Journal of Computer and Communications, 2022, 10, 86-99
https://www.scirp.org/journal/jcc
ISSN Online: 2327-5227
ISSN Print: 2327-5219

A Comprehensive Analysis of Quality of Service (QoS) in ZigBee Network through Mobile and Fixed Node

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How to cite this paper: Islam, N., Hossain, Md.I. and Rahman, A. (2022) A Comprehensive Analysis of Quality of Service (QoS) in ZigBee Network through Mobile and Fixed Node. *Journal of Computer and Communications*, **10**, 86-99.
https://doi.org/10.4236/jcc.2022.103006

Received: December 18, 2021
Accepted: March 21, 2022
Published: March 24, 2022

Abstract

The standard specification of IEEE 802.15.4 is called ZigBee Propocol. ZigBee protocol required security, low data transfer rate, power efficient network. In addition, the ZigBee mobility function makes the ZigBee network more interactive and multi-purpose. The ZigBee mobile node has a significant effect on network parameters, namely MAC delay, end-to-end delay, MAC throughput and network load. However, a particular significant ZigBee node affects network data traffic and reduces the strength of the Quality of Service (QoS). The key issues are to analyze the QoS in order to increase overall performance of the network. The study proposes a ZigBee network with the mobile node and fixed node based on a variety of MAC layer settings. The Riverbed Network Simulator (Academic Modeler Release 17.5) is used for configuring and simulating the ZigBee network in a variety of conditions. The simulation results show that ZigBee with a fixed node performs better than the ZigBee mobile node. The ZigBee network with fixed node produces a lower network load and a high ratio of successfully transmitted data. The analysis of this study allows the ZigBee network to be better designed.

Keywords

WAPNs, ZigBee, IoT, QoS, Mobile Node

1. Introduction

The widely recognized technology for developing a wireless sensing network is ZigBee. The Standards Association's Institute of Electrical and Electronics Engineers (IEEE) standardizes the ZigBee network based on 802.15 specifications.

ZigBee is designed to monitor networks and sensors in conformance with the IEEE 802.15.4 wireless standard for Personal Wireless Networks (WAN). The ZigBee wireless personal sensor network operates at 2.4 GHz, 900 MHz and 868 MHz frequencies. ZigBee can be used in the Physical layer. ZigBee Device Objects are responsible for tasks such as tracking device roles, managing network membership applications, and discovering and securing devices. The ZigBee network offers greater efficiency in communicating from the machine to the wireless machine and from the sensor to the machine. It is also used in the industrial monitoring and control system in the field of the Internet of Things (IoT). In addition, intelligent household environment management, remote sensing, hospital automation and heat detection, intelligent energy management where light is connected via the ZigBee network.

In addition, an extended battery is available through either method. One is the extended network connection that is increased safely draining the battery and draining the battery even more slowly. ZigBee is completely trustworthy. Because it works with a "handshaking" data transfer protocol. The maximum packet size in IEEE ZigBee is 133 octets, including all headings. The ZigBee network is set up ZigBee routers, ZigBee terminals and a ZigBee coordinator. A co-ordinator is a specific type of router. The coordinating body is responsible for setting up a network. It also has the responsibility to decide how to secure a network. The coordinator is employed within a network. The coordinator used the backbone of the network or a link to another network. Also, there is precisely a ZigBee coordinator that stores information on the network. ZigBee routers are responsible for routing traffic on multiple nodes. He is also responsible for the reception or storage of messages for his child nodes. ZigBee terminals are not delivering traffic. It is responsible for requesting all pending messages from its parent node (either the coordinator or a router); it is incapable data transfer with alternative devices. All ZigBee devices are either mobile or fixed. Mobile devices carry out the concept of mobility in the ZigBee network.

A mobile node which is an Internet-connected device to a location and an Internet connection point which can be changed frequently. A mobile node which moves from one network or sub-network to another and continuously modifies the IP address of the nodes. In the fixed node in which the location of the connected devices and the Internet connection point are attached.

Previously, several studies have been implemented in the network to evaluate a mobile ZigBee network such as mobility support in ZigBee network has been studied [1], the effect of mobile Coordinator in ZigBee network [2]. The distinction between the ZigBee mobility concepts was also analyzed on the basis of the randomized and octagonal mobility configuration model [3]. Chai-Keong describes the mobile wireless network protocol and its system in the book [4]. The authors [5] propose a framework for the deployment of ZigBee nodes and tree construction in order to increase the rate of data transmission and attenuate the effects of packet loss due to node mobility. Network performance is analyzed with ZigBee terminals, ZigBee coordinator and ZigBee routers failing [6]. As far as we know, the performance of ZigBee mobile nodes alongside fixed nodes has yet to be studied. This prompted us to develop a new simulation model for the effect of mobility within the ZigBee network alongside the fixed network. The paper shows the distinction between ZigBee fixed network and ZigBee mobile network performance based on an end-to-end delay, and MAC delay, MAC load, and throughput of the proposed network.

The remaining sections of this document are organized in the following manner. In Section 2, discuss work related to the ZigBee network. In Section 3, provide evidence of your research methodology. In Section 4, provide a new simulation model for ZigBee devices. Section 5 presents our simulation results. Section 6 draws conclusions with respect to future opportunities.

