Comparative Analysis of Star Topology and Multihop Topology Outdoor Propagation Based on Quality of Service (QoS) of Wireless Sensor Network (WSN)

Subuh Pramono, Arisa Olivia Putri, EndroWarsito, Budi Basuki S
Department Of Electrical Engineering
Politeknik Negeri Semarang
Semarang, Indonesia
subuhpramono@gmail.com, arisa.olivia@gmail.com, endrosswsgtm@gmail.com, budi.basuki2010@gmail.com

***Abstract*- Wireless technology becomes one of the most widely used technology in everyday life. The technology makes it possible to exchange information quickly, without the use of cable transmission medium. Wireless sensor networks use wireless communications to convey information from every node that is deployed in different areas. This research analyzes how the performance of WSN based on Quality of Service (QoS) from 2 WSN topologies which are star and multihop. The results show that outdoor propagation pathloss exponent value is n = 1.5763 and the farthest distance of real Xbee S2C is 660 meters. Highest throughput is 4109 bps for star topology and 3014 bps for multihop topology. The highest packet loss is 4% for star topology and 5.5% for multihop topology. The biggest delay is 269 ms for star topology and 554 ms for multihop topology.**

Keywords— Zigbee; Propagasi; Quality of Service; MQ-9; Throughput; Delay; Packet Loss.

I. INTRODUCTION

Wireless sensor network is one of the systems being developed as a means of exchanging information quickly and accurately [1]. Wireless technology has been widely implemented in all aspects of life from a large sector of industry class, to small sectors such as households. Wireless technology is particularly vulnerable in data transmission, because wireless communications send electromagnetic waves to transmit remote signals [2] transmitted over the air, data transmission processes will not run optimally if there is an obstacle between the sender and the receiver. Building is one of the most common obstacles in wireless communication systems, where wireless communications are often implemented in buildings for example classrooms or connecting 2 different buildings using point to point techniques. Trees and humans can also interfere with wireless sensor network communications. A common solution taken to minimize attenuation of wireless signals is to reduce the obstacles bypassing through proper placements and selecting devices that are sufficiently reliable to pass obstacles. Drive test can also be one solution to determine the place with the best areas to implement the system. Drive test results can be used for consideration, so that wireless systems can still be implemented even though there are many obstacles.

Based on the research, it was found that energy efficiency and delay became a frequent problem in wireless sensor networks [3]. Unfortunately, in previous studies there has been no direct implementation in the field. Network analysis is only done using Network Simulator 2 software [3]. Another research has also been conducted which analyzes the performance of ZigBee network from a different side, i.e. end to end delay, MAC delay, drop threshold data, Queuing delay and Queue size, Throughput, Number of Hops [4]. Stochastic models and Widest Path models were used in the study to determine the best routing paths based on mathematical calculations. The research resulted by using stochastic model has delay greater than Widest Path Model, but a model of widest Path Model experienced MAC data dropped larger than another model [4].

In our study, we will compare the performance of the ZigBee protocol in 2 topologies, so that based on the existing test sites can be determined the best topologies that can be implemented. Star topology and multihop topology will be compared according to parameters quality of service (QoS) include delay, throughput, and packet loss. A RSSI analysis is also done to measure how strong the signal is for each node placement and to analyze whether it is related to the quality of service (QoS) results obtained. This model uses the ZigBee protocol that supports star topology and multihop topology. The wireless sensor network circuit is also equipped with MQ-9 sensor which will generate sensor data and then sent from the end device node to the coordinator node.

This paper introduces problems in wireless sensor networks and some solutions that are done in part 1, followed in part 2 of supporting theories such as wireless sensor network images and topologies. Then the method used in section 3, the test results and discussion in Section 4, and Section 5 includes the conclusions and future system development plans.

II. WIRELESS SENSOR NETWORK

The Wireless Sensor Network (WSN) can be defined as a network of multiple connected devices, often called nodes, that can monitor and exchange information collected from a controlled area via a wireless channel [5]. There is little difference with the wireless network of computers located on the address, where Wireless Sensor Networks use the Personal Area Network (PAN) ID in accordance with 802.15.4 Institute of Electrical and Electronics Engineers (IEEE) standards. Three important aspects of Wireless Sensor Network are signal/data processing, Media Access Control (MAC) and Communication Protocol. Generally, Wireless Sensor Network is shown in Fig. 1 and sensor node in Fig. 2 [6].

