International Journal of Latest Research in Engineering and Technology (IJLRET)
ISSN: 2454-5031
www.ijlret.com || Volume 11 - Issue 10 || October 2025 || PP. 44-52

The effects of Throughput, Delay and Data Traffic on WSN Topologies

Naseem Kadhim Baqer
Department of Electrical Engineering, Faculty of Engineering, University of Kufa, Najaf, Iraq

Abstract: Wireless Sensor Networks (WSNs) are systems that consist of hundreds or possibly even thousands of sensor nodes. Sensor nodes may be deployed either randomly or strategically to carry out complex tasks like sensing, data collection, calculations, and data transmission based on predetermined parameters. This study utilised the IEEE 802.15.4/ZigBee wireless communication standard. Compared to other wireless communication standards, the Zigbee has several advantages, including low battery and power consumption, as well as support for three distinct global frequency bands. It also provides excellent performance for short-range sensors. Simulations were conducted using the RIVERBED Academic Edition 17.5 simulator, which has the ability to producehighly accurate results in real-world network applications. Using this simulator, a comparison was made of four key performance parameters namely, delay, throughput, data traffic sent, and data traffic received for the mesh, tree, and star topologies provided by the ZigBee standard. The aim of this study is to establish the best topology from these three primary topologies. It is found that the star topology performs better in terms of productivity and data transmission rate in comparison to the tree and mesh topologies, however, it underperforms in terms of data received rate. By contrast, the mesh architecture provides the maximum data received rate when compared to the two other scenarios. The tree architecture proved itself optimal for networks with a small number of sensor nodes because it can transport data to its destination rapidly and without overwhelming the central node.

Keywords: WSN, ZigBee, RIVERBED, OPNET, Wireless Network Topologies.

I. Introduction

A wireless sensor network (WSN) is a network architecture composed of sensor nodes that collect data from their surrounding environment using their designated capabilities. These nodes then process the databefore sending it to a base station via other sensor nodes[1]. Recent advancements in wireless communication, along withimprovements in processor quality, memory capacity, and low power consumption, have further underlined the importance of micro electro-mechanical systems (MEMS) [2].

Sensor networks built with compact devices are now more readily deployedat lower cost, and self-organising devices facilitate easier communication among sensors. In such networks, sensors perform various functions. Those that process raw data from other sensors and temporarily store it in internally for use at specific times are referred to as main sensors. Analogue data collected by other sensors from their surroundings is transmitted to one or more additional sensors. WSNs can be beneficial in a wide range of environments, including homes, businesses, industries, outdoor areas, military installations, hospitals, and much more. They are also suitable for deployment in remote or hazardous locations, such as high mountains and dangerous zones [3].

In this study, the IEEE 802.15.4/ZigBee standard was used in a simulator to analyse the performance of different wireless network topologies. The results may offer a solution to the problems encountered in developing real-world applications. Researchers employ a range of simulation tools, including OMNET++, J-Sim, TOSSIM, QUALNET, GLOMOSIM and JIST/SWANS, SensorSim, EmStar, and Network Simulator (NS-2). However, because it offers a comprehensive performance analysis of ZigBee networks with respect to quality of service (QoS) requirements,the simulation application RIVERBED Modeller Academic Edition 17.5 was employed in this study.Three ZigBee network scenarios were developed using the RIVERBED simulator. For each topology, QoS parameters such as throughput, MAC delay, data traffic received, and data traffic sent were evaluated.

II. WSNs

Wireless sensor networks (WSNs) are distributed network topologies made up of numerous wirelessly connected sensors that enable communication between themselves. Wireless communication refers to the transfer of information between a transmitter and a receiver using light or electromagnetic waves without the use of physical cables.

Sensors are components used in electrical applications to detect a wide range of physical quantities and to measure a wide range of parameters, includingvolume, area, length, mass air flow, flux density, magnetic torque, heat transfer, resistance, temperature, strength, electric current, voltage, condensation, content, and oxidation/reduction.

The main components of a sensor node are: the memory, receiver-transmitter, power supply, microcontroller and one or more additional modules. Various types of sensor nodes are available on the market for WSN development, including Sensenode, eMote, micaZ, mica2, TelosA, TelosB, and IMote2[4].

WSNs comprise a layered architecture that includes a physical layer, data link layer, network layer, transport layer, and application layer, similar to the Open Systems Interconnection (OSI) model. Various routing techniques are used to transfer data packets through different routing methods on the network layer[5]. While wireless networks allow for multiple topologies, the most popular ZigBee-based sensor network topologies are star, mesh, and tree [6]. ZigBee differs from other communication technologies such as Wi-Fi, Bluetooth, and WiMAX through features like low power consumption and support for small-sized data transmissions [7].

WSNs are widely regarded as an important field of research, and many academics have used this platform to create a range of tracking, control, and monitoring systems. These include smart buildings [8], smart grids [9], IoT [10], localization systems [11], smart alarms, computer networks [12], track cycling [13], energy monitoring and management [14-15], health care [17-19], solar cells [20], and agriculture [21],to name but a few.