2. Related Work

The ZigBee network is used in different automation systems because of its flexibility. There are some articles that concentrate on the formation of ZigBee networks. Reported by Wang *et al.* [7], the pricing methodology is an efficient technique to differentiate the performance of devices with different priorities. The author has configured a ZigBee network with and without a rating approach with the topological tree. The paper concluded that shorter end-to-end delays in the system for higher priorities and lower priorities result in longer end-to-end delays.

The performance comparison of mobility concept of ZigBee network was analyzed on the basis of the randomized and the octagonal mobility configuration model in a document [3]. As a result of these mobility models, the ZigBee network adapts better. The performance of the ZigBee network in different network topologies is assessed and discussed in a further article by Sercan VANN and Ebubekir ERDEM [8]. The evaluation of end-to-end delay, throughput, MAC load and inbound traffic is provided. In this article, the author employed topologies of stars, trees and meshes. Document [9] assesses the ZigBee routing protocol based on priorities for WPAN. They improved routing efficiency by using priority in various modes. The improvement of the ZigBee routing protocol was analyzed in an article [10]. The comparison of the AODV routing protocol with ZBR (ZigBee Routing Protocol) is presented here. The article concludes that AODV has a lower delay than ZigBee's proposed routing. The study [11] focuses on average power consumption and the evolution of the coordination process delays the average of nodes moving through the network.

The QoS in the ZigBee network based on the deviated priority of nodes was discussed in a document [12]. Document [13] states that the network QoS is more visible than the non-priority network. Different areas are set up there and their priority is different. The network was analyzed based on end-to-end delay, MAC delay, MAC load, MAC speed. Xiaolong Li proposed an OPNET based mobile ZigBee sensor network in his article [14]. The study [15] shows that the use of the proposed architecture reduces the communication time and power consumption of moving nodes. The proposed model can significantly enhance performance in networking, routing and support of node mobility. Among ZigBee nodes such as mobile and fixed nodes, research on their ability to transmit and receive combined data is a domain to be studied extensively. Venkataramana proposes a transversal design to enhance QoS on ad-hoc mobile networks [16]. Study [17] reviewed mesh and cluster tree arrangements for reliable transmission. The performance of the system was analyzed on the basis of measurements. Experimental results [18] show that network performance is greatly improved by using various network topologies by changing node size, network load and ACK mode. Yu Gus's document [19] presents a study on well mobility management and the wireless sensor network. Study [20] proposed a study on mobility management protocols in WLNs using 6LoWPAN technology. A ZigBee protocol feasibility analysis of WDSN applications is provided in document [21]. The impact of various mobility models of a network configured specifically with ZigBee for WLN was analyzed in an article [22].

Kims *et al.* [23] an analysis of the performance of routing protocols in ZigBee wireless mesh networks is provided. Managing and controlling data transmission on high-mobility wireless networks was the subject of an article [24]. Paper [25] focused on the performance of the ZigBee network topology. Section [26] deals with the performance of the ZigBee network in the 5G network environment. Another study [27] deals with the simulation and evaluation of a wireless sensor network implementing the ZigBee protocol using the optimized network engineering tool in fixed and mobile networks. The book proposes a thorough study of the foundations and principles of wireless communication, with problems of homework throughout [28]. The writers [29] improved the design of the ZigBee wireless sensor network. Study [30] compares two MAC protocols—RI-MAC, an asynchronous service cycle MAC protocol initiated by the recipient. Furthermore, performance 802.15.4 Low Speed Personal Wireless Network (LR-WPAN) in a large-scale wireless sensor network (WSN) application is covered in [31]. Paolo *et al.* [32] proposed an overview of ZigBee, which provides an overview of energy efficiency, reporting, data management and security options adopted by the standard. The book shows the ZigBee protocol constructed over IEEE 802.15.4 is used in WSN [33]. All these documents have given us the incentive to research on the comparison of ZigBee mobile and fixed network.

And IoT is a new paradigm that improves living standards by connecting all devices. The author discusses the question of privacy and security for the IoT. This study also analyses many different approaches and techniques for confidentiality requirements. Another study [34] examines mathematical models of the stability of the connection with the surviving energy for a route. This work also selects the optimum routing algorithm for connection stability and route energy consumption. On paper [35], the authors' analysis the performance of the ZigBee network for nuclear medicine applications. The results indicate the network parameters such as throughput, end-to-end delay and load, etc. According to [36], proposed an energy-efficient contention-based hybrid MAC protocol which is support emergency condition to barratry. The network parameters such as end-to-end delay, packet drop and throughput are also analyzed. The study [37], the authors show that performance hybrid communication with LoRa ZigBee. Both the ZigBee clusters and LoRa sensors are used to combine for communication which is monitored by Lore Gateway.

3. Methodology

An unambiguous literature review was undertaken to analyze the performance of the mobility-based ZigBee network under the Tree routing protocol. ZigBee serves to handle an intelligent network for office automation, home automation and the IoT. The challenge of mobility in ZigBee makes the network more versatile. A careful observation was made on ZigBee mobility before it was implemented. The academic modeler of the river bed is used to analyze the performance of the suggested model. A variety of Network Software Tools such as Network Simulator-2 (NS-2), Network Simulator-3 (NS-3), MATLAB, OMNET, MININET and Riverbed were used to evaluate the ZigBee wireless sensor network (WSN). Among these, it is seen that Riverbed work more efficiently and accurately in simulation. The riverbed is comparatively easier to install and configure. It provides the quickest used to assess the different network performance parameters and has a wide range of acceptable. During the assessment of various network performance parameters, Riverbed offers the best simulation of discrete events.