At the signal processing stage is divided into several steps such as digital signal processing, compression, error correction, and encryption. The second process is control and actuation, which is done by grouping network and join network mode. The third is communications, including routing and forwarding processes as well as connectivity management. [7]

S2C XBee working principle is similar to a computer network using an access point, wherein the device using air as the transmission medium. Similarly, computer networks, Zig Bee protocol also consists of a couple of layers as shown in Fig. 3.

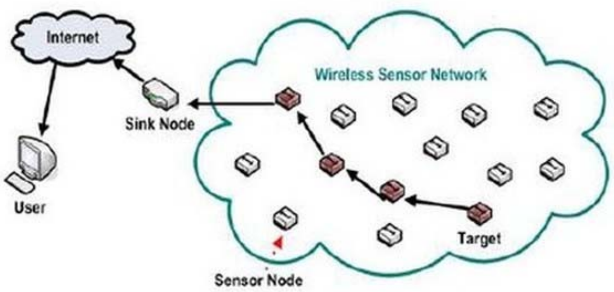

Fig.1. Wireless Sensor Network[6]

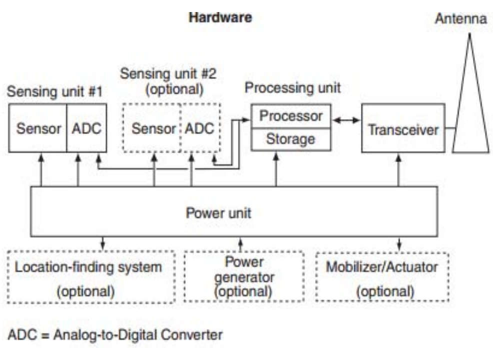

Fig.2. Parts of Sensor Node[7]

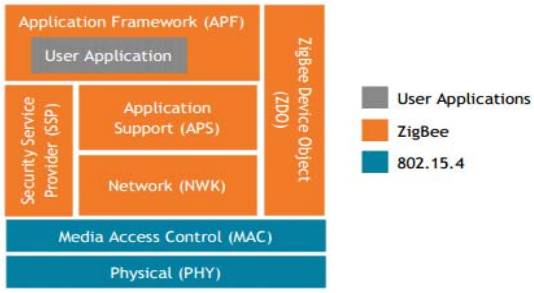

Fig.3. ZigBee layer [8]

A. *Wireless Sensor Network Topology*

1) *Star*

Star is the simplest topology between Tree and Mesh on Zigbee protocol. Comprising a coordinator and several end devices are connected directly. The weakness of this topology is the limited range of coverage, only on the scope of one area only. This topology is as shown in Fig. 4.

2) *Tree*

This topology is the development of a star topology, in order to obtain a wider range of distance/remote. In this topology, there is a router that serves as a repeater network, as shown in Fig. 5.

3) *Mesh*

In the mesh topology is the development of tree topology, where there are additional routing paths that can serve as a backbone when one path cannot be connected to the previous node. This topology is shown as in Fig. 6.

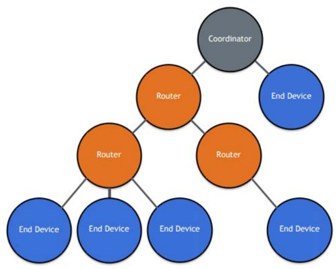

Fig.5. Tree Topology [8]

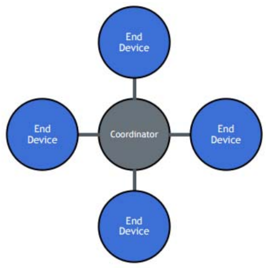

Fig.4. Star Topology[8]

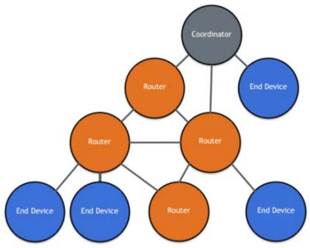

Fig.6. Mesh Topology [8]

