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The effects of mobile sensors on throughput and delay for ZigBee-Based WSN Architectures

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Abstract

The WSN architecture has a significant impact on their performance; the most popular configurations are star, tree, mesh, and cluster. With an emphasis on throughput and delay, this study carries out a comparative analysis these four ZigBee-based WSN architectures. According to our results, mesh networks are best suited for large and dynamic networks because of their multiple routing paths, which also allow them to excel in throughput and reliability. In contrast, while tree architecture is more effective at aggregating data, proved to have higher delays as the network size increases. Meanwhile, star architecture are more energy-efficient but have limitations in terms of scalability and data traffic handling because they depend on a single central node. After switching all the sensors from fixed to mobile operation in a second set of simulations, all four WSN architecture were evaluated using the same primary performance criteria, namely throughput and delay. This exercise shows how sensor mobility modifies throughput and delay for the various WSN topologies. Lastly, the cluster architecture hasn't received much attention previously. So, it will be discussed in this paper from throughput and delay point of view.

Keywords: WSN; ZigBee; RIVERBED; OPNET; Mobile sensors

1. Introduction

A Wireless Sensor Network (WSN) is made up of sensor nodes equipped with specific capabilities to gather data from their environment and then process that data before sending it to a base station often via neighboring sensor nodes [1]. Recent advances in wireless communication, including improvements in processor quality, memory capacity, and low power consumption, have increased the importance of micro- electromechanical systems (MEMS)[2]. The greater availability of reasonably priced small-scale, device-based and self-organizing sensor networks have made intersensor communication considerably simpler.

In a typical application, sensors gather data from their surroundings while certain other sensors act as primary nodes that process raw data from nearby sensors and temporarily store it in their internal storage before forwarding it on. Other sensors receive analogue information from their environment and transmit it to one or more nearby sensors.

With the aid of a simulator, the performance of wireless network topologies based on the IEEE 802.15.4/ZigBee standard was analyzed in this study. Researchers have access to a variety of simulator technologies, such as TOSSIM, J-Sim, QUALNET, EmStar, OMNET++, Network Simulator, GLOMOSIM, JIST/SWANS, and SensorSim, but we opted for the RIVERBED Modeler Academic Edition 17.5 simulation program because it provides a comprehensive performance analysis of ZigBee based networks in terms of quality-of-service (QoS) parameters.

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For this study, four ZigBee architectures—mesh, tree, star, and cluster—were evaluated for two key QoS parameters, namely throughput and delay.

The same infrastructure of one coordinator and sixteen sensor nodes was used to test the respective performance of the four different WSN architectures mentioned above. In the first scenario, all sixteen sensors remained fixed, whereas in the second scenario all the sensors were mobile. Throughput and delay for all four WSN architecture in fixed and in mobile mode were assessed with the aim of determining the effect of mobility of the sensors on ZigBee-based WSNs.

2. WSN Applications

ZigBee-based WSNs have a wide range of applications, which include: -

- Smart Home Systems (used to control lighting, HVAC (heating, ventilation, and air conditioning) systems, security system and household appliances [3-5]).
- Industrial Processes (used to monitor and control industrial processes remotely, including safety systems, energy management and equipment condition monitoring [6-7]).
- Healthcare (Wearable devices and remote patient monitoring systems employ ZigBee technology to gather and send health data, such as heart rate, blood pressure, and glucose levels [8-9]).
- Smart Cities and Agriculture (used to keep an eye on environmental parameters such as soil moisture, temperature, humidity, and air quality, thereby supporting precision agricultural technology, for example, to optimize irrigation and crop management [10]).
- Energy Management (used in smart grids and home energy management systems to enable demand- response systems, smart meters and real-time monitoring and control of energy consumption [11–12]).
- Retail and Logistics (used in asset tracking, management of inventories, and in optimizing the supply chain, for example, real-time inventory tracking in warehouses [13-14]).
- Building Management (used in intelligent building management/smart office systems, to automate temperature and lighting in response to occupancy detection to improve energy efficiency [15]).
- Disaster Management (used in areas that are prone to natural disasters to provide emergency communication and early warning systems, including monitoring for earthquakes or floods. [16-17]).
- Transportation (Intelligent transportation systems employ ZigBee technology for smart parking systems that guide vehicles to available parking spaces, to track vehicles, to monitor traffic and manage parking spaces [18-19]).

3. Literature Review

The performance of Zigbee-based WSNs has been the subject of several research studies [20]. A number of these recent studies have looked at key aspects of these networks, including load, data traffic, throughput, and delay; with much attention being paid to how different ZigBee-based WSN architecture impact on these key measurements [21]. Comparing various routing techniques has also been the subject of several academic articles. For example, one research study found that tree-based routing outperforms mesh routing in WSNs in terms of throughput, latency, traffic received, and MAC-layer load [22].

Increasing the number of sensors in a ZigBee-based WSN proved detrimental to both throughput and latency; which has been explored, analyzed, and evaluated using the RIVERBED simulation platform [24]. Throughput and delay (latency) for single and multiple coordinators in mesh, tree, and star ZigBee WSNs architecture were also investigated using the OPNET module [25–27]. Other simulations shed light on the patterns of data traffic scenarios, including transmitted and received data traffic, for four different system scenarios [28–30].

