Prototype of Building Monitoring System Using Vibration Sensor Based on Wireless Sensor Network

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***Abstract*— The building is a critical civil infrastructure for human life, so it needs maintenance. One way of maintenance is to monitor the condition of the building regularly so that it can minimize early damage and use can last as planned at the beginning of manufacture. The monitoring process can be done manually, but it is less efficient considering the increasingly advanced technological developments. Wireless sensor network technology can be used to monitor this because it does not require a wire loop, and data transmission is carried out wirelessly where sensors have been placed in several locations. Therefore, a prototype was tested using a vibration sensor (SW-420) which detects vibrations. The protocol used is the ZigBee protocol (802.15.4) with a mesh topology. The results of the tests that have been carried out are that distance dramatically affects. The RSSI parameter is influenced by the distance, namely, the farther the distance between the transmitter and receiver, the smaller the RSSI value, which means the signal is of poor quality, and vice versa. This result is evidenced at a distance of 4 m RSSI average of -75.7 dBm and a distance of 16 m RSSI average of -81.7 dBm.**

Keywords—Wireless Sensor Network (WSN), ZigBee, RSSI.

I. INTRODUCTION

The building is one of the elements of civil infrastructure that is very important for human life. However, in its lifetime, this infrastructure becomes an easy target for natural disasters that often occur, one of which is earthquakes. As a result, it often causes unwanted losses, one of which is damage to buildings, resulting in a decrease in durability. It is necessary to implement a monitoring system to minimize the occurrence of building damage. Multisensory systems can be found in various areas, both indoors and outdoors (Rosadi and Sakti, 2017). These sensors are connected to a data acquisition device and then sent to the database via cable media so that data from these sensors can be used to analyse the structural capabilities of a building. If we continue to use cable media, it feels less effective because cable installation requires a relatively expensive cost depending on the distance of the reach.

From these conditions emerged an alternative data communication system that is more efficient and commonly known as wireless media (wireless). To describe the above conditions more precisely, using Wireless Sensor Network (WSN) technology. A wireless sensor network consists of several sensors located in different locations, where these sensors carry out the monitoring process on a particular object and transmit data wirelessly. Wireless Sensor Network (WSN) is a wireless sensor network that connects sensor devices, routers, and sink nodes that are connected on an Ad-hoc basis. In the wireless sensor network, several topologies and protocols are used, and each has its advantages and disadvantages. Wireless sensor networks can be implemented in various fields: military, agriculture, health, environment, and others.

Previous structural health monitoring system research was implemented to test the bridge structure. However, this study lacks scheduling in receiving data packets from the coordinator node. As a result, at the time of receiving data packets experience a long delay. So it is necessary to add several algorithms to overcome this (Cahya, 2016).

In this study, the scope of data communication used is the IEEE 802.15.4 (ZigBee) protocol with a mesh topology consisting of sensor nodes, routers, and coordinator nodes and uses static routing. The sensor used is a vibration sensor (SW-420). The parameters to be measured in this study are RSSI, delay, and success rate carried out inside the building with varying distances between transmitter (Tx) and receiver (Rx).

II. RESEARCH METHOD

The location of the prototype test was carried out in a multi-story building in the University of Jember, Tegal Boto Campus, more precisely in the Bio-Engineering Laboratory Building, Faculty of Engineering, which consists of 6 floors. This building has a length of 50 m with a width of 12-16 m. The bird view of the building can be seen in Figures 1 and 2.

Figure 1. Bird view of Bio-Engineering Laboratory Building Length

Figure 2. Bio-Engineering Laboratory Building Width

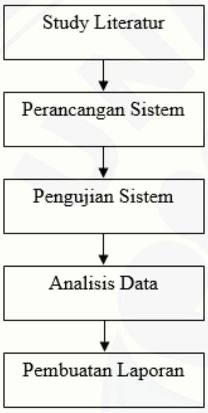


Figure 3. Research block diagram

Figure 3. is a block diagram of research that begins with a literature study, which is the initial stage of research by conducting research from relevant previous studies through books, the internet, as well as national and international journals to find out the basis of the research to be carried out. Furthermore, system design is the stage in preparing the tools and materials needed to build a prototype based on a wireless sensor network. The hardware design consists of Arduino UNO, XBee pro S2C, vibration sensor (SW-420), Node MCU, 9V battery, and laptop. The design software consists of Arduino IDE, XCTU, and Thinger.io. Then, system testing is a test of a prototype that has been designed with conditions determined at the beginning, and the data collection process occurs at this stage. After that, data analysis is a way to compare the results of several data collections with changing conditions. Then the report is made from the research results that have been done, and decision-making is based on the results of data analysis and calculations using the appropriate method. In addition, reporting must also pay attention to suggestions for research development.