B. Receive Signal Strength Indicator

TABLE I. THE VALUE OF EXPONENT PATHLOSS

Environment	Exponent path loss value (n)
Free Space	2
Urban Area Cellular Radio	2.7-3.5
Shadowed Urban Cellular Radio	3-5
In Building LOS	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 6

RSSI is comparing the transmitted power to the received power of the wireless signal based on the distance between nodes.

$$\mathrm{Pr(dBm)} = \mathrm{A} - \mathrm{log10nlog_d} \qquad (1)$$

The RSSI equation is written in equation (1). Pr is a strong signal received at the receiver. Pt is the transmitted power from the sender side. d is the distance between the sending node and the receiving node. n is the pathloss exponent value whose value depends on the surrounding environment as shown in Table 1. Table 1 shows the value of n exponent pathloss for several different environments [9]

C. 'A' Value

The value of 'A' serves to get the average value of the robust RSSI signal at a distance of 1.5 meters. For the equation is formulated as follows:

$$\mathrm{A} = \frac{\sum_{i=1}^{n} \mathrm{data(dbm)}}{\mathrm{n}} \qquad (2)$$

D. Throughput

Throughput is the number of bits that is passed on a network in one second [10].Throughput used to measure how fast data can be passed through a transmission medium such as cable or wireless. Throughput is obtained from the total number of received data bits divided by the time of routing the data. Throughput formula is shown in equation (3).

$$\mathrm{Tn} = \mathrm{Tbr/Sr} \qquad (3)$$

Where Tn is the throughput value of the number of bits passed by the delivery time. Tbr is the number of data bits received and Sr is the data transmission time.

E. Delay

Delay is the amount of delay delivery of packets from the transmitter to the receiver. We use end to end delay on this research. The delay formula is shown in equation (4).

$$\text{Delay} = \text{packet receiving time-packet delivery time} \qquad (4)$$

F. Packet Loss

Packet loss is a test of how well the data is sent from the transmitter to the receiver. By calculating the number of packets sent and received, it will be known how good the quality of data transmission. Packet loss is usually influenced by several factors including distance and obstacle like a building, or a tree. The packet loss formula is shown in equation (5) .

$$\text{PL} = \Sigma\text{packets received}-\Sigma\text{packets sent} \qquad (5)$$

III. DESIGN SYSTEM

This paper compares two topologies based on the result of Quality of Service. The star topology and multihop topology is shown in Fig. 7 and Fig. 8, respectively. This system uses MQ-9 air pollution sensor as a node which its data will be transmitted to the coordinator node. Sensor's data is processed by Arduino Uno which will be displayed on serial monitor, from each node that will be sent to the coordinator node. The coordinator node will collect all the data from each sensor node to be displayed again in the serial monitor. Sensor's data will be converted into ppm and RSSI unit.