Recent evaluations of power monitoring, control, and management systems currently in use found that noise and co-channel interference were the main shortcomings with ZigBee-based WSNs [31]. The personal-area network's traffic load increases when a WSN has more routers added to it, degrading performance [32-33]. The primary issue with sensors in densely packed WSNs is that high traffic and packet collisions during packet transfers between sensors cause a decline in throughput [34].

By measuring received signal strength indicator (RSSI) features (distance, throughput, and latency) for different ZigBee communication topologies, the network performance for both indoor to outdoor setups was ascertained [35]. This study is important because it reveals how routing techniques affect network performance, which is critical for maximizing

WSN effectiveness. Lastly, the consequences of sensor mobility on the performance of different ZigBee-based WSN topologies were examined, showing how node mobility impacts on the key performance metrics [36-37].

The network layer for peer-to-peer, tree, and star topologies is specified by ZigBee. These may be used to create more intricate cluster-tree topologies in [38]. ZigBee sets the maximum depth of the tree and the number of routers and end devices that each router may have as children in order to regulate the network topology.

In [39], a considerable effort was put into creating cluster formation processes and selecting cluster leaders to minimize transmission overhead. The energy efficiency, network lifetime, and success rate of the cluster topology was discussed in [40]. A dual-path multi-scale attention guided network for enhanced cluster head selection and energy-efficient routing in a Cluster WSN environment is suggested in [41]. In [42], a new, energy-efficient method for creating clusters and choosing the head of each cluster for mixed WSN is talked about.

4. Design Strategy

Four ZigBee architectures- mesh, tree, cluster and star- were used to construct a WSN system for this study, which relied on the Riverbed Modeler Academic Edition 17.5 simulation tool. With the help of this tool, robust network connections and a variety of system models can be created, allowing for a thorough examination of ZigBee standard performance across different WSN architecture. Four alternative scenarios—mesh, tree, cluster, and star architectures—were taken into consideration in order to evaluate the performance of various WSN architecture utilizing the ZigBee standard. Throughput and latency were used to compare these scenarios. All the ZigBee networks employ sixteen sensors and one coordinator in each of the four architectures. One hour was chosen as the simulation duration. The size of the data packets delivered was fixed at 1 Kbytes and a random destination was chosen.

All sixteen sensors are fixed in the first simulation. While in the second simulation, all the sensors are mobile. A mesh WSN architecture is shown in Figure 1, followed by a tree architecture in Figure 2 and a star WSN architecture in Figure 3. Figure 4 represents the cluster architecture, where four sensors considered as heading sensors (node1, node2, node3, and node4) and each one of them is connected with three sensors as a star connection.