III. Zigbee Based Wsn

In an industrial context, various wireless communication protocols are used. One such protocol is IEEE 802.11x, a standard communication technology based on IEEE 802.11, more generally known as Wi-Fi. It can transfer data at speeds between 1 Mbps and 50 Mbps. A high-power antenna can send data over far greater distances than a regular antenna, which can only send data up to 100 meters. Bluetooth is a more robust personal area network (PAN) standard than IEEE 802.11x. It was developed specifically for short-range data transfer between computing and mobile devices[22]. ZigBee is one of the most useful technologies currently available for WSNs. It was founded upon the IEEE 802.15.4 standard, first published in 2003 [23]. ZigBee is based on the Medium Access Control (MAC) and Physical (PHY- powerful radio) layers, as defined by IEEE 802.15.4. It uses the popular CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) technique and supports mesh, star, and tree topologies.

IEEE 802.15.4 defines three frequency bands as license-free:

1. The first band uses the 2.4 GHz frequency spectrum with 16 channels and a data rate of 250 kbps.
2. The second band uses 10 channels in the 902-928 MHz frequency range and a data rate of 40 kbps.
3. The third operates in the 868–870 MHz frequency band and has a single channel and a data rate of 20 kbps[24].

ZigBee does more than just carry data between devices in personal area networks (PANs); it also manages network measurements, detection, monitoring, and application verification. However, it is not suitable for large-scale file transfers, which are more suited to Wi-Fi or Bluetooth. ZigBee also differs from Wi-Fi and Bluetooth in terms of how many devices may be connected to each other. It also supports communication with lower bandwidth requirements and runs on relatively simple networks that consume less energy and are more cost-effective [25]. Unlike Bluetooth, which has an average battery life of 1–7 days, ZigBee has a battery life of 100–1000 days.

In summary, it may be said that while Wi-Fi's traditional success is characterized by speed and adaptability, ZigBee's success is dependent on cost efficiency, low power consumption and durability [25].The ZigBee protocol supports three types of nodes: coordinators, routers, and end devices (sensors) [26]. ZigBee technology has three basic topologies: mesh, tree, and star, as illustrated in Fig. 1.

The star topology, as shown in Fig. 1, boasts centralised communication and management. Its architecture revolves around a central node, where sensors instead of communicating directly to one another, exchange information via the coordinator. The coordinator is the only ZigBee device in the area with a known PAN ID.The star topology consumes battery power rapidly since communication is focused on the centre. Moreover, ZigBee clustering is challenging to implement in large scale networks, making the star topology unsuitable for conventional WSNs [26].

The mesh architecture, also shown in Fig. 1, is centralised, in a similar way to the star topology, but allows every node in the network to connect and communicate with any other node. This increases network flexibilitybut makes end-to-end communication more challenging. The mesh topology is more efficient at power and battery consumption than the star layout as it does not rely on a single communication path between nodes[26].

The tree topology, also, shown in Fig. 1, is a much better option for WSNs due to its low cost and low power consumption [27]. Although the IEEE 802.15.4/tree topology works well for WSNs, it has drawbacks in terms of band usage and routing capabilities [28]. Data flow is slowed down significantly by any disruption in the tree structure, and the recovery procedures add a substantial amount of labour. The tree topology uses fewer routes. However, it uses less memory than the mesh topology because there is just one path from the source node to the destination node, avoiding the need to store multiple routing paths [26].

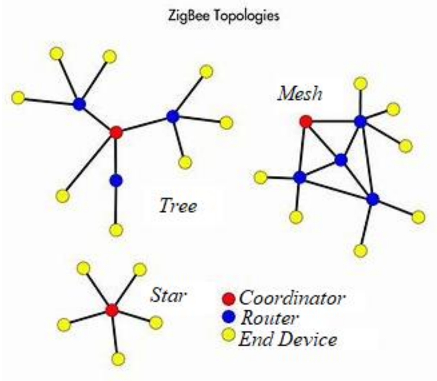

Fig. 1: ZigBee topologies

The main problem with the sensor architecture of WSNs is that throughput decreases as packets are moved between sensors due to high traffic volumes and packet collisions [29]. To minimise mistakes and avoid collisions and retransmissions, the latency must be sufficiently small while developing a strategy [30]. All latency in coordinators, switches, routers, and other WSN components is included in the delay [31],[32]. The delay is the average amount of time that passes between the source node sending the data packet and the destination node receiving it [33].

IV. Literature Review

Recent studies have shown a growing interest in the performance analysis of Zigbee-based WSNs. Key Parameters including throughput, delay, load, and data traffic in these networks have been the subject of numerous research. In particular, the impact of different ZigBee-based WSN topologies has received considerable attention. Research comparing tree and mesh routing in WSNs, found that the tree structurewas more effective in terms of throughput, delay, traffic received, and MAC load [34]. The RIVERBED simulation tool has been used to analyse and test the effects of increasing the number of sensors in ZigBee-based WSNs on throughput and delay [35-36].In a similar vein, the OPNET module was used to evaluate throughput and delay for single and multiple coordinators in tree, star, and mesh ZigBee WSNs [34], [37]. Elsewhere, a study using a simulation application in four distinct system configurations, showed the consequences of various data traffic scenarios, including sent and received data traffic [12], [38], and [39]. In their study of some of the most advanced power monitoring, control, and management systems, Nguyen et al. discovered that noise and co-channel interference posed the largest obstacles [40].