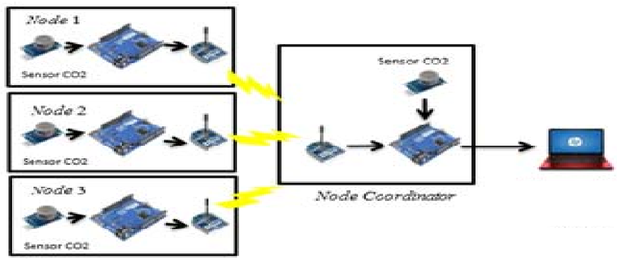

Fig.7. Star topology design

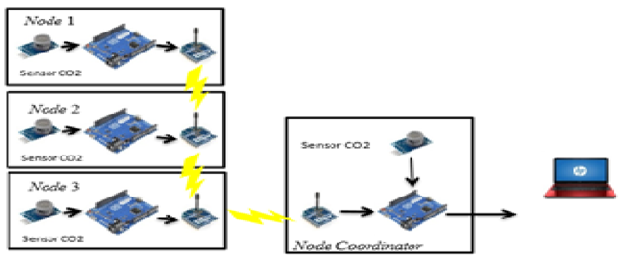

Fig.8. Multihop topology design

A. Floor Plan Simulation

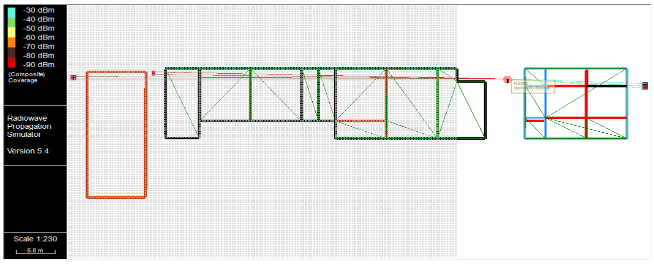

Fig 9. Floor plan

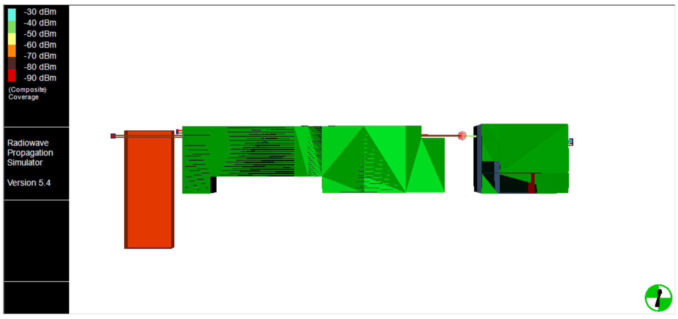

Fig 10. Received signal level mapping

Using radio wave propagation simulator we can simulate the wave propagation that is influenced by surrounding buildings.

The gradually brighter color on the floor plan shows in Fig. 9 and Fig. 10. A stronger received signal level. The nearest area from the transmitter receives the strongest signal. There is building as an obstacle that causes a high attenuation for the farthest area.

IV. RESULT AND DISCUSSION

A. Propagation Distance

Based on experimental LOS propagation, we get the farthest distance is 660 m with -96 dBm RSSI level, Fig. 11.

B. Throughput

The first scenario that we use a 10 m distance that implemented in two different topologies include star topology and multihop topology. Fig. 12 shows that the multihop topology generates more stable throughput than the star topology which is considerable fluctuation.

Based on Fig. 13 shows that the multihop topology creates gradually decreased throughput at a 20 m distance term. Meanwhile, the star topology tends to be unaffected its throughput mostly stable.

A similar result is shown in Fig. 14 as a function of 30 m distance. The multihop is still producing incrementally decreased throughput. Furthermore, the star topology seems to look starting unstable throughput.