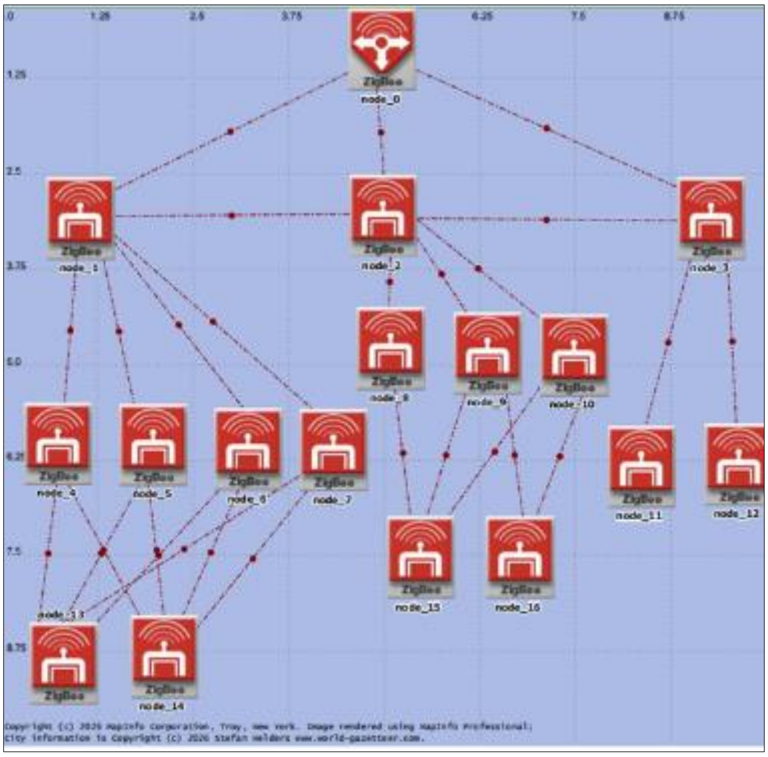

Figure 1 A Mesh Architecture

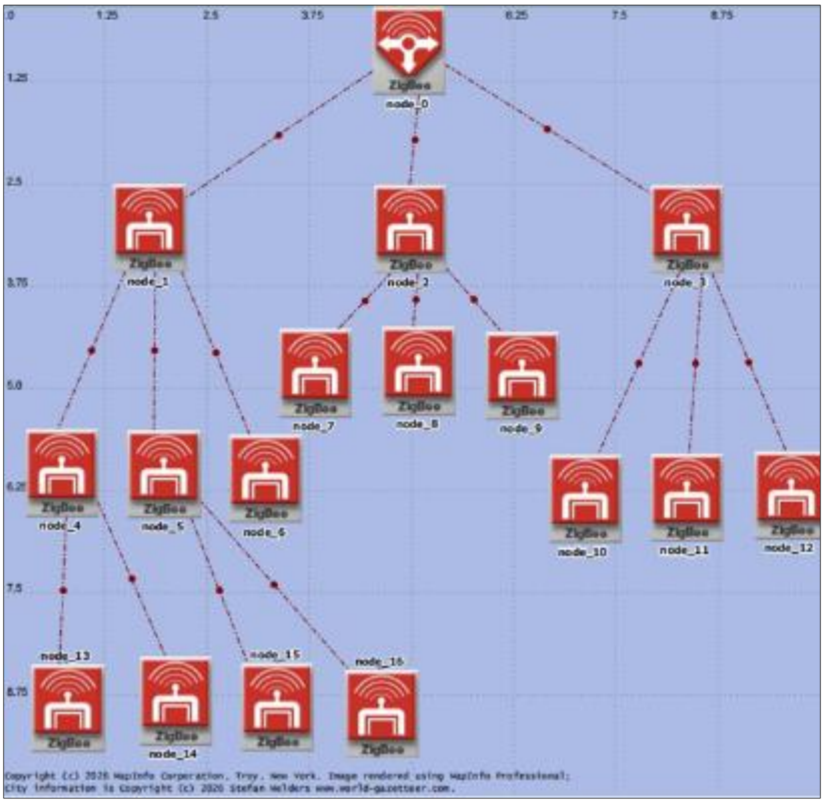

Figure 2 A Tree Architecture

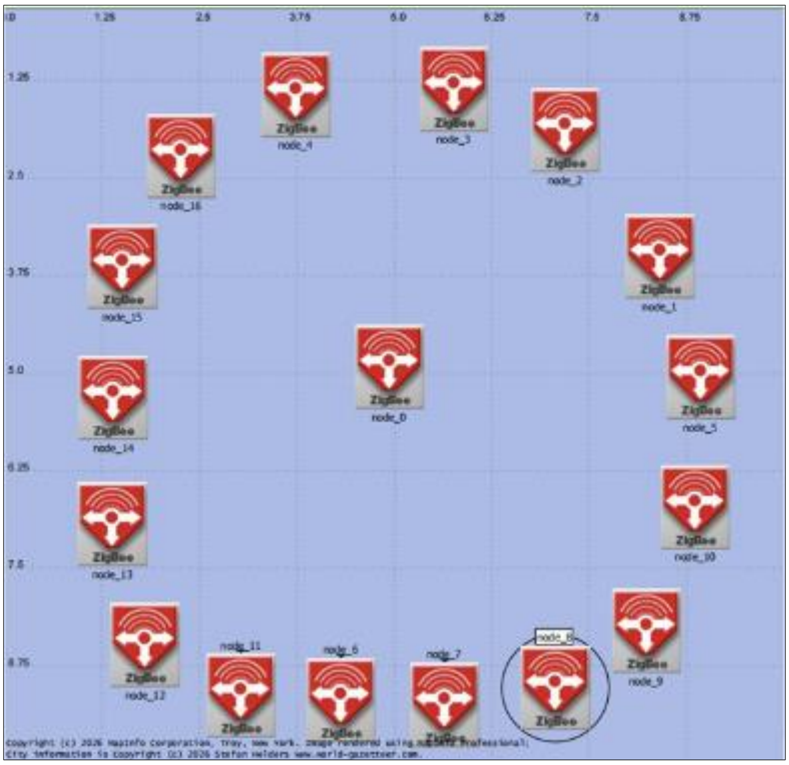

Figure 3 A Star Architecture

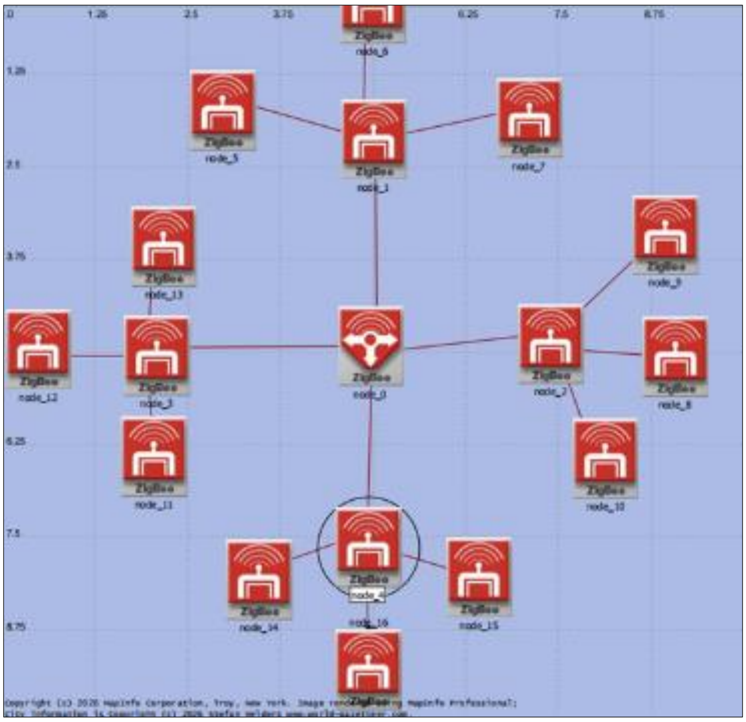

Figure 4 A Cluster Architecture

5. Outcomes

5.1. First Simulation (Fixed Sensors)

The average throughput for the mesh (blue curve), tree (green curve), star (red curve) and cluster (brown curve) WSN architectures is displayed in Figure 5. The star architecture has the highest throughput in steady state, whereas the tree architecture has the lowest. It is evident that when every sensor is linked straight to the coordinator, throughput rises. The throughput figures for the four architectures at the conclusion of the simulation period (one full hour) are 35.31 kbps (star), 29.16 kbps (cluster), 25.02 kbps (mesh), and 20.73 kbps (tree). According to the sensor configuration in the networks, as the branches increases the throughput decreases.

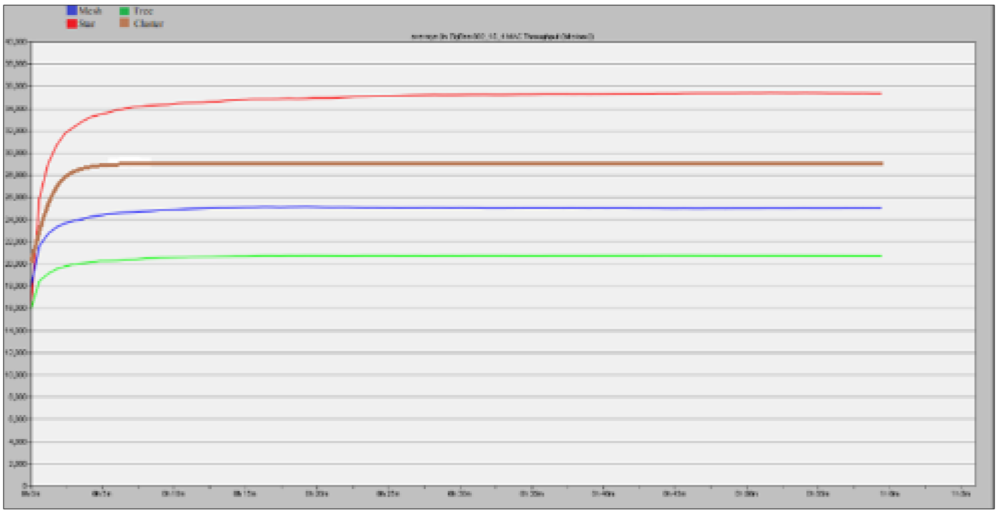

Figure 5 Throughput for fixed sensors

The average delay for the four network architectures under investigation is displayed in Figure 6. The findings clearly show that the mesh and tree topologies have almost the same delay over the hour-long simulation, with values of 21.2

msec and 21.3 msec, respectively at the steady state. On the other hand, the star topology displays a somewhat reduced delay of 18.2 msec. In contrast to the star topology which recorded the lowest delay in the fixed nodes configuration, WSN topology has minimal effect on delay for both mesh and tree. For cluster architecture, the delay at the steady state is 20.16 msec. From delay point of view, the star topology is the best because of the direct connection for all the sixteen sensors to the coordinator.

Because each sensor interacts directly with the coordinator via a single hop, the star topology offers the lowest steady-state latency for a network with 16 sensors and one coordinator. Although aggregation at the cluster head lessens congestion, the cluster architecture has a little greater latency since data often goes via a cluster head before reaching the coordinator. Because packets may transit over several hops and need route discovery or forwarding choices, the mesh topology exhibits increased latency. Because traffic from lower-level nodes is focused at parent nodes close to the root, creating bottlenecks and queueing delays, the tree architecture results in the maximum latency at steady state.