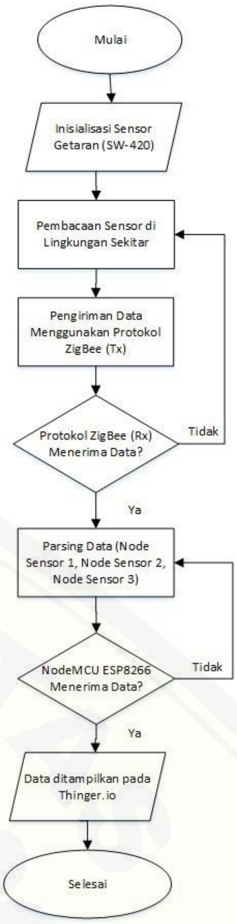


Figure 4. Research flowchart

Figure 4. is a functional flowchart of a multi-story building monitoring system prototype using a vibration sensor based on a wireless sensor network. This prototype uses a mesh topology consisting of 3 sensor nodes and one coordinator node. The first thing to do is to connect the system to a voltage source so that it can start the reading process in the surrounding environment, which is carried out by the vibration sensor (SW-420), which has been uploaded to the Arduino Uno. The sensor node functions as a transmitter that will display sensor data on the Arduino serial monitor. Then, the sensor data will be sent to the coordinator node. However, it will be reread if the coordinator node cannot receive sensor data. After that, the coordinator node will display on the serial monitor and parse data from sensor node 1, sensor node 2, and sensor node 3. Then the sensor data will be displayed on XCTU and the IoT platform, thinger.io, which has been connected to the Node MCU ESP8266. However, data parsing will be repeated if the coordinator node is not connected to Wi-Fi.

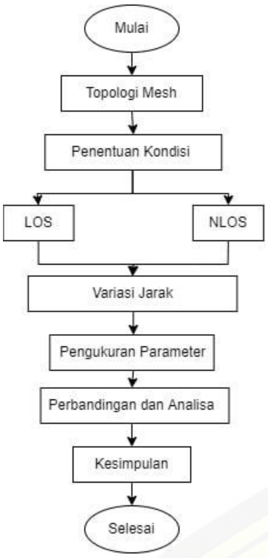


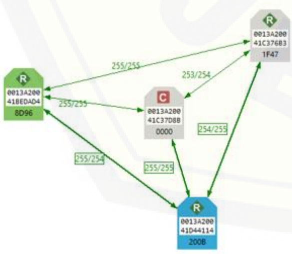
Figure 5. Research flowchart

Figure 5. is a flow chart of the research to be carried out. This study uses a mesh topology that has been configured in XCTU software. After that, two conditions were tested, namely LOS and NLOS in high-rise buildings. Tests on LOS conditions vary in distances of 8 m, 16 m, 24 m, and 32 m. In comparison, the test on NLOS conditions has variations in distances of 4 m (5th floor), 8 m (4th floor), 12 m (3rd floor), 16 m (2nd floor), and 20 m (1st floor). The parameters of RSSI, delay, packet loss, and success rate are measured for each condition. After that, an analysis of the things that affect these parameters is carried out.

III. RESULTS AND DISCUSSION

Testing RSSI, packet loss, success rate, and delay is a test of signal quality at the receiver using XCTU software with 100 packets sent. The test is carried out on two conditions, namely LOS and NLOS, with placement at several points, which aims to determine the effect of distance. The coordinator node is on the 6th floor, while the sensor node is on the 1st floor to the 5th floor in the Biotechnology-Engineering Laboratory Building, Faculty of Engineering, University of Jember.