Various amounts of data in separate layers are supported by ZigBee protocol layers for simulation. While assessing the different performance parameters of the network, Riverbed offers the best simulation of discrete events. Suitable diagrams are drawn appropriately from the analysis of simulated data. Several graphs will be plotted which represent the comparative performance of ZigBee mobile nodes and fixed node configuration. The analysis is carried out in configuration of network connection of mobile node network and ZigBee fixed node in regard to several network parameters such as an end-to-end delay, MAC load, MAC delay and throughput, etc. The ZigBee Media Access Control (MAC) layer allows multiple topologies without the introduction of complexity. It is also designed to operate with a wide variety of connecting devices.

4. Simulation

The Riverbed Network simulator is highly effective software for simulating a network with different protocols. The Riverbed Academic Modeler tool is constructed from source code C and the programming language C with an impressive library workstation based on Riverbed processors.

Within this simulation, two different scenarios are designed. **Figure 1** is configured in the random setup with movable nodes. Riverbed Academic Modeler is used for the implementation of all mobile nodes with its mobility function. Coordination and routers across the surface. The router transmits information from one device to another. ZigBee devices and routers have been randomly placed

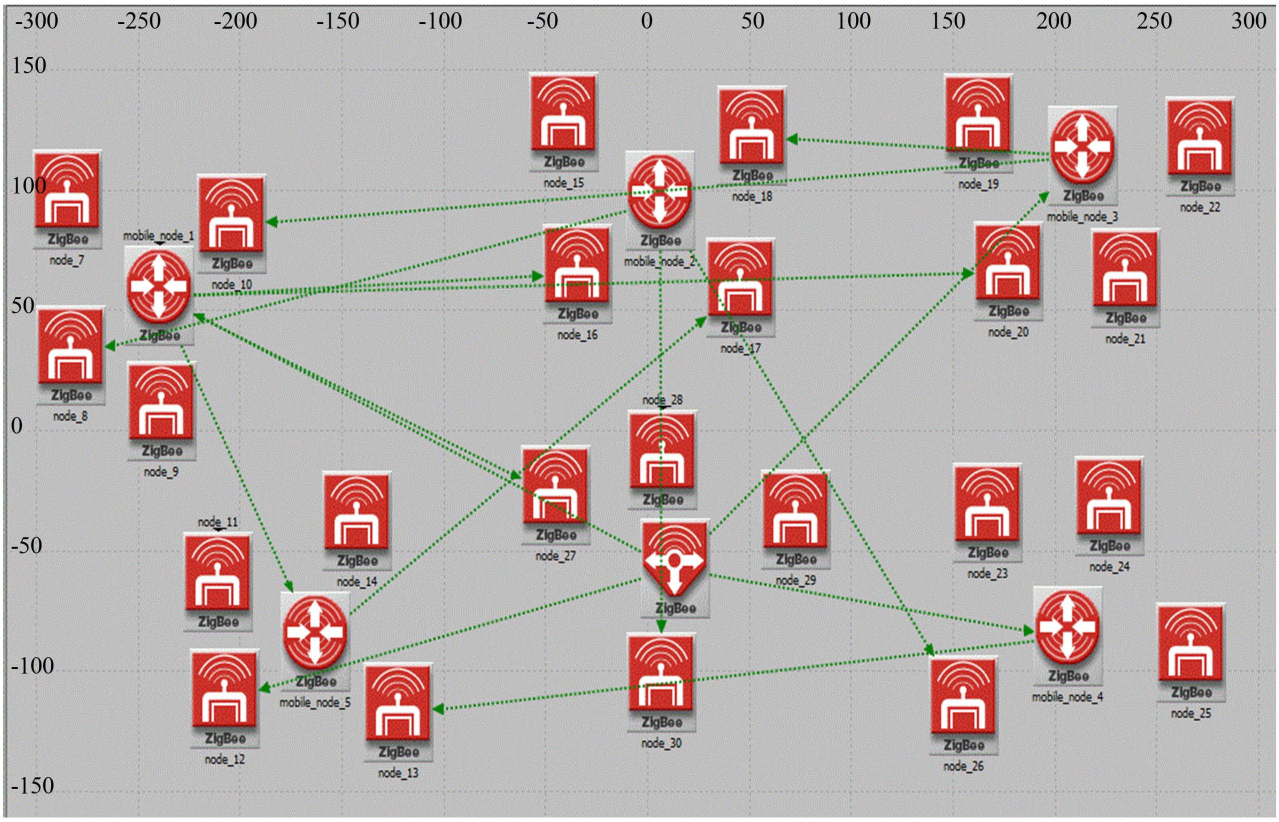

Figure 1. ZigBee mobile network configuration.

onto the surface of the network. However, Figure 2 shows that all routers, coordinators and terminals are fixed.

The ultimate configuration includes 30 ZigBee nodes. It is made up of 5 routers, 24 terminals and a network coordinator. A ZigBee network coordinator that connects to the center of the network and can support up to 65,535 devices at once. Based on this incentive, a large-scale simulation was configured on 30 devices. The network size covers up to 500 square meters in the 2.45 GHz frequency bands. The mobile co-ordinator and the routers, travels at a fixed speed of 1 m/s. Figure 1 shows that coordinator and routers move randomly across the entire surface. Furthermore, Figure 2 shows that all devices are fixed.

