	Throughput	43,646.1	74,798.9	55,203.1
	Data Dropped	1,877.5	5,943.6	2,287.44
	Delay	0.0071	0.0081	0.0070
60 Sensors	Throughput	37,582	112,505	50,795
	Data Dropped	816.45	22,640.3	2,133.23
	Delay	0.0066	0.0094	0.0068

6. Discussion of QoS parameters (delay, throughput and data dropped)

After the network is modeled and simulated utilizing the Riverbed Modeler simulation program. Discrete Event Statistics had been selected for each scenario and the simulation was run and the results were collected. The previous studies had investigated IoT WSN in different application systems but this study investigated the role of routing topology to increase the system performance in terms of QoS parameters (throughput, data dropped and delay). As indicated in the results, in terms of throughput and when the number of sensors was 15, WSN with Tree topology improved the proposed WSN because it achieved the highest throughput than mesh and star topologies as shown in Fig. 8 with the highest data dropped and delay while the star topology achieved the smallest data dropped and delay but at the expense of throughput as shown in Fig. 9, 10, respectively. When the number of sensors was increased to 30, the star topology improved the proposed network in terms of throughput as shown in Fig. 11 with the highest data dropped and delay as shown in Fig. 12, 13, respectively. It could be shown that with the number of sensors of 30 and 60, the mesh topology achieved the throughput as shown in Fig. 14, as well as the smallest data dropped and delay as shown in Fig. 15, 16, respectively. It could be shown that the selection of an appropriate routing topology played a vital role in the improvement of network performance.

The limitation of this study is the occurrence of interference between ZigBee and Wi-Fi since they utilize the same frequency band (2.4 GHz) in which this study tried to improve the degradation of performance by selecting an appropriate routing topology. The future work for this study is to develop an IoT WSN routing protocol, which can aid in increasing network efficiency.

7. Conclusions

1. Throughput, data dropped and delay in the three cases (Mesh Routing topology, Tree routing topology and Star routing topology) when the number of sensors was 15 indicating qualitative or quantitative indicators of research results showed that from the throughput point of view, IoT WSN tree topology is the best because it achieved higher throughput than mesh and star topologies at the expense of data dropped with acceptable delay.

2. Throughput, data dropped and delay in the three cases (Mesh Routing topology, Tree routing topology and Star routing topology) when the number of sensors was 30 indicating qualitative or quantitative indicators of research results showed that star topology achieved the higher throughput with higher data dropped. There is a slight difference in the delay between the three topologies.

3. Throughput, data dropped and delay in the three cases (Mesh Routing topology, Tree routing topology and Star routing topology) when the number of sensors was 60 indicating qualitative or quantitative indicators of research results showed that mesh topology achieved the smallest data dropped with low throughput. There is a slight difference in the delay between the three topologies.

Conflict of interest

We declare that we have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Data will be made available on reasonable request.

References

1. Lavanya, P., Muthu Mayil, K. (2019). IoT - Based Wireless Sensors for Agriculture Monitoring. International Journal of Recent Technology and Engineering, 8 (2S4), 177–181. doi: https://doi.org/10.35940/ijrte.b1033.0782s419
2. Ma, L., Li, Z., Zheng, M. (2019). A Research on IoT Based Smart Home. 2019 11th International Conference on Measuring Technology and Mechatronics Automation (ICMTMA). doi: https://doi.org/10.1109/icmtma.2019.00033
3. Karray, F., Triki, M., Wassim Jmal, M., Abid, M., M. Obeid, A. (2018). WiRoTip: an IoT-based Wireless Sensor Network for Water Pipeline Monitoring. International Journal of Electrical and Computer Engineering (IJECE), 8 (5), 3250. doi: https://doi.org/10.11591/ijece.v8i5.pp3250-3258
4. Jothikumar, C., Ramana, K., Chakravarthy, V. D., Singh, S., Ra, I.-H. (2021). An Efficient Routing Approach to Maximize the Lifetime of IoT-Based Wireless Sensor Networks in 5G and Beyond. Mobile Information Systems, 2021, 1–11. doi: https://doi.org/10.1155/2021/9160516
5. Agarwal, A., Singh, M., Singh, S., Singh, A., Singh, A. (2022). Wireless Sensor Network Based Internet of Things for Precision Agriculture. SSRN Electronic Journal. doi: https://doi.org/10.2139/ssrn.4031983
6. Haseeb, K., Ud Din, I., Almogren, A., Islam, N. (2020). An Energy Efficient and Secure IoT-Based WSN Framework: An Application to Smart Agriculture. Sensors, 20 (7), 2081. doi: https://doi.org/10.3390/s20072081
7. Roopa, G. K., Shetty, R. (2019). IOT & Wireless Sensor Networks in Precision Agriculture. International Journal of Science and Research (IJSR), 8 (1), 401–404.
8. Mendoza-Cano, O., Aquino-Santos, R., López-de la Cruz, J., Edwards, R. M., Khouakhi, A., Pattison, I. et al. (2021). Experiments of an IoT-based wireless sensor network for flood monitoring in Colima, Mexico. Journal of Hydroinformatics, 23 (3), 385–401. doi: https://doi.org/10.2166/hydro.2021.126