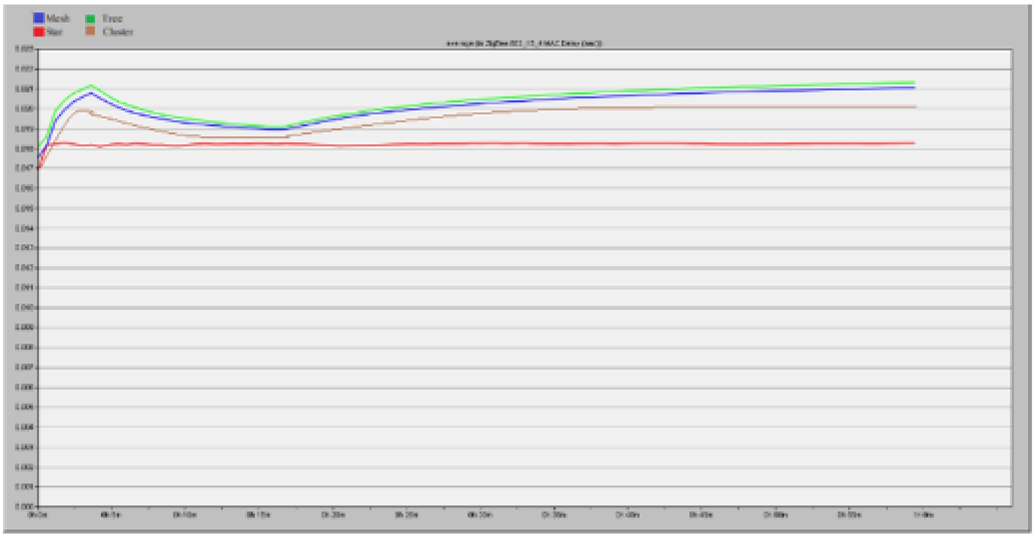

Figure 6 Delay for fixed sensors

5.2. Second Simulation (Mobile Sensors)

The sixteen sensors (shown in Figures 1, 2, 3, and 4) are switched from fixed to mobile state in the second simulation. Figures 7 and 8 show the average throughput and delay, respectively.

Figure 7 illustrates that the tree architecture has the lowest average throughput, whereas the star architecture has the highest. The throughput figures for the four architectures at the conclusion of the hour-long simulation period are 20.9 kbps (tree), 28.18 kbps (cluster), 25.15 kbps (mesh), and 35.2 kbps (star). We can see that the throughputs are almost equal to throughput results for the fixed sensors shown in Figure 5. Therefore, we can say that in all four WSN architecture, sensor mobility has no effect on throughput.

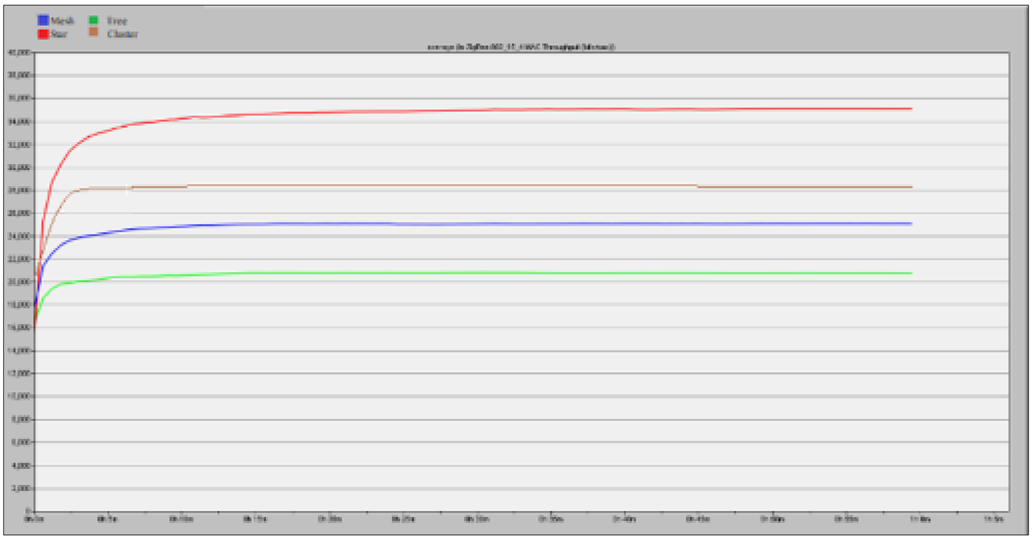

Figure 7 Throughput for mobile sensors

The delays for the four WSN architecture slowly converge at the steady-state, as seen in Figure 8. The respective delay values for the four architecture-star, tree, cluster and mesh- at the end of the one-hour long simulation period are 21.8 msec, 21.4 msec, 21.7 msec, and 21.1 msec. We can conclude that the delay values are about the same for mesh and tree topologies, but increases by roughly 16.5% for the star architecture when we compare these values with those in Figure 6 (delay for fixed sensors). This indicates that the mesh and tree topologies are relatively unaffected by sensor mobility, however the star topology is. For the cluster, an increase in delay about 7% when the all sensors mobile.