According to [41], the Personal Area Network (PAN) experiences a larger traffic burden when more routers are added to a WSN. The primary issue with sensors in WSNs is that high traffic volumes and packet collisions cause throughput to drop when packets are transferred from one node (sensor) to another node [29]. The received signal strength indicator metrics-specifically distance, throughput, and latency-were investigated for several ZigBee communications topologies for the purpose of assessing both indoor and outdoor network performance [42]. Also, the effect of router existence on the WSN topologies was examined in the reference [43].

V. Design Strategy

The development of a Wireless Sensor Network (WSN) system utilizing multiple ZigBee topologies is described in this work. The evaluation and analysis of the system were performed through simulation using a tool called RIVERBED (formerly OPNET) Modeller Academic Edition 17.5, which also provides predictionswhich reflect the real-world systemperformance. RIVERBED purchased the original OPNET company and subsequently improved the software to support multiple system models, strong network connectivity and communication between the administrator, PAN coordinator, routers, and end devices.

This study analyses the performance of WSN topologies based on the ZigBee standard. This is accomplished by evaluating and comparing three different scenarios: tree, mesh, and star WSN topologies.

These three scenarios were compared using the performance metricsof overall delay, throughput, data traffic delivered and data traffic received. In all three scenarios, a single coordinator, five routersand twelve sensors were employed in the network configuration.

A. The First Scenario

The star configuration shown in Figure 2 consists of a single central master node (a coordinator), five routers and twelve end devices (sensors). All twelve sensors transmit traffic to and receive traffic from the coordinator.

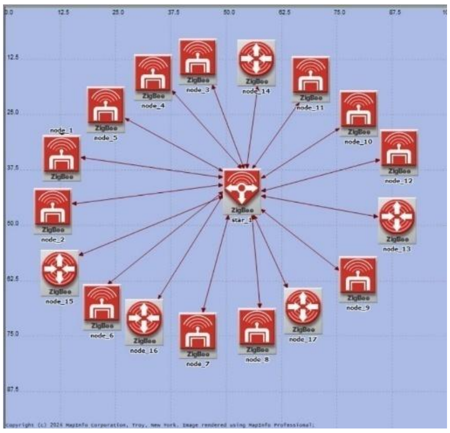

Fig. 2: First Scenario (Star topology).

B. The Second Scenario

In this scenario, the twelve sensors, five routers, and single coordinator are distributed in the tree configuration, as shown in Figure 3. One sensor and three (primary) routers are directly connected to the coordinator.Theremaining two routers andeleven sensors are connected to the primary routers. The twelve sensors are all ZigBee WSN peripherals.

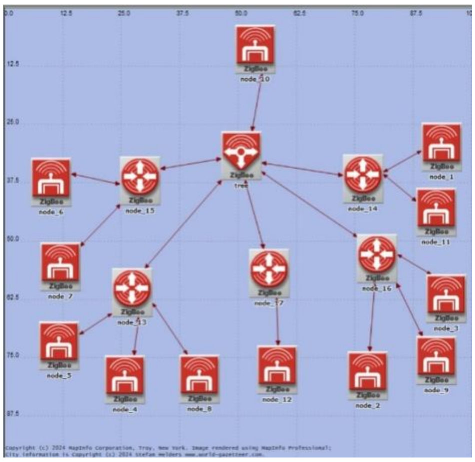

Fig. 3: Second Scenario (Tree topology).

C. The Third Scenario

In this configuration, the mesh architecture shown in Figure 4 consists of twelve sensors, five routers, and a single coordinator. Only two (primary) routers and one sensor are directly connected to the coordinator. The remaining eleven sensors and three routers are connected to the two primary routers. The twelve sensors are all ZigBee WSN peripherals.

International Journal of Latest Research in Engineering and Technology (IJLRET)
ISSN: 2454-5031
www.ijlret.com || Volume 11 - Issue 10 || October 2025 || PP. 44-52

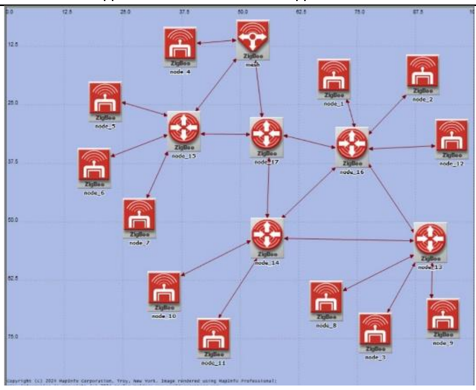

Fig. 4: Third Scenario (Mesh topology).