9. Kumar, S., Tiwari, P., Zymbler, M. (2019). Internet of Things is a revolutionary approach for future technology enhancement: a review. Journal of Big Data, 6 (1). doi: https://doi.org/10.1186/s40537-019-0268-2
10. Gabhane, J. P., Thakare, S., Craig, M. (2017). Smart Homes System Using Internet-of-Things: Issues, Solutions and Recent Research Directions. International Research Journal of Engineering and Technology (IRJET), 04 (05), 1965–1969.
11. Davidovic, B., Labus, A. (2016). A smart home system based on sensor technology. Facta Universitatis - Series: Electronics and Energetics, 29 (3), 451–460. doi: https://doi.org/10.2298/fuee1603451d
12. Sisavath, C., Yu, L. (2021). Design and implementation of security system for smart home based on IOT technology. Procedia Computer Science, 183, 4–13. doi: https://doi.org/10.1016/j.procs.2021.02.023
13. Salim, A., Ismail, A., Osamy, W., Khedr, A. M. (2021). Compressive sensing based secure data aggregation scheme for IoT based WSN applications. PLOS ONE, 16 (12), e0260634. doi: https://doi.org/10.1371/journal.pone.0260634
14. El-Sayed, H. H., Bayatti, H. A. (2021). Improving Network Lifetime in WSN for the application of IoT. Applied Mathematics & Information Sciences, 15 (4), 453–458. doi: https://doi.org/10.18576/amis/150407
15. Sharma, S., Verma, V. K. (2022). An Integrated Exploration on Internet of Things and Wireless Sensor Networks. Wireless Personal Communications, 124 (3), 2735–2770. doi: https://doi.org/10.1007/s11277-022-09487-3
16. Anandhavalli, A., Bhuvaneswari, A. (2018). IoT Based Wireless Sensor Networks – A Survey. International Journal of Computer Trends and Technology, 65 (1), 21–28. doi: https://doi.org/10.14445/22312803/ijctt-v65p104
17. Shafiq, M., Ashraf, H., Ullah, A., Masud, M., Azeem, M., Z. Jhanjhi, N., Humayun, M. (2021). Robust Cluster-Based Routing Protocol for IoT-Assisted Smart Devices in WSN. Computers, Materials & Continua, 67 (3), 3505–3521. doi: https://doi.org/10.32604/cmc.2021.015533
18. Saleh, M. (2020). WSNs and IoT Their Challenges and applications for Healthcare and Agriculture: A Survey. Iraqi Journal for Electrical and Electronic Engineering. The 3rd Scientific Conference of Electrical and Electronic Engineering Researches (SCEEER), 37–43. doi: https://doi.org/10.37917/ijeee.sceeer.3rd.6
19. Ghayvat, H., Mukhopadhyay, S., Gui, X., Suryadevara, N. (2015). WSN- and IOT-Based Smart Homes and Their Extension to Smart Buildings. Sensors, 15 (5), 10350–10379. doi: https://doi.org/10.3390/s150510350
20. Coboi, A. E., Nguyen, V., Nguyen, M., Duy, N. T. (2021). An Analysis of ZigBee Technologies for Data Routing in Wireless Sensor Networks. ICSES Transactions on Computer Networks and Communications (ITCNC).
21. Ali, H., Chew, W. Y., Khan, F., Weller, S. R. (2017). Design and implementation of an IoT assisted real-time ZigBee mesh WSN based AMR system for deployment in smart cities. 2017 IEEE International Conference on Smart Energy Grid Engineering (SEGE). doi: https://doi.org/10.1109/sege.2017.8052810
22. Vançin, S., Erdem, E. (2015). Design and Simulation of Wireless Sensor Network Topologies Using the ZigBee Standard. International Journal of Computer Networks and Applications (IJCNA), 2 (3), 135–143.
23. Nourildean, S. W., Hassib, M. D., Mohammed, Y. A. (2022). Internet of things based wireless sensor network: a review. Indonesian Journal of Electrical Engineering and Computer Science, 27 (1), 246. doi: https://doi.org/10.11591/ijeecs.v27.i1.pp246-261
24. Ameen, S. Y., Nourildean, S. W. (2013). Coordinator and router investigation in IEEE802.15.14 ZigBee wireless sensor network. 2013 International Conference on Electrical Communication, Computer, Power, and Control Engineering (ICECCPCE). doi: https://doi.org/10.1109/iceccpce.2013.6998748
25. Sharma, R., Vashisht, V., Singh, U. (2020). Modelling and simulation frameworks for wireless sensor networks: a comparative study. IET Wireless Sensor Systems, 10 (5), 181–197. doi: https://doi.org/10.1049/iet-wss.2020.0046
26. Wail Nourildean, S., Mohammed Salih, A. (2022). Internet of Things based Wireless Sensor Network - WiFi Coexistence in Medical Applications. 2022 8th International Engineering Conference on Sustainable Technology and Development (IEC). doi: https://doi.org/10.1109/iec54822.2022.9807574
27. Nourildean, S. W., Jasim, S. I., Abdulhadi, M. T., Jaber, M. M. (2022). Point coordination mechanism based mobile ad hoc network investigation against jammers. Eastern-European Journal of Enterprise Technologies, 5 (9 (119)), 45–53. doi: https://doi.org/10.15587/1729-4061.2022.265779