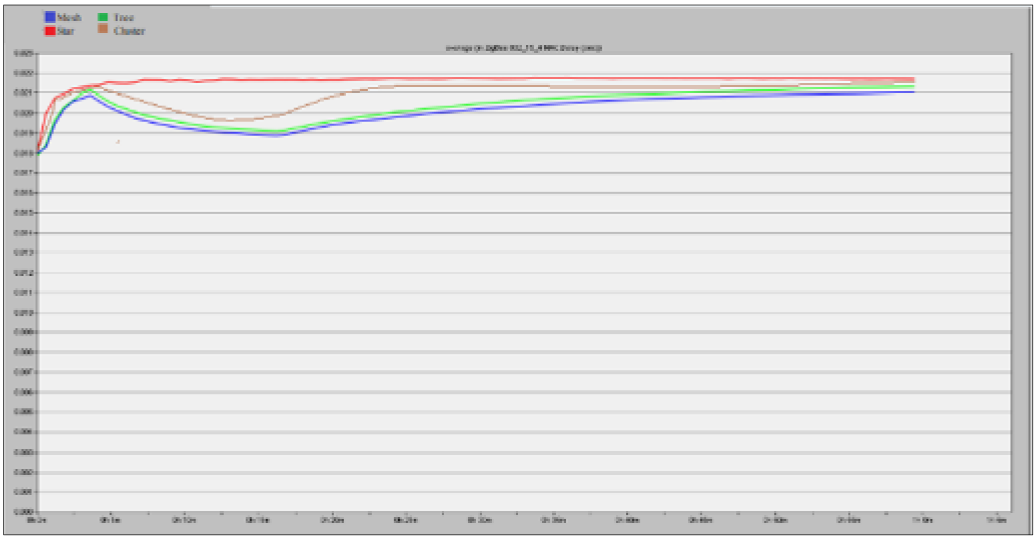

Figure 8 Delay for mobile sensors

6. Conclusion

This paper used the RIVERBED Academic Edition V17.5 simulation program to analyze the performance of four specific WSN architecture based on the IEEE 802.15.4 ZigBee standard. Two separate simulations were executed:

- -the first simulation was conducted with fixed sensors to evaluate the WSN topologies from the throughput and delay perspective; and
- -the second simulation was conducted to evaluate the impact of mobile sensors on the four WSN topologies.

The results of our chosen WSN topologies based on key performance metrics are as follows:-

- **Star Topology**: - despite connection issues over long distances, of the four architectures, star, because of its centralized nature, proved itself the most suitable for throughput (highest) and delay (lowest) in the fixed configuration. With mobile sensors, the throughput remained stable because packets still follow a direct path, while delay increases because sensors may temporarily move away from optimal communication range causing re-transmissions and link re-establishment procedures.

The reasons for highest throughput are:-

  - No routing overhead is required
  - Np packet re-transmissions due to multi-hop forwarding
  - Less processing is performed cause no intermediate sensors
  - More bandwidth is available for actual data transmission.

The reason for lowest delay is that:- the transmission path consists of only one hop (from sensor to co-ordinator). Therefore:-

  - No routing decisions are needed
  - No queueing delay at relay sensors
  - No store and forward delay
- **Tree Topology**: - in the fixed sensor mode, throughput in the tree topology always managed the lowest values, while delay values were almost identical in both the tree and mesh architecture. With mobile sensors, throughput and delay were largely immune from variation with no significant impact on network performance because tree is hierarchical, so sensor mobility is limited:-
  - Parent-child relationships remain mostly unchanged
  - Routing remains stable

The reason for lowest throughput is that:- data is forwarded through parent-child relationships before reaching the coordinator. This would causes

  - Multiple forwarding opertions
  - Increasing routing overhead
  - High probability of packet loss at upper-level sensors.
  - Traffic concentration near the root of the tree
  - Bottlenecks occur for sensors that close to the coordinator.

The delay remains stable and close to the mesh topology because the packets travel through multiple hops, the routing path is pre-determined and advantages we get are:-

  - No route discovery process
  - No predictable communication path.
- Mesh Topology: - Mesh performance comes between star and tree from the throughput perspective because the mesh topology provides multiple paths between sensors which causes the following advantages:-
  - Alternative routes increase reliability
  - Packet delivery success rate improves.

While the disadvantages are:-

  - Route selection introduces overhead
  - Routing tables must be maintained
  - Additional control packets consume bandwidth.

The delay is almost identical to tree topology because the packets often traverse several hops before reching the coordinator. Although multi routes exist, routing algorithms usually choose efficient paths. Thus:-

  - Delay is higher than in star topology
  - Delay is similar to tree toplogy.

For mobile sensors, throughput and delay were mostly unaffected with no impact on the performance of WSN because:-

- Alternative routes can be discovered automatically
- Network connectivity is maintained despite node movement.

- **Cluster Topology**:- the throughput is stable because of the cluster topology itself (due to cluster head existence and its function). This would reduces:-
  - Direct connection among all 16 sensors
  - Channel congestion.

Since cluster heads manage communications efficiently, the overall amount of delivered data remains nearly unchanged even when sensors move.

The delay was increased about 7% when sensors become move because:-

- Some nodes may move farther from their cluster head.
- Cluster reassociation may occur
- Cluster heads require additional management operations

In summary, the star topology is the “star performer” for fixed networks but comes up short in mobile, dynamic applications. This contrasts with the mesh and tree architecture which can be trusted to deliver consistently stable performances in mobile applications.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Godi, R. K. Bhoothpur, V. Bhanshreek, K. J. Ambika, B. J. and Gowda, N. C. Enhancing Cybersecurity in Wireless Sensor Networks: Innovative Framework for Optimized Data Aggregation // International Journal of Online and Biomedical Engineering (iJOE), 2025; 21(1): 151-164. DOI: 10.3991/ijoe.v21i01.50953.

[2] Trigka, M. and Dritsas, E. Wireless Sensor Networks: From Fundamentals and Applications to Innovations and Future Trands // IEEE Access, 2025; 13: 96365-96399. DOI: 10.1109/access.2025.3572328.

[3] Frolov, A. Dedova, M. Kochetova, N. and Vinnikov, A. Computer Model of a Secure Wireless Sensor Network of a Smart Home. In Cyber-Physical Systems, 2024. DOI: 10.1007/978-3-031-67911-7_16.