VI. Outcomes

The RIVERBED modeller was used to simulate three network scenarios overa one-hour period. To evaluate the network's performance in terms of throughput, delay, sent and received data traffic, the findings were analysed statistically with the objective of determining the optimal network structure. In all the combined results presented, the red curve stands for scenario 1; sky-blue is for scenario 3 and dark blue for scenario 4. The results are as follows:

A. Throughput

Throughput is defined as the total number of bits (measured in bits per secondor bps) transmitted from the 802.15.4 MAC layer to higher layers in each node of a wireless personal area network (WPAN) [44]. The throughput curves for each of the three WSN scenarios are illustrated in Fig. 5. It is evident that the mesh topology has the lowest throughput, whereas the star topology has the highest. The throughput values for scenario 1 (star), scenario 2 (tree), and scenario 3 (mesh) at steady state (reached after 20 minutes of operation) are approximately 20 kbps, 14.9 kbps, and 6.15 kbps, respectively. Therefore, from a throughput perspective, the star topology is the optimal topology.

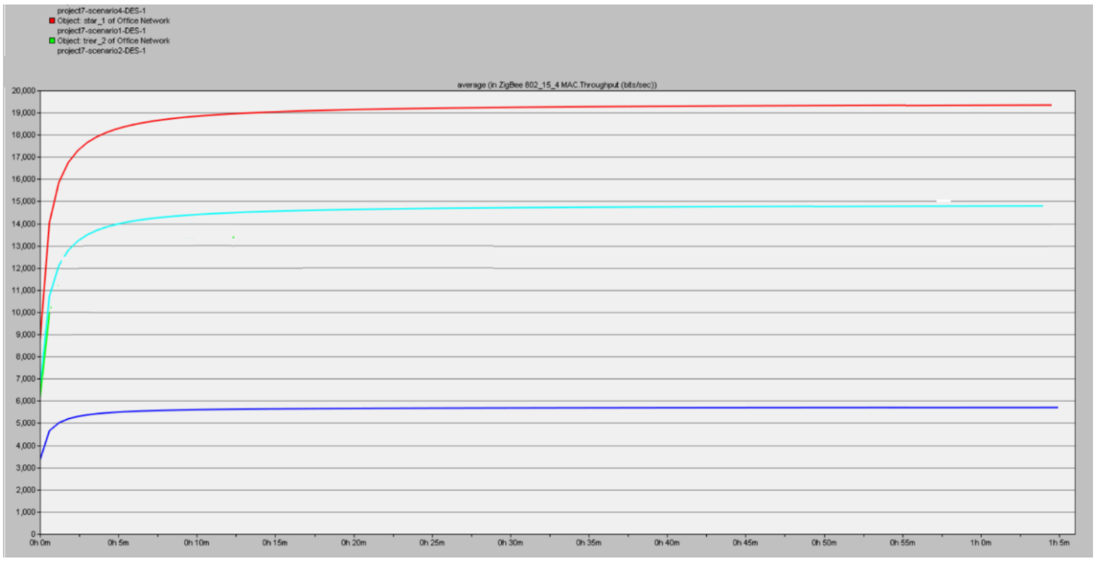

Fig. 5: The average throughput of the three scenarios.

B. Delay

Figure 6 represents the average total delay for the three previously described WSN scenarios, measured in milliseconds (ms). It is evident from the results displayed in thefigure thatafter ten minutes of program execution, the delays in scenarios two and three are nearly the same, indicating similar performance in terms of latency for both mesh and tree topologies. In contrast, from the perspective of delay, the star topology(scenario 1) performs better than the tree and mesh topologies. At steady state (after 20 minutes), the average cumulative delays for scenarios 1, 2 and 3 are approximately 11.186 ms, 11.21 ms, 12.061 ms, respectively,