Multiple key settings are used in the simulation. These include ACK status, packet size, data rate, re-transmission attempts, type of mobility, packet destination, the high rate of movement, traffic destination, etc. All of these items are held constant as per the definition in Table 1. The total simulation time for the two setups is 600 seconds.

5. Results and Analysis

Based on the above simulation parameters, numerical results are presented and considered in this section. The result is based upon the ZigBees layer realization analysis (application and MAC). The graphs are generated using various ZigBee network settings.

Table 1. ZigBee network scenario details.

Parameters details	
ACK status	Enabled
No. of end devices	24
No. of re-transmissions	5
Frequency band	2.45 GHz
Data rate	Auto calculates
Mobility type	Random and fixed
No. of coordinator	1
Pause probability	0
No. of routers	5
The time between packages	Constant (1.0)
Packet size	Constant (1024)
Moving speed	1 m/s
Network dimensioning	500 m 500 m
Traffic destination	All coordinators and routers
No. of nodes (overall)	30
Simulation time	600 sec

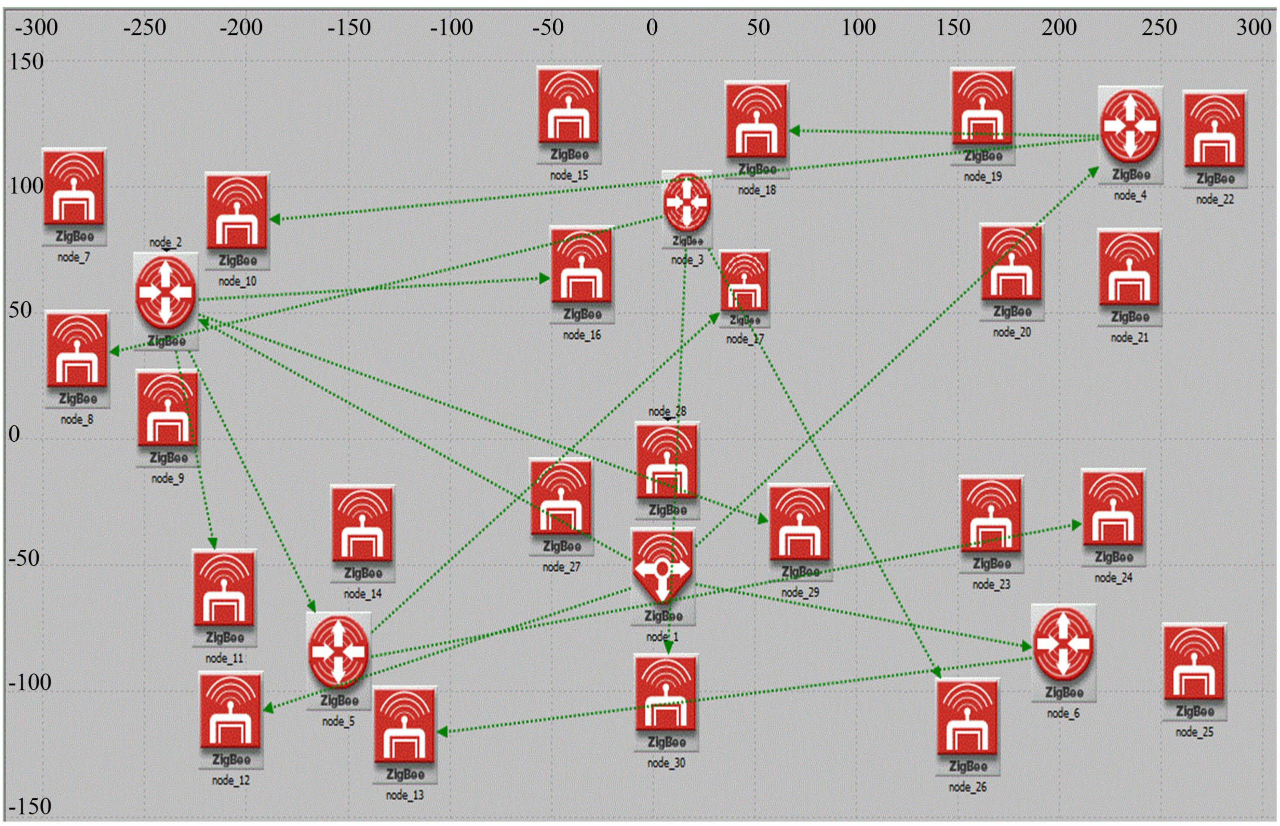

Figure 2. ZigBee fixed network configuration.

5.1. End-to-end Delay

End-to-end delay is measured to pass a packet across the ZigBee network from one one device to another device in the application layer. As such, the elements of delay:-

$$D_{\text{end}} = N\left[d_{\text{trans}} + d_{\text{prop}} + d_{\text{proc}}\right]$$

The total time from beginning to end depends on the number of links (N) and the router time. Each router has their own delivery time (d_{trans}), propagation time (d_{prop}), and processing time (d_{proc}). When a node attempts to contact another node, the request is processed based on the node type. When a mobile node communicates with a mobile node, the total time from creation to receipt of the application packets generated by that node is high. When a fixed node communicates with a fixed node, the overall duration of this node is shorter.

The line graph shows the percentage of end-to-end delay for fixed and mobile node networks from 0 (s) to 350 (s) simulated time. One can see that in 0 (sec) and 250 (sec) the favorite attractions were the end-to-end delay for the fixed network. Between 130 (sec) and 180 (sec) the end-to-end delay was higher for the fixed-node network compared to mobile-node networks. Along with the average end-to-end time for the fixed-node network is lower than the mobile-node network.