A. Testing Betwen Nodes



Gambar 6. Test connection between nodes

Testing between nodes aims to determine whether or not there is a connection between the sensor node and the coordinator node. This study uses three sensor nodes that function as routers and one coordinator node that functions as a coordinator. The results of the mesh topology test can be seen in Figure 6. All nodes are interconnected between the coordinator node, the sensor node, and the sensor node with the sensor node.

Table 1. Test connection between nodes

Testing	**Connection**					
	C ↔ NS 1	*C ↔ NS 2*	*C ↔ NS 1*	*NS 1 ↔ NS 2*	*NS 1 ↔ NS 2*	*NS 2 ↔ NS 3*
1st	√	√	√	√	√	√
2nd	√	√	√	√	√	√
3rd	√	√	√	√	√	√
4th	√	√	√	√	√	√
5th	√	√	√	√	√	√
6th	√	√	√	√	√	√
7th	√	√	√	√	√	√
8th	√	√	√	√	√	√
9th	√	√	√	√	√	√
10th	√	√	√	√	√	√

Description:

C = Node Coordinator

NS = Node Sensor

The test of mesh topology connection test was carried out ten times. The results of the connection test can be seen in Table 1. that all nodes are connected as a whole. The connection test was conducted by placing the coordinator node on the 6th floor and the sensor node on the 1st to 5th floor. However, there were several experiments where sensor node 3 had a long time to connect with other nodes. This happened because the device's reliability on sensor node three has decreased.

B. Testing of *RSSI*

Table 2. *RSSI* Test Result *NLOS* Condition

Distance (m)	**RSSI (dBm)**		
	1st try	2nd try	3rd try
4 (5th floor)	-72	-74	-79
8 (4th floor)	-73	-76	-78
12 (3rd floor)	Lost	Lost	Lost
16 (2nd floor)	-80	-81	-84
20 (1st floor)	Lost	Lost	Lost

Testing is done by placing nodes in the corridor of each floor right in the middle of the building floor. However, each floor has a different building form. In testing the distances of 4 m (5th floor), 8 m (4th floor), and 16 m (2nd floor), the RSSI value is obtained, which can be seen in Table 2. Furthermore, in the 12 m (3rd floor) distance test, data transmission will not be able to, but the node is still connected to other nodes. This result happened due to differences in the shape of the building. So that the placement of nodes at a distance of 12 m is different from the other nodes. The shape of the building on the 1st and 3rd floors has a corridor in the middle because on both sides there are classrooms.

Meanwhile, the 2nd, 4th, 5th, and 6th floors have corridors on the edge because only one side has a classroom. So from the above discussion, nodes' placement affects the RSSI value. Then at a distance of 20 m (1st floor), the same thing with a distance of 12 m, namely unable to send data packets, but this is due to the coordinator who cannot find the router. This result is because the XBee's range has reached its maximum.

Table 3. *RSSI* Test Result *LOS* Condition

Distance (m)	RSSI (dBm)		
	1st try	2st try	3st try
8	-72	-67	-66
16	-73	-72	-74
24	-74	-72	-73
32	-80	-71	-74

Tests on the conditions of LOS and NLOS there are differences. Testing on the LOS condition is carried out by placing the nodes on the 6th-floor corridor horizontally, and the nodes are in a straight line with a distance between nodes of 8 m. The test was carried out at a distance of 8 m, 16 m, 24 m, and 32 m, and the RSSI value was obtained, which can be seen in Table 3. good signal quality. This can be seen in Tables 2. and 3. The presence of a barrier causes the difference, wherein in the LOS condition, there is no barrier at all, while in the NLOS condition, it is blocked by concrete. So, from the discussion above, the room divider is one factor affecting the RSSI value.