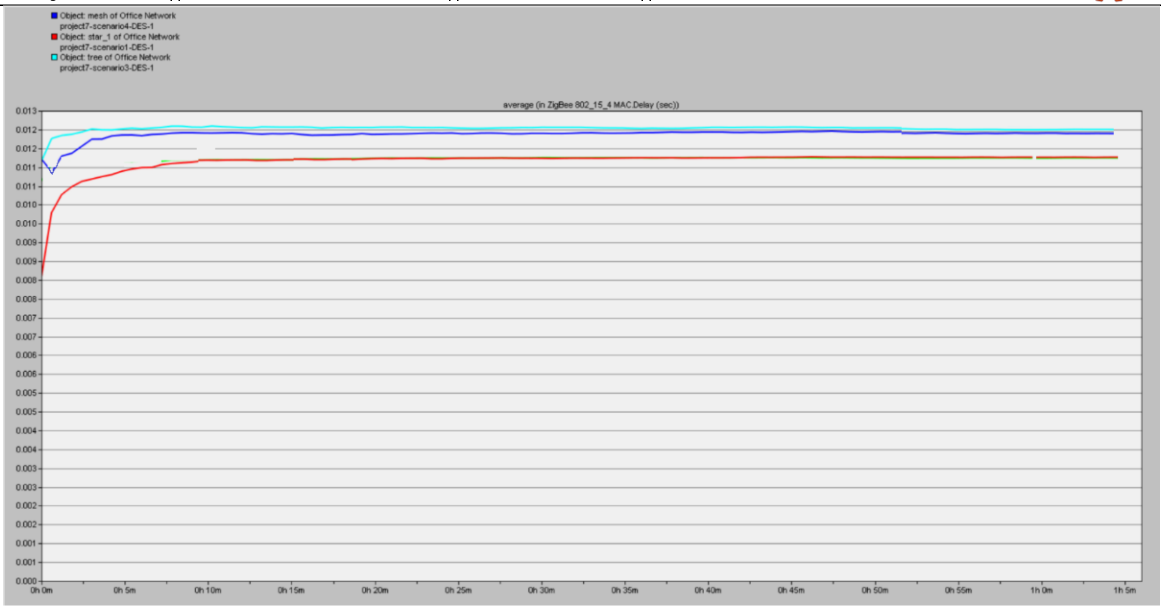

Fig. 6: The average total delay for the three scenarios

C. Data Traffic Received (DTR)

Data Traffic Received (DTR) refers to all successfully received traffic at the MAC layer, including retransmissions, measured in kilobits per second (kbps). Fig. 7 shows the DTR for each of the three WSN scenarios. By the end of the program's execution, the mesh topology has the highest DTR of 45.85 kbps, closely followed by the tree topology with a DTR of 39.9 kbps. The star topology, scenario 1, recorded the lowest DTR of 22.15 kbps.

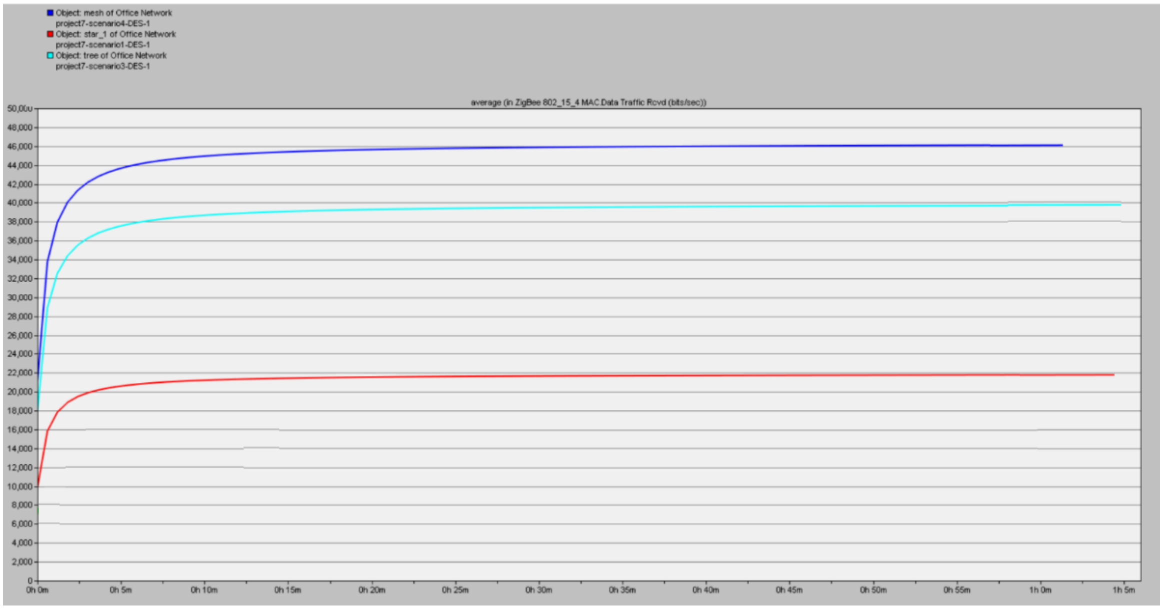

Fig. 7: The average DTR for the three scenarios

D. Data Traffic Sent (DTS)

The average DTS for the three WSN scenarios is displayed in Fig. 8. The image clearly indicates that while the tree topology has a higher DTS than mesh, the star topology is higher still. At the conclusion of the program's execution, the DTS values for scenarios1 (star), 2 (tree) and 3 (mesh)are, respectively, 23.25 kbps, 14.32 kbps, and 6.45 kbps.