[4] Baqer, N. K. Harbi, Y. J. and Al-Asady, H. A. Impact of Delay in ZigBee WSNs for Smart Home Applications // Journal of Engineering Research and Reports, 2024; 26(8): 372-380: 10.9734/jerr/2024/v26i81252.

[5] Nourildean, S. W. Mohammed, Y. A. and Abdulhadi, M. T. Investigating the impact of network architecture on the IoT-based WSN in smart home monitoring system // Eastern-European Journal of Enterprise Technologies, 2022; 6(9): 6-14. DOI: 10.15587/1729-4061.2022.266990.

[6] Gutierrez, J. A. et al. IEEE 802.15.4: A Developing Standard for Low Power Low-Cost Wireless Personal Area Networks // IEEE Network, 2001; 15(5): 12-19. DOI:10.1109/65.953229.

[7] Gharghan, S. K. Nordin, R. and Ismail, M. A Survey on Energy Efficient Wireless Sensor Networks for Bicycle Performance Monitoring Application // Journal of Sensors, 2014;. 2014(153604). https://doi.org/10.1155/2014/153604

[8] Bouani, A. et al. A Comprehensive Survey of Medium Access Control Protocols for Wireless Body Area Networks // Wireless Communications and Mobile Computing, 2021; 2021(1): 1-16. DOI: 10.1155/2021/5561580.

[9] Jassim, S. I. and Nourildean, S. W. IEEE 802.15.4 ZigBee-Based Wireless Sensor Network in Medical Application // Iraqi Journal of Science, 2012; 53(4): 1055-1066.

[10] Baronti, P. et al. Wireless Sensor Networks: A Survey on the State of the Art and the 802.15.4 and ZigBee Standards // Computer Communications, 2007; 30(7): 1655-1695. DOI: 10.1016/j.comcom.2006.12.020.

[11] Yilmaz, S. and Dener, M. Security with Wireless Sensor Networks in Smart Grids: A Review // Symmetry, 2024; 16(10): 1-40. DOI.org/10.3390/sym16101295.

[12] Galli, S. et al. For the Grid and Through the Grid: The Role of Power Line Communications in the Smart Grid. In Proceedings of the IEEE, 2011; 99(6): 998-1027.

[13] Bhatnagar, S. et al. Efficient Logistics Solutions for E-Commerce Using Wireless Sensor Networks // IEEE Transactions Consumer Electronics, 2024; 70(4): 6838 - 6845. DOI: 10.1109/TCE.2024.3375748

[14] Zhang, Z. et al. Wireless Sensor Networks for Logistics and retail. In: Networked Sensing Systems (INSS); 2009; Pittsburgh, PA, USA. 2009, p. 1-4, DOI: 10.1109/INSS.2009.5409943.

[15] Farahani, S. ZigBee Wireless Networks and Transceivers, 1st ed. Newnes, 2008. doi: 10.1016/B978-0-7506-8393-7.X0001-5

[16] Lloret, J. Garcia, M. Bri, D. and Sendra, S. A wireless sensor network deployment for rural and forest fire detection and verification // Sensors, 2009; 9(11): 8722–8747. DOI: 10.3390/s91108722

[17] Chavan, S. D. and Kulkarni, A. V. Event Based Clustering Localized Energy Efficient Ant Colony Optimization (EBC_LEE-ACO) for Performance Enhancement of Wireless Sensor Network // Engineering, Technology & Applied Science Research, 2018; 8(4): 3177-3183. https://doi.org/10.48084/etasr.2121

[18] Madhmitha, Ms. Chitra, B. A Comprehensive Survey of Distributed Consensus Algorithms for Wireless Sensor Networks // International Journal of Scientific Research in Computer Science Engineering, 2026; 12(1): 173–182. DOI: 10.32628/CSEIT2612111

[19] Uchegbu, U. B. Nosiri, O. C. and Akande, A. O. Enhancement of an energy efficient wireless sensor network using position responsive routing protocol // International Journal of Science and Research Archive, 2025; 16(01): 2359-2368. DOI: https://doi.org/10.30574/ijsra.2025.16.1.2124

[20] Panbude, S. Iyer, B. Nandgaonkar, A. B.and Deshpande, P. S. DFPC: Dynamic Fuzzy-based Primary User Aware clustering for Cognitive Radio Wireless Sensor Networks // Engineering, Technology & Applied Science Research, 2023; 13(6): 12058-12067. https://doi.org/10.48084/etasr.6279.

[21] Perepelitsyn, S. and Perepelitsyn, A. Compromise Between Topology Connection, Load Balance and Wireless Sensor Networks'Anomalies (WSN) // American Journal of Information Science and Technology, 2025; 9(2): 79-86. DOI: 10.11648/j.ajist.20250902.12.

[22] Baqer, N. K. Salih, B. A. and Abbas, A. W. A Study of WSN Topologies for IEEE 802.15.4 ZigBee Standard // International Journal Computational Engineer, 2024; 1(3): 68-74.

[23] Sutgishni, N. P. and Shanmugapriya, D. A Survey on Spoofing and Selective Forwarding Attacks on Zigbee based WSN // Mapana Journal of Science, 2023; 22(Special Issue 2): 397-419. DOI: 10.12723/mjs.sp2.23

[24] Tang, R. Aridas, N. K. and Abu Talib, M. S. Design of Wireless Sensor Network for Agricultural Greenhouse Based on Improved ZigBee Protocol // Agriculture, 2023; 13(8): 1-13.