During the 40 (sec) to 110 (sec) period, there was an average end-to-end delay of 1.7 (sec) for fixed nodes, followed by a reduction to 1.6 (sec) in the 340 (sec) period. Over the 60 (sec) to 110 (sec) simulation period, the end-to-end delay was 1.8 (sec) for the mobile node array. For the simulation period, it was 1.85 (sec) for the mobile hub network. And during the 340 (sec) simulation, the end-to-end delay was 1.7 (sec).

Figure 3 shows that an end-to-end delay is lower for the network using fixed nodes compared to the network of mobile nodes. The average delay in the fixed

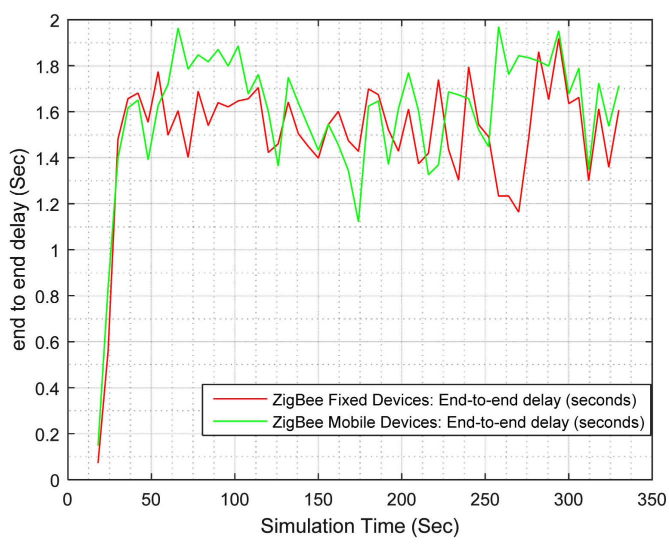

Figure 3. End-to-end delay (sec) for fixed and mobile node network.

node network is approximately 1.7 seconds. The mobile node network is also running about 1.9 seconds behind schedule. The average end-to-end delay is insignificantly lower within the fixed node network. As a result, the fixed devices transmit packet in a short time from source to destination than the mobile devices.

5.2. Mac Delay

The duration of the MAC queue for a packet is set as the duration taken from the packet entering the MAC layer queue. MAC delay is dependent on various protocol settings within MAC layer. This is the overall end-to-end delay that ZigBee WPAN nodes receive in the network. Packets are deposited when there is a limited duration of media access. In addition, it has high, according to the priority of the nodes and their location.

Figure 4 shows the percent MAC delay for the fixed and mobile network between simulation time 10 (sec) and 340 (sec). One can see that in 10 (sec) and 320 (sec) the favorite attractions were less late MAC for the fixed network. Between 150 (sec) to 190 (sec) the MAC delay was higher for fixed node network than mobile node networks. At the same time as the end-to-end mean, the end-to-end duration of the fixed-node network is lower than that of the mobile-node network.

During the simulation time 40 (sec) to 90 (sec) the average MAC delay for the fixed node network was 0.3 (sec) and for the simulation time 250 (sec) to 300 (sec) the average MAC delay was 0.35 (sec) which is lower than mobile node network. And for simulation time 50 (sec) to 110 (sec) the average MAC time was 0.5 (sec) for the mobile node network which is larger in relation to fixed nodes.

The MAC delay is shorter for the network using fixed nodes relative to the network of mobile nodes. Fixed network nodes are confronted with an average

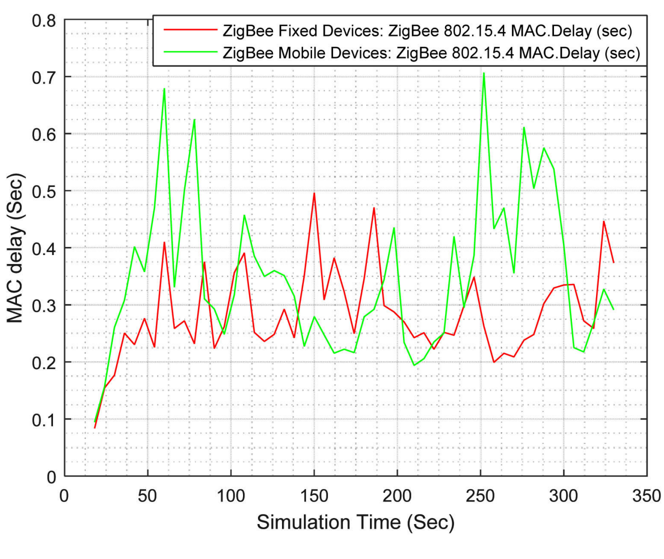

Figure 4. MAC delay (sec) for fixed and mobile node network.

Mac delay of about 0.4 seconds. Therefore, the network of mobile nodes faces a delay of around 0.6 s. The average Mac delay is comparatively smaller in the fixed node setup network.

5.3. Mac Load

MAC load defined as a whole load subjected to ZigBee WPAN nodes in the network by all upper layers. MAC load depends heavily on the different settings of the ZigBee MAC layer protocol. Figure 5 shows that mobile node networks have a higher, MAC load compared to the fixed node network.