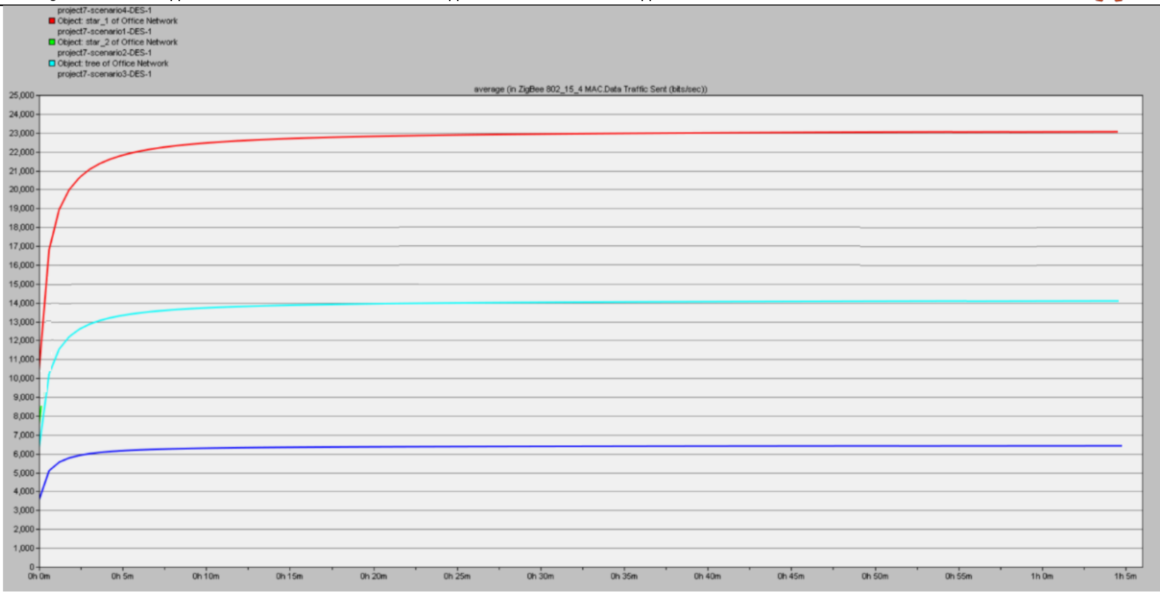

Fig. 8: The average DTS for the three scenarios

VII. Conclusions

This study evaluated the performance of ZigBee-based wireless network topologies using the RIVERBED Academic Edition V17.5. The following are the findings from the three simulated scenarios:

1. **Performance Comparison:** Four key metrics- throughput, data sent, data received, and overall latency- were used to compare the star, tree and mesh topologies. The results showed that the star topology outperforms the tree and mesh topologies in terms of data received rate and also excels in productivity and data transfer rate. However, the mesh topology achieved the highest data reception rate, making it more effective in intricate networks with a large number of nodes. This observation is supported by findings from previous research.
2. **Network Quality:** The tree topology outperformed both the mesh and star topologies in terms of overall network quality. Its ability to transmit data to its destination rapidly and without overloading the central node, means that the tree architecture is well suited for networks with a limited number of sensor nodes.
3. **Energy Efficiency:** Additionally, because communication protocols like ZigBee help reduce energy consumption in WSNs, designers have exploited this advantage in applicationsinvolving the transfer of small amounts of data.

In conclusion, while the ZigBee protocol offers benefits in energy efficiency and data transmission across various applications, ultimately, the choice of network topology will invariably depend on a number of criteria, including network complexity, the number of nodes and desired performance metrics.

References

[1] SU. Aslan, “The effects of hierarchy on mobile wireless sensor network coverage,” M.S. thesis, Middle East Technical Univ., Ankara, Turkey, 2006.

[2] F. Othman, and K. Shazali, “Wireless sensor network applications: study in environment monitoring system,” *International Symposium on Robotics and Intelligent Sensors (IRIS ’12)*, vol. 41, pp. 1204–1210, Dec. 2012.

[3] S. K. Gharghan, R. Nordin, and M. Ismail, “A Survey on Energy Efficient Wireless Sensor Networks for Monitoring Application,” *J. of Sensors*, vol. 12, pp 1-17, 2014.

[4] S. Kumagai and H. Higaki, “Signal Processing and Communication Systems (ICSPCS),” *8th Int. Conf.*, Vol. 8, pp 1-8, 2014.

[5] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, “An application-specific protocol architecture for wireless micro sensor networks,” *IEEE Trans. on Wireless Commun.*, vol. 1, no. 4, pp. 660–670, Nov. 2002.

[6] M. Youn, and J. Lee, “Topology Control Algorithm considering Antenna Radiation Pattern in Three-Dimensional Wireless Sensor Networks,” *Int. J.of Distributed Sensor Networks*, vol. 2014, pp 1-11, Jun. 2014.

[7] U. Pesovic, J. Mohorko, S. Randic and Z. Cucej, "Hidden node avoidance mechanism for IEEE 802.15.4 wireless sensor network," *J. of Microelect., Electronic Comp. and Materials*, vol. 43, no. 1, pp 14 – 21, Mar. 2013.

[8] N. K. Baqer, Y. J. Harbi, and H. A. Al-Asady, "Impact of Delay in ZigBee WSNs for Smart Home Applications,"*J. of Eng. Rsearch and Reports*, Vol. 26, issue 8, pp. 372-380, 2024.DOI: *https://doi.org/10.9734/jerr/2024/v26i81252*.

[9] R. Khan, N. Islam, S. K. Das, S. M. Muyeen, S. I. Moyeen, F. Ali, Z. Tasneem, R. Islam, D. K. Saha, F. R. Badal, H. Ahamed, K.Techato, "Energy Sustainability–Survey on Technology and Control of Microgrid,
Smart Grid and Virtual Power Plant,"*IEEE Access* **2021**, *9*, 104663–104694, https://doi.org/10.1109/access.
2021.3099941.

[10] M. T. Nguyen, "An energy-efficient framework for multimedia data routing in Internet of Things (IoTs),"*EAI Endorsed Trans. Ind. Networks Intell. Syst.* **2019**, *6*, https://doi.org/10.4108/eai.13-6-2019.159120.