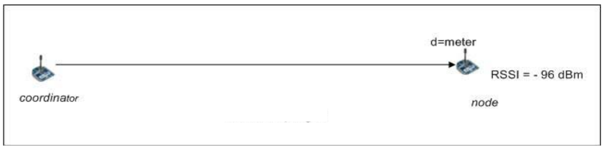

Fig.11. Propagation distance

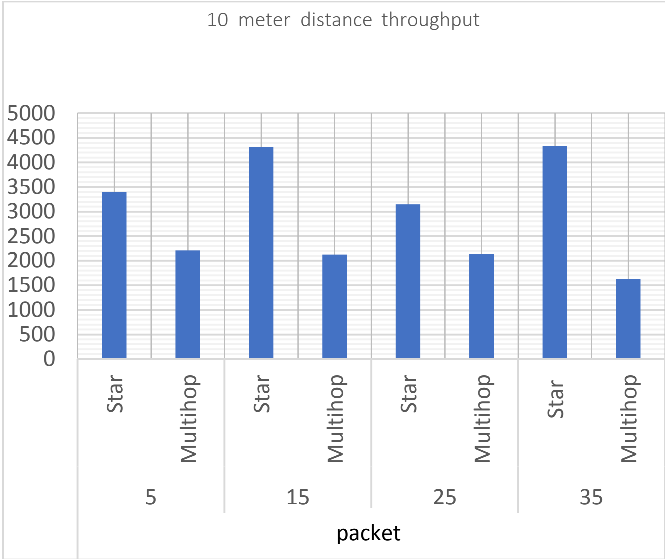

Fig.12. Throughput profile at a 10 m distance

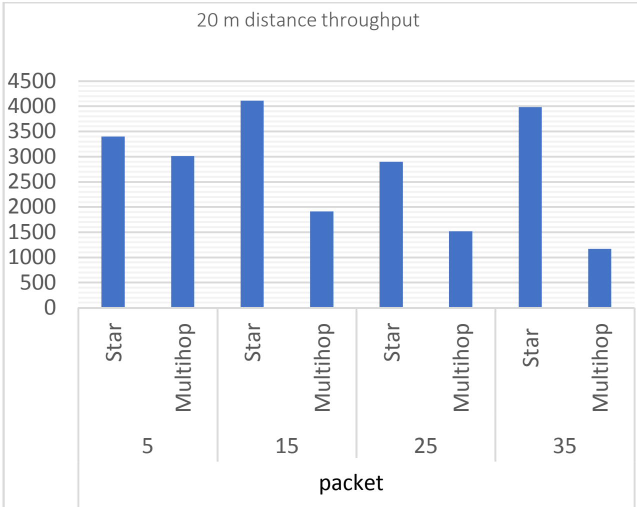

Fig.13. Throughput profile at a 20 m distance

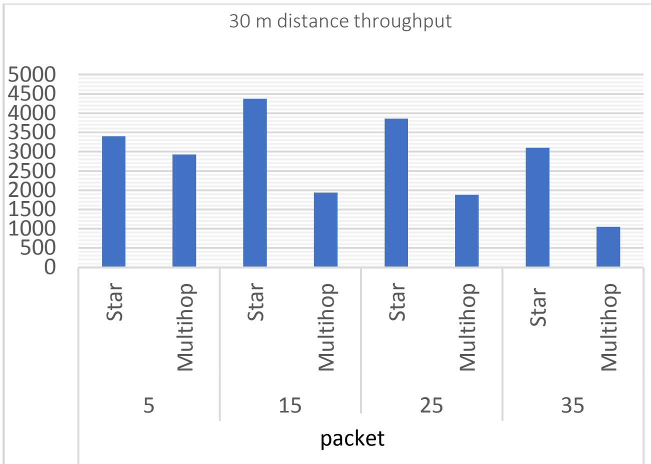

Fig.14. Throughput profile at a 30 m distance

C. Delay

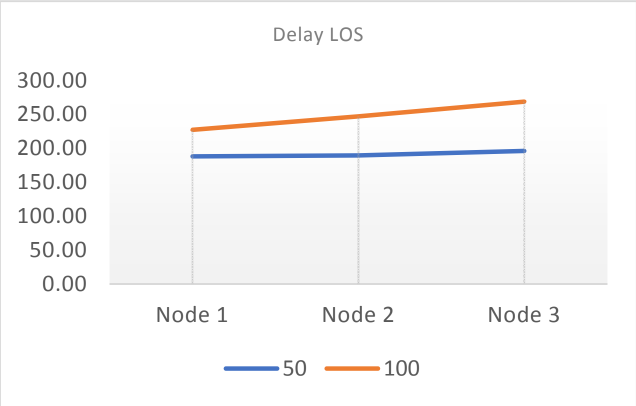

Fig.15. Delay profile vs distance node

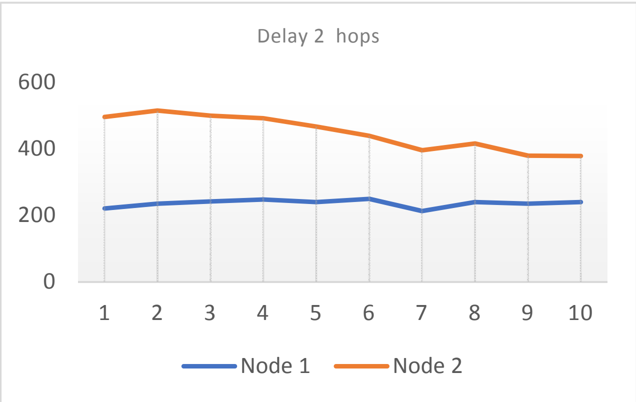

Fig.16. Two hops delay profile

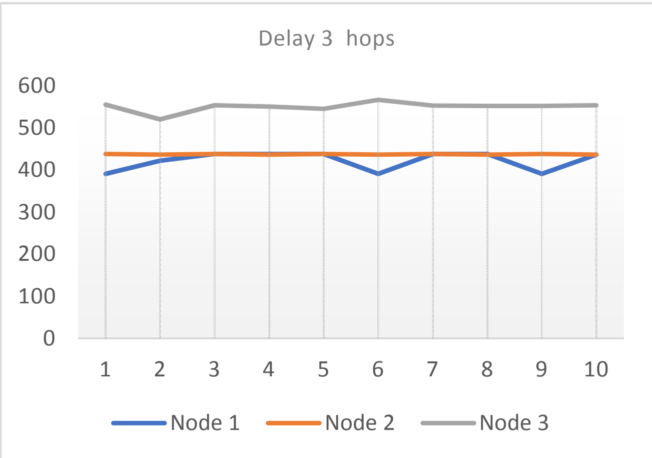

Fig.17. Three hops delay profile

Based on Fig. 15 that shows the delay is linearly increased as increasing distance of the node. Node 3 has been positioned in the farthest distance that generates the biggest delay with its average delay is 199 ms for 50 packets and 269 ms for 100 packets. Node 1 is placed at the shortest distance from the coordinator node, it has the smallest delay that is 184 ms for 50 packets and 236 ms for 100 packets.

Based on Fig. 16, there is increasing delay system. Two hops system yielded a worse delay than single hop system. Two node system generated a delay in range of 400 until 500 ms while single hop created approximately 200 ms. The larger delay is caused by increasing number of routing paths allowing more delay. Three hops system, comparing to Fig. 17 that pictured two hops system, has a bigger delay system. Adding the number of node affects routing path delay. Three node system has a delay approximately 580 ms.

D. Packet Loss

Packet loss result, Fig. 18 described a trend of packet loss in star topology and multihop topology. The star topology yielded significantly different packet loss to multihop topology. At 25 packets transmitted that there is clearly seen a packet loss raised at star topology but this condition is very different at 30 packets transmitted.