The graph shows the performance of the MAC load for both the mobile node network and the fixed node network at simulation time 0 (sec) at 330 (sec). It is found that MAC load is similar to simulation time 0 (sec) to 20 (sec) for mobile and fixed network. Second, the MAC load is between 140,000 bits/s and 180,000 bits/s for the mobile node network and between 150,000 bits/s and 160,000 bits/s for the fixed node network.

The MAC load is approximately 150,000 bits/s and 160,000 bits/s respectively, for fixed and mobile nodes on the global network. The mobile node has a huge load because of its mobility characteristic.

5.4. Throughput

Throughput is the rate at which the packet is passed from one node to another network node. The bitrate depends on network path delay, nervousness and TCP window size.

Figure 6 shows the performance of MAC load for mobile node network and fixed node network at the simulation time 10 (sec) to 340 (sec). The whole simulation time 20 (sec) is highest for fixed node network and low for simulation time 220 (sec). In the configuration of mobile nodes, the highest flow rate is in simulation time 20 (sec) and the lowest at simulation time 140 (sec). Between

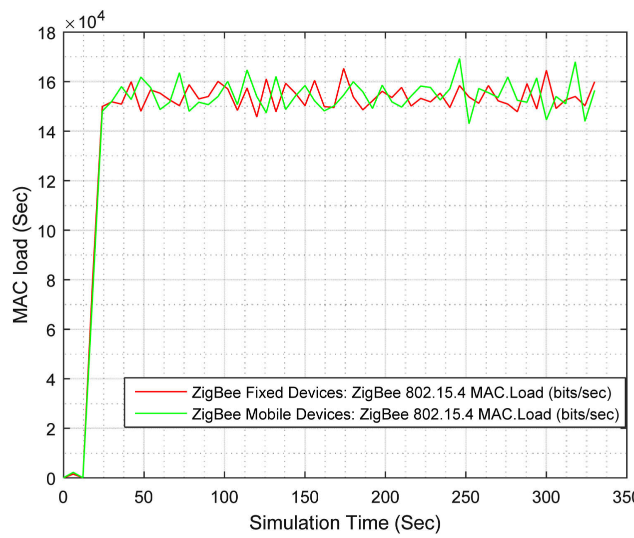

Figure 5. MAC load (bits/sec) for fixed and mobile node network.

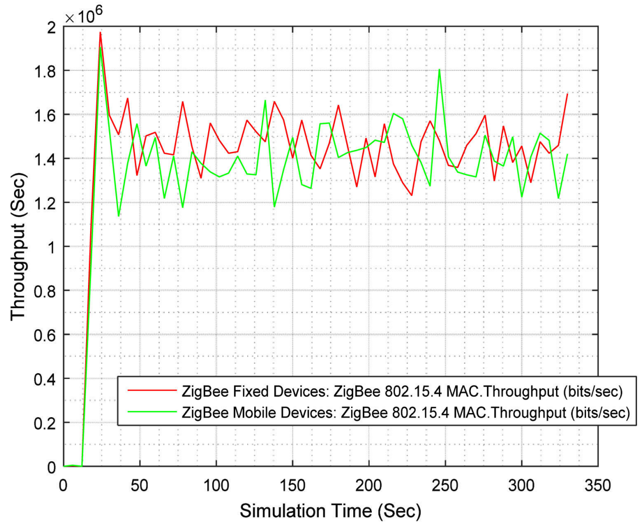

Figure 6. Throughput (bits/sec) for fixed and mobile node network.

the simulation time 25 (sec) to 140 (sec) the average throughput of the fixed node network is 1500,000 bits/sec which is higher than the mobile node network which is 1,300,000 bits/sec. And for the simulation time 280 (sec) to 340 (sec) the average throughput is 1,400,000 bits/sec for fixed node network and average throughput is 1,500,000 bits/sec for the mobile node network. At the moment of the simulation 340 (sec) the network throughputs of fixed nodes is 1,700,000 bits/sec and 1,450,000 bits/sec for the network of mobile nodes.

The average network speed for the fixed node network is close to 1,700,000 bits/s. Moreover, for the network of mobile nodes, it is only about 1,500,000 bits/s. In the mobile node network, a high ratio of uncommitted messages ultimately leads to reduced throughput and degraded network performance. Lower throughput causes packets to be deposited over the network of mobile nodes and a lower quality of network connections. High packet loss within the mobile network results in packet transfer and low physical hardware processing power. High throughput offers lower packet loss and better network connection quality within the fixed node network.

A number of QoS performance parameters are analyzed from fixed nodes against the mobile node network. In almost all the statistics presented here, the performance of fixed-node networks dominates compared with mobile-node networks.

6. Conclusions

The paper analyses the performance of ZigBee fixed nodes and ZigBee mobile node network based on MAC delay, MAC load, throughput and end-to-end delay. Simulation results show the performance comparison between the two scenarios of the proposed network. The study also shows that the network performance parameters of fixed nodes, including MAC delay are 33.33%, end-to-end delay is 10.52%, and throughput is 11.76% better than the mobile node configuration. However, the load of MAC mobile nodes is 6.25% higher than that of fixed nodes.