[11] A. Elkenawy, J. Judvaitis, "Transmission Power Influence on WSN-Based Indoor Localization Efficiency," *Sensors*, vol. 22, no. 11, pp 1-18. May 2022. DOI: 10.3390/ s22114154. PMID: 35684775; PMCID: PMC9185369.

[12] M. T. Nguyen, H. R. Boveiri, "Energy-efficient sensing in robotic networks,"*Measurement* **2020**, *158*, 107708, https://doi.org/10.1016/j.measurement.2020.107708.

[13] S. K. Gharghan, R. Nordin, and M. Ismail, "A Wireless Sensor Network with Soft Computing Localization Techniques for Track Cycling Applications," *Sensors (Basel)*, vol. 16, no. 8, pp. 1-23, Aug. 2016. DOI: 10.3390/s16081043. PMID: 27509495; PMCID: PMC5017318.

[14] A. Muscat, S. Bhattacharya, and Y. Zhu, "Electromagnetic Vibrational Energy Harvesters: A Review," *Sensors*, vol. 22, no. 15, pp. 1-17, Jul. 2022. DOI: 10.3390/s22155555. PMID: 35898058; PMCID: PMC9331882.

[15] S. Sadeq, R. Hassan, H. Sallehudin, A. H. Aman, and A. H. Ibrahim, "Conceptual Framework for Future WSN-MAC Protocol to Achieve Energy Consumption Enhancement," *Sensors*, vol. 22, no. 6. Mar. 2022. DOI: 10.3390/s22062129. PMID: 35336298; PMCID: PMC8955616.

[16] J. Phengsuwan*et al.*, "Use of Social Media Data in Disaster Management: A Survey," *Future Internet*, vol. 13, no. 2, pp. 46-70, Feb. 2021.

[17] S. K. Swami, B. Duraisamy, and A. J. Thirukrishna, "Certain Investigation on Healthcare Monitoring for Enhancing Data Transmission in WSN," *Int. J. of Wireless Inf. Net.*, vo. 30, pp.:103–110, Aug. 2021.

[18] D. Naranjo, J. Reina-Tosina, and L. M. Roa, "Body Sensors Networks for E-Health Applications," *Sensors (*Special Issue*)*, vol. 20, no. 14, Jul. 2020. DOI: 10.3390/s20143944. PMID: 32708538; PMCID: PMC7412528.

[19] T. A. Le, A. Jivalagian, T. Hiba, J. Franz, S. Ahmadzadeh, T. Eubanks, L. Oglesby, S. Shekoohi, E. M. Cornett, and A. D. Kaye, "Multi-agent Systems and Cancer Pain Management," *Curr Pain Headache Rep*. Sep., vol. 27, no. 9, pp. 379-386, Jun. 2023. DOI: 10.1007/s11916-023-01131-4. Epub 2023 Jun 29. PMID: 37382870.

[20] L. Liu, and S. Choi, "Miniature microbial solar cells to power wireless sensor networks," *Biosensors and Bioelectr.*, vol. 177, pp. 1-26. Apr. 2021. DOI: 10.1016/j.bios.2021.112970. Epub 2021 Jan 4. PMID: 33429201.

[21] Y. Sun *et al.*, "On Enabling Mobile Crowd Sensing for Data Collection in Smart Agriculture: A Vision," *IEEE Sys. J.*, vol. 16, no. 1, pp. 132-143, Mar. 2022. DOI: 10.1109/JSYST.2021.3104107.

[22] A. E. Coboi, C. V. Nguyen, et al., "An Analysis of ZigBee Technologies for Data Routing in Wireless Sensor Networks," *ICSES Transactions in Computer Networks and Communications (IFCNC)*, vol.X, no,Y, pp. 1-10, Aug. 2021.

[23] D. M. Amzucu, H. Li, and E. Fledderus, "Indoor radio propagation and interference in 2.4 GHz wireless sensor networks: measurements and analysis," *Wireless Per. Commun.*, vol. 76, no. 2, pp. 245–269, May 2014.

[24] K. Benkic, P. Planinsic and Z. Cucej, "Custom wireless sensor network based on Zigbee," *49th Int. Symp.*, ELMAR, UAE, 2007, pp 259-262.

[25] S. Safaric and K. Malaric, "ZigBee wireless standard," *48th Int. Symp.*, Elmar, UAE, 2006, pp: 259-262.

[26] S.W. Nourildean, "A study of ZigBee network topologies for wireless sensor network with one coordinator and multiple coordinators," *Tikrit J. of Eng.Sci.*, vol.19, no.4, pp. 65-81, Dec. 2012.

[27] G. Hong and S. Jianxiu, “Design of the temperature signal wireless receiver and display system on polishing interface in chemical mechanical polishing,” *Procedia Eng.*, vol. 24, pp. 417–421, Dec. 2011. DOI: 10.1016/j.proeng.2011.11.2668. 2011

[28] M. A. Indrajaya, R. Fauzi, and E. Adrias, “ZigBee-based Wireless Sensor Network Topology Design and Comparison in Residential Area,” *Electronic, Control, Telecommunication, Information, and Power Engineering*,vol. 10, pp. 42-51. DOI: 10.33019/jurnalecotipe.v10i1.3704

[29] B. Chen, “Wireless Communication Chip Designs: analysis of the Wireless Integrated Network Sensors,” *Highlights in Sci., Eng. and Techn.*, vol. 70, pp. 580-587, Nov. 2023.DOI: 10.54097/hset.v70i.13989.