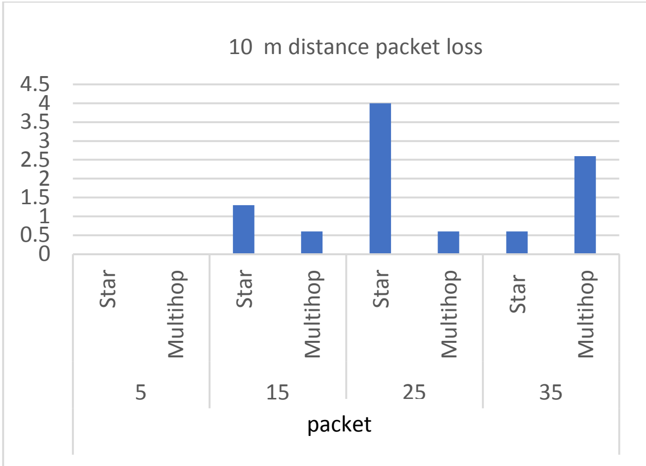

Fig.18 Packet loss profile at 10 m distance

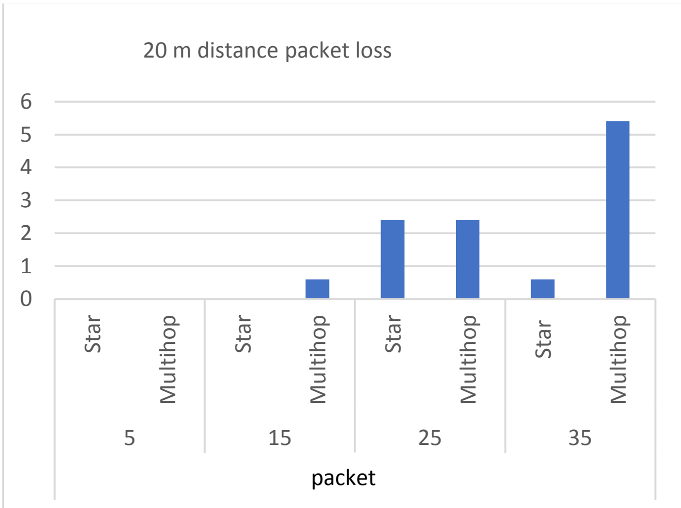

Fig. 19. Packet loss profile at 20 m distance

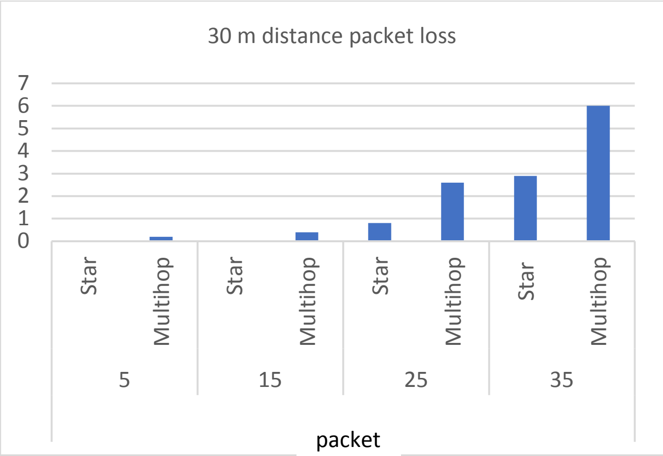

Fig. 20. Packet loss profile at 20 m distance

Based Fig. 19 and Fig. 20 respectively, the number of packet loss is increasing as a function of distance both in star topology and multihop topology. In case 20 m distance, the number of packet loss is not clearly seen linear as a function of the distance, there is still fluctuating. This condition is very different when the system taking 30 m distance, there is clearly seen that the number packet loss is linearly increased by increasing distance.

V. Conclusion

The farthest distance Zigbee can reach in outdoor LOS is 660 meters.The highest throughput on star topology occurs at a distance of 20 meters that data rate reaches 4109 bps. The highest throughput on multihop topology occurs at a distance of 20 meters with a data rate of 3014 bps. The highest packet loss at a distance of 20 meters (star topology) is 4% while the multihop topology is 5.5%. The highest delay on the topology star is about 269 ms with 100 transmitted packets, The multihop topology has a 554 ms delay in 3 hops scenario.

Acknowledgements

The authors would like to acknowledge Directorate Research & Community Service-Directorate General of Research and Development Strengthening - Indonesian Ministry of Research, Technology and Higher Education for their funding of this research under Applied Research Contract Grant.

References

[1] Meng-Shiuan Pan, Yu-Chee Tseng, “Zigbee Wireless Sensor Networks and Their Applications,” Department of Computer Science, National Chiao Tung University, Taiwan, 2011.

[2] Raghavendra C., Sivalingam K., Znati T. "Wireless Sensor Networks," Springer, New York, NY, USA: 2004.

[3] F. Cuomo, A. Abbagnale, and E. Cipollone, “Cross-layer network formation for energy-efficient IEEE 802.15.4/ZigBee Wireless Sensor Networks,” Ad Hoc Networks, vol. 11, no. 2, pp. 672–686, 2013.

[4] N. Islam, M. J. H. Biddut, A. I. Swapna, and S. Asaduzzaman, “Improved Quality of Service in ZigBee network with statistical modeling,” Proc. 2015 3rd Int. Conf. Adv. Electr. Eng. ICAEE 2015, pp. 174–177, 2016.

[5] C. Buratti, A. Conti, D. Dardari, and R. Verdone, “An Overview of Wireless Sensor Networks Technology and Evolution,” Sensors (Basel) Journal, pp. 6869–6896, 2009.

[6] Verdone R., Dardari D., Mazzini G., Conti A. "Wireless Sensor and Actuator Networks," Elsevier, London, UK, 2008.

[7] K. Sohraby, D. Minoli, and T. Znati, “Wireless Sensor Networks Technology, Protocols, and Applications,” John Wiley & Sons, Inc., New York, 2007

[8] M. Hillman, “An Overview of ZigBee Networks A guide for implementers and security testers,” MWR InfoSecurity, pp. 1–12, 2016.

[9] P. M. Tsai, “Path-loss and Shadowing (Large-scale Fading),” University of Texas, 2011.

[10] H. Kaur, “Performance Analysis of Zigbee and WiMAX Based on QOS,” International Journal of Technology Enhancements and Emerging Engineering Research, vol. 3, no. 7, pp. 73–78, 2015.