This work focused on the mobility of the ZigBee network and looked at the QoS in a various ZigBee network. The outcome pinpoints that when networks are fixed, ZigBee terminals are more behind in the creation and receipt of application packets than the ZigBee mobile network. This also shows that the total queue time for packets entering a MAC layer queue on ZigBee's fixed network is shorter than that of the mobile network.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Chen, L.-J., Sun, T. and Liang, N.-C. (2010) An Evaluation Study of Mobility Support in ZigBee Networks. *Journal of Signal Processing Systems*, **59**, 111-122. https://doi.org/10.1007/s11265-008-0271-x

[2] Dhaka, H., Jain, A. and Verma, K. (2010) Impact of Coordinator Mobility on the Throughput in a ZigBee Mesh Networks. 2010 *IEEE* 2*nd International Advance Computing Conference* (*IACC*), Patiala, 19-20 February 2010, 279-284. https://doi.org/10.1109/IADCC.2010.5422995

[3] Islam, N., Biddut, M.J.H., Arif, M.F.H., Rahman, M.M., and Rahman, M.S. (2016) Mobility Issue on Octagonal Structured ZigBee Network Using Riverbed. *International Journal of Communications*, *Network and System Sciences*, **9**, 55-66. https://doi.org/10.4236/ijcns.2016.93005

[4] Toh, C. K. (2001) Ad Hoc Mobile Wireless Networks: Protocols and Systems. Pearson Education.

[5] Shih, Y.-Y., Chung, W.-H., Hsiu, P.-C. and Pang, A.-C. (2013) A Mobility-Aware Node Deployment and Tree Construction Framework for ZigBee Wireless Networks. *IEEE Transactions on Vehicular Technology*, **62**, 2763-2779. https://doi.org/10.1109/TVT.2013.2245693

[6] Kaur, J.P., Kaur, R. and Mann, G.S. (2016) Performance Analysis of ZigBee Mesh Networks under Nodes Failure. *Proceedings of the International Conference on Recent Cognizance in Wireless Communication & Image Processing*, New Delhi, 589-598. https://doi.org/10.1007/978-81-322-2638-3_66

[7] Wang, J., Chen, M., and Leung, V.C.M. (2013) Forming Priority Based and Energy Balanced ZigBee Networks—A Pricing Approach. *Telecommunication Systems*, **52**, 1281-1292.

[8] Vançin, S. and Erdem, E. (2015) Design and Simulation of Wireless Sensor Network Topologies Using the ZigBee Standard. *International Journal of Computer Networks and Applications* (*IJCNA*), **2**, 135-143.

[9] Choudhury, N., Matam, R. and Deka, V. (2016) Priority Based ZigBee Routing Protocol for LR-WPAN. 2016 *IEEE Students' Technology Symposium* (*TechSym*), Kharagpur, 30 September-2 October 2016, 196-201. https://doi.org/10.1109/TechSym.2016.7872681

[10] Kasraoui, M., Cabani, A. and Mouzna, J. (2012) Improvement of Zigbee Routing Protocol. 2012 *IEEE International Conference on Green Computing and Commu-*

nications, Besancon, 20-23 November 2012, 788-793. https://doi.org/10.1109/GreenCom.2012.150

[11] Chaabane, C., Pegatoquet, A., Auguin, M. and Jemaa, M.B. (2012) Energy Optimization for Mobile Nodes in a Cluster Tree IEEE 802.15.4/ZigBee Network. 2012 *Computing*, *Communications and Applications Conference*, Hong Kong, 11-13 January 2012, 328-333. https://doi.org/10.1109/ComComAp.2012.6154866

[12] Islam, N., Bawn, C., Hasan, J., Swapna, A. and Rahman, M. (2016) Quality of Service Analysis of Ethernet Network Based on Packet Size. *Journal of Computer and Communications*, **4**, 63-72. https://doi.org/10.1109/ComComAp.2012.6154866

[13] Biddut, M.J.H. Islam, N., Karim, M.M. and Miah, M.B.A. (2016) An Analysis of QoS in ZigBee Network Based on Deviated Node Priority. *Journal of Electrical and Computer Engineering*, 2016, Article ID: 6254395. https://doi.org/10.1155/2016/6254395

[14] Li, X.H., Peng, M.P., Cai, J., Yi, C.Y. and Zhang, H. (2016) OPNET-Based Modeling and Simulation of Mobile Zigbee Sensor Networks. *Peer-to-Peer Networking and Applications*, **9**, 414-423. https://doi.org/10.1007/s12083-015-0349-8

[15] Anantdeep, E., Kaur, E.S. and Kaur, E.B. (2010) Mobile Zigbee Sensor Networks. *Journal of Computing*, **2**, 95-99.

[16] Attada, V. and Pallam Setty, S. (2015) Cross Layer Design Approach to Enhance the Quality of Service in Mobile ad Hoc Networks. *Wireless Personal Communications*, **84**, 305-319. https://doi.org/10.1007/s11277-015-2609-6

[17] Moridi, M.A., Kawamura, Y., Sharifzadeh, M., Chanda, E.K., Wagner, M. and Okawa, H. (2018) Performance Analysis of ZigBee Network Topologies for Underground Space Monitoring and Communication Systems. *Tunnelling and Underground Space Technology*, **71**, 201-209. https://doi.org/10.1016/j.tust.2017.08.018

[18] Zhang, C.Y. and Luo, W.G. (2013) Topology Performance Analysis of Zigbee Network in the Smart Home Environment. 2013 5*th International Conference on Intelligent Human-Machine Systems and Cybernetics*, Hangzhou, 26-27 August 2013, **2**, 437-440. https://doi.org/10.1109/IHMSC.2013.251