[30] S. Dutt, S. Agrawal, and V. Renu, “Delay-Sensitive, Reliable, Energy-Efficient, Adaptive and Mobility-Aware (DREAM) Routing Protocol for WSNs,” *Wireless Pers. Commun*, vol. 120, no. 1, pp. 1675-1703. Sep. 2021.DOI: 10.1007/s11277-021-08528-7.

[31] S. Ihsan, “Comparison between AODV and DSDV Protocols in WSN Based on End to End Delay,” *4th Int. Integ. Sci.Conf.*, Baghdad, Iraq, 2021, pp. 1-5.

[32] O. Jerew and N. AlBassam, “Delay Tolerence and Energy Saving in Wireless Sensor Networks with a Mobile Base Station,” *Wireless Communications and Mobile Computing*, vol. 2019, pp. 1-12, https://doi.org/10.1155/2019/3929876.

[33] R. Tang, N. K. Aridas, and M. S. Abu Talib, “Design of Wireless Sensor Network for Agricultural Greenhouse Based on Improved ZigBee Protocol,” *Agriculture*, 2023, vol. 13, pp. 1-13.

[34] N. K. Baqer, B. A. Salih, and A. W. Abbas, “A Study of WSN Toplogies for IEEE 802.15.4 ZigBee Standard,” *Int. J. on Computational Eng.*, vol. 1, no. 3, pp. 68-74, 2024.

[35] N. K. Baqer, A. W. Abbas, and H. A.Al-Asady, “Throughput and Delay Behaviour in ZigBee Wireless Sensor Networks,” *5th Int. Conf. on Comm. Eng. and Compt. Science (CIC-COCOS)*, Arbil, Iraq, 2024, pp. 418-421. DOI: http://doi.org/ 10.24086/cocos2024/paper.1549

[36] N. K. Baqer, Fixed and Mobile Sensors: ZigBee-Based WSN Topologies A Comparison, *International Journal of Latest Research in Engineering and Technology (IJLRET)*, vol. 11, issue 8, pp. 29-39, Aug. 2025.

[37] N. K. Baqer, A. M. Al-Modaffar, and G. H. Shahtoor, “Throuphut Study of IEEE 802.15.4 ZigBee-Based WSNs for Greenhouse Environment,” *Int. J. of Sci. Res. Eng. & Technol*., vol. 7, pp. 171-176, Mar. 2018.

[38] N, K. Baqer, A. W. Abbas, and B. A. Salih, “Data and Management Traffic of IEEE 802.15.4 ZigBee-Based WSN,” *Int. J. of Advanced Sci. Comput. and Eng.*, vol. 6, issue 2, pp. 80-83, 2024.

[39] N. K. Baqer, A. M. Al-Modhaffar, and E. A. AlKadly, “A study of Delay and Data Traffic of IEE 802.15.4 ZigBee-Based WSN in a Smart Home,” *Int. J. on Advanced Sci. Eng.*, vol. 8, no. 3, pp. 956–962, Mar. 2018.

[40] V. Nguyen, A. E. Coboi, N. V. Bach et al., “ZigBee based data collection in wireless sensor networks,” *Int. J. of Inf. and Commun. Technol.*, vol. 10, no. 3, pp. 211–224, Dec. 2021. DOI: 10.11591/ijict.v10i3.

[41] O. Mau, T. C. Lam, and T. H. Nguyen, “Performance Evaluation of MAC Layer Protocol over Wireless Body Area Sensor Networks,” *EAI Endorsed Trans on Industrial Net. and Intell.Sys.*, vol. 8, no. 5, pp. 1–7, Apr. 2021.

[42] D. Setiabudi, D. I. Atmaja, D. W. Herdiyanto, and G. A. Rahardi, “RSSI Measurement Analysis of ZigBee-Based Wireless Sensor Networks in Various Topologies for Solar Panel Monitoring,” *MajalahIlmiahTeknologi Elektro*, vol. 22, no. 2, Jul. 2023. DOI: https://doi.org/10.24843/MITE.2023.v22i02.P14.

[43] N. K. Baqer, Y. J.Harbi,. and H. A. Al-Asady, “Router Impact on IEEE 802.15.4 ZigBee Based WSN Topologies,”*8th IntConf on Engand Techn for Future Sustainability*, 2025, Manila, Philippines. to be published.

[44] M. A. Indrajaya, R. Fauzi and E. A. Sapultra, “ZigBee-Based Wireless Sensor Network Topology Design and Comparison in Residential Areas, JurnalEcotipe,” *Elect., Cont., Telecommun., Inf, and Power Eng.*,” vo. 10, Issue1, pp. 42-51, Apr. 2023. ISSN 2355-5068; e-ISSN 2622-4852 DOI: 10.33019/ jurnalecotipe.v10i1.3704.