[25] Baqer, N. K. Abbas, A. W. and Al-Asady, H. A. Throughput and Delay Behaviour in ZigBee Wireless Sensor Networks. In: Proceeding of the 5th International Conference on Communication Engineering and Computer Science (CIC-COCOS), 2024; Arbil, Iraq. p. 418-421. DOI: http://doi.org/10.24086/cocos2024/paper.1549.

[26] Nourildean, S. W. ZigBee-Based wireless sensor network topologies using one and multiple coordinators // Periodicals of Engineering and Natural Sciences (PEN), 2020; 8(3): 1625-1640. DOI: 10.21533/pen.v8i3.1591.

[27] Baqer, N. K. Al-Modaffar, A. M. and Shahtoor, G. H. Throughput Study of IEEE 802.15.4 ZigBee-Based WSNs for Greenhouse Environment // International Journal of Scientific Research Engineering & Technology (IJSRET), 2018; 7(3): 171-176.

[28] Coboi, A. Nguyen, M. T. Pham, V. N. Vu, T. C. Nguyen, M. D. and Nguyen, D. T. ZigBee Based Mobile Sensing for Wireless Sensor Networks // Computer Networks and Communications, 2023; 1(2): 325-341. DOI: https://doi.org/10.37256/cnc.1220233923.

[29] Baqer, N. K. Abbas, A. W. and Salih, B. A. Data and Management Traffic of IEEE 802.15.4 ZigBee-Based WSN // International Journal of Advanced Science Computing and Engineering, 2024; 6(2): 80-83.

[30] Baqer, N. K. Al-Modhaffar, A. M. and AlKadly, E. A. A Study of Delay and Data Traffic of IEEE 802.15.4 ZigBee-Based WSN in a Smart Home // International Journal on Advanced Science Engineering Information Technology, 2018; 8(3): 956–962.

[31] Nguyen, V. Coboi, A. E. Bach, N. V. et al. ZigBee based data collection in wireless sensor networks // International Journal of Informatics Communication Technology, 2022; 10(3): 211–224. DOI:10.11591/ijict.v10i3.

[32] Mau, D. O. Lam, T. C. and Nguyen, T. Performance Evaluation of MAC Layer Protocol over Wireless Body Area Sensor Networks // EAI Endorsed Transactions on Industrials Networks and Intelligent Systems, 2021; 8(27): 1–7. DOI: 10.4108/eai.21-4-2021.169417

[33] Kaddi, M. Omari, M. and Alnatoor, M. EECLP: A Wireless Sensor Networks Energy Efficient Cross- Layer Protocol // Computers, Materials & Continua, 2024; 80(2): 2611-2631. DOI: 10.32604/cmc.2024.052048.

[34] Chen, B. Wireless Communication Chip Designs: analysis of the Wireless Integrated Network Sensors // Highlights in Science Engineering and Technology, 2023; 70: 580-587. DOI: 10.54097/hset.v70i.13989.

[35] Setiabudi, D. Atmaja, D. I. Herdiyanto, D. W. and Rahardi, G. A. RSSI Measurement Analysis of ZigBee-Based Wireless Sensor Networks in Various Topologies for Solar Panel Monitoring // Majalah Ilmiah Teknologi Elektro, 2023; 22(2): 255-264. DOI:10.24843/MITE.2023.v22i02.P14.

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

[37] Coboi, A. et al. Zigbee Based Mobile Sensing for Wireless Sensor Networks // Computer Networks and Communications, 2023; 1(2): 325-342. DOI: https://doi.org/10.37256/cnc.1220233923.

[38] Cuomo, F. at al. Topology Formation in IEEE 802.15.4: Cluster-Tree Characterization. 2008 6th Annual IEEE International Conference on Pervasive Computing and Communications (PerCom), Hong Kong, China; 2008; p. 276-281. DOI: 10.1109/PERCOM.2008.26.

[39] Hada, R. P. S. and Srivastava, A. Dynamic Cluster Head Selection in WSN // ACM Transactions on Embedded Computing Systems, 2024; 23(4): 1-27. DOI: 10.1145/3665867

[40] Chaurasia, N. and Kumar, P. CREN: Energy-Efficient Cluster-Based Network for Secure IoT-WSNs // IEEE Sensors Journal, 2026; PP(99):1-1. DOI: 10.1109/JSEN.2026.3682539

[41] Dawood, M.S., Sridevi, S., Sujatha, C. et al. Enhanced cluster head selection and energy efficient routing using optimized dual-path multi-scale attention guided network in WSN environment // Peer-to-Peer Networking and Applications, 2025; 19(22). DOI: 10.1007/s12083-025-02165-8

[42] Mood, R. and Kulkarni, V. Energy-Efficient Algorithm for Cluster Formation and Cluster Head Selection for WSN. 2022 IEEE Bombay Section Signature Conference (IBSSC); 2022; Mumbai, India: p. 1-6. DOI: 10.1109/IBSSC56953.2022.10037545