[19] Gu, Y., Ren, F., Ji, Y. and Li, J. (2016) The Evolution of Sink Mobility Management in Wireless Sensor Networks: A Survey. *IEEE Communications Surveys Tutorials*, **18**, 507-524. https://doi.org/10.1109/COMST.2015.2388779

[20] Bouaziz, M. and Rachedi, A. (2016) A Survey on Mobility Management Protocols in Wireless Sensor Networks Based on 6LoWPAN Technology. *Computer Communications*, **74**, 3-15. https://doi.org/10.1016/j.comcom.2014.10.004

[21] de Almeida Oliveira, T., and Godoy, E.P. (2016) ZigBee Wireless Dynamic Sensor Networks: Feasibility Analysis and Implementation Guide. *IEEE Sensors Journal*, **16**, 4614-4621. https://doi.org/10.1109/JSEN.2016.2542063

[22] Nand, P., Astya, R. and Ali, A.W. (2016) Performance Analysis and Impact of Different Mobility Model on Specific Configured Network with IEEE 802.15.4 for WSNs. 2016 *International Conference on Computing*, *Communication and Automation* (*ICCCA*), Greater Noida, 29-30 April 2016, 405-410. https://doi.org/10.1109/CCAA.2016.7813772

[23] Kim, S.H., Chong, P.K. and Kim, T. (2017) Performance Study of Routing Protocols in ZigBee Wireless Mesh Networks. *Wireless Personal Communications*, **95**, 1829-1853. https://doi.org/10.1007/s11277-017-3996-7

[24] Giri, M., Seethalakshmi, R. and Jyothi, S. (2018) Managing and Control of Data Transmission in a High Mobility-based Wireless Networks. *Artificial Intelligence and Evolutionary Computations in Engineering Systems*, **168**, 177-186.

https://doi.org/10.1007/978-981-10-7868-2_17

[25] Moridi, M.A., Kawamura, Y., Sharifzadeh, M., Chanda, E.K., Wagner, M. and Okawa, H. (2018) Performance Analysis of ZigBee network Topologies for Underground Space Monitoring and Communication Systems. *Tunnelling and Underground Space Technology*, **71**, 201-209. https://doi.org/10.1016/j.tust.2017.08.018

[26] Mu, J.S. (2017) An Improved AODV Routing for the ZigBee Heterogeneous Networks in 5G Environment. *Ad Hoc Networks*, **58**, 13-24. https://doi.org/10.1016/j.adhoc.2016.12.002

[27] Deepika and Sharma, M. (2014) Effective Data Flow in ZigBee Network Using OPNET. 2014 *International Conference on Communication and Signal Processing*, Melmaruvathur, 3-5 April 2014, 1155-1158. https://doi.org/10.1109/ICCSP.2014.6950035

[28] Stüber, G.L. (1996) Principles of Mobile Communication. Vol. 2, Springer Science+Business Media New York, Norwell. https://doi.org/10.1007/978-1-4757-6268-6

[29] Liu, Y.F., Wang, C., Qiao, X.J. and Zhang, Y.H. (2009) An Improved Design of ZigBee Wireless Sensor Network. 2009 2*nd IEEE International Conference on Computer Science and Information Technology*, Beijing, 8-11 August 2009, 515-518.

[30] Jain, R. (2018) Comparative Analysis of Contention Based and TDMA Based MAC Protocols for Wireless Sensor Networks. *International Journal of Information Technology*, **12**, 245-250. https://doi.org/10.1007/s41870-018-0152-xc

[31] Kohvakka, M., Kuorilehto, M., Hännikäinen, M. and Hämäläinen, T.D. (2006) Performance Analysis of IEEE 802.15. 4 and ZigBee for Large-Scale Wireless Sensor Network Applications. *Proceedings of the* 3*rd ACM International Workshop on Performance Evaluation of Wireless ad Hoc*, *Sensor and Ubiquitous Networks*, Torremolinos, 6 October 2006, 48-57. https://doi.org/10.1145/1163610.1163619

[32] Baronti, P., Pillai, P., Chook, V.W.C., Chessa, S., Gotta, A. and Hu, Y.F. (2007) Wireless Sensor Networks: A Survey on the State of the Art and the 802.15.4 and ZigBee Standards. *Computer Communications*, **30**, 1655-1695. https://doi.org/10.1016/j.comcom.2006.12.020

[33] Gislason, D. (2008) Zigbee Wireless Networking. Newnes.

[34] Sen, A.A.A., Eassa, F.A., Jambi, K. and Yamin, M. (2018). Preserving Privacy in Internet of Things: A Survey. *International Journal of Information Technology*, **10**, 189-200. https://doi.org/10.1007/s41870-018-0113-4

[35] Gomaa, R.I. (2020) Performance Analysis of Wireless Sensor Networks for Nuclear Medicine Applications. *Journal of Radiation Research and Applied Sciences*, **13**, 714-720. https://doi.org/10.1080/16878507.2020.1828021

[36] Ajmi, N., Helali, A., Lorenz, P. and Mghaieth, R. (2021) SPEECH-MAC: Special Purpose Energy-Efficient Contention-Based Hybrid MAC Protocol for WSN and Zigbee Network. *International Journal of Communication Systems*, **34**, e4637.

[37] Truong, V.T., Nayyar, A. and Showkat, A.L. (2021) System Performance of Wireless Sensor Network Using LoRa-Zigbee Hybrid Communication. *Computers*, *Materials & Continua*, **68**, 1615-1635. https://doi.org/10.32604/cmc.2021.016922