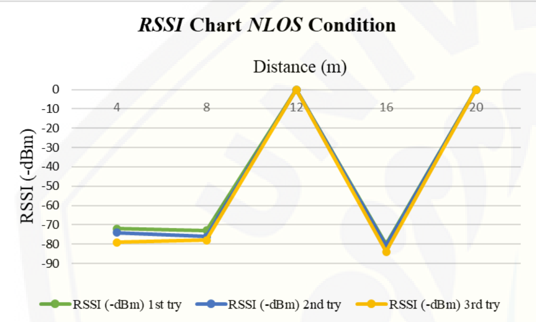


Figure 7. *RSSI* Test Graph *NLOS* Condition

In testing the distance of 4 m and 8 m with three trials, the RSSI value is in the range of -70 dBm. While at a distance of 16 m, the RSSI value decreased, which was in the range of -80 dBm. This was because the distance between the sensor node and the coordinator node was getting farther away. In addition, a distance of 12 m and 20 m cannot transmit data. So from Figure 7, the graph shows that the distance affects the RSSI value. The farther the distance from the transmitter to the receiver, the smaller the RSSI value (away from zero), which means the signal quality is getting worse. Vice versa, the closer the distance between the transmitter to the receiver, the greater the RSSI value (close to zero), which means the signal is getting better, according to the RSSI theory.

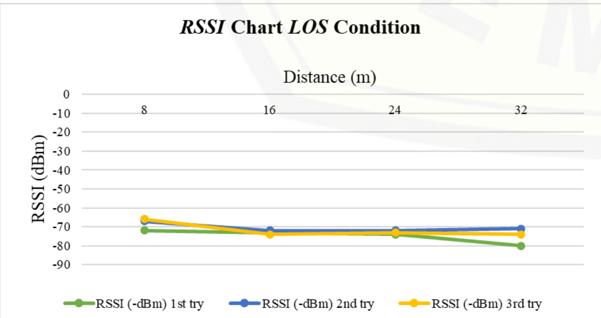


Figure 8. *RSSI* Test Graph *LOS* Condition

In the 8 m distance test, the RSSI value ranges from -60 dBm to -70 dBm. Furthermore, the RSSI value decreased at a distance of 16 m and 24 m, which was in the range of -70 dBm. Then at a distance of 32 m, the RSSI value decreased again from the previous test, which was in the range of -70 dBm to -80 dBm. This is because the distance between the sensor node and the coordinator node is getting farther away. So from Figure 8, the graph shows that the distance affects the RSSI value. The farther the distance from the transmitter to the receiver, the smaller the RSSI value (away from zero), which means the signal quality is getting worse. Vice versa, the closer the distance between the transmitter to the receiver, the greater the RSSI value (close to zero), which means the signal improves.

C. Testing of *Packet Loss* and *Succes Rate*

Table 4. *Packet Loss* and *Succes Rate* Test Result *NLOS* Condition

Distance (m)	Packet Loss (%)			Succes Rate (%)		
	Experiment					
	1st	2nd	3rd	1st	2nd	3rd
4 (5th floor)	0	30	25	100	70	75
8 (4th floor)	6	51	60	94	49	40
12 (3rd floor)	100	100	100	0	0	0
16 (2nd floor)	49	93	91	51	7	9
20 (1st floor)	Lost	Lost	Lost	Lost	Lost	Lost

The placement of nodes in the packet loss and success rate tests is the same as the placement of nodes in the RSSI test. In Table 4. the 4 m distance test in the second and third experiments has a higher packet loss and a lower success rate when compared to the 1st experiment. This result occurred because the environmental conditions between the first and second experiments differed at the time of testing. The conditions in the 1st experiment were with a surrounding open environment and those in the second and third experiments with a closed surrounding environment. So from the above discussion that the surrounding environmental conditions affect packet loss and success rate.

Furthermore, at a distance of 12 m, packet loss obtained is 100%, and the success rate is 0%. This error happened because the XBee module could not transmit data due to the shape of the building. Then at a distance of 20 m, the same thing as a distance of 12 m, which cannot transmit data, but this is because the coordinator cannot find the router.

Table 5. *Packet Loss* and *Succes Rate* Test Result *LOS* Condition

Distance (m)	Packet Loss (%)			Succes Rate (%)		
	Experiment					
	1st	2nd	3rd	1st	2nd	3rd
8	0	29	27	100	71	73
16	0	3	5	100	97	95
24	0	6	11	100	94	89
32	0	8	15	100	92	85

The placement of nodes in the packet loss and success rate tests is the same as the placement of nodes in the RSSI test. The test was carried out at a distance of 8 m, 16 m, 24 m, and 32 m, and the packet loss and success rate values were obtained, which can be seen in Table 5. In Table 5. the packet loss and success rate obtained when compared with NLOS conditions, LOS conditions have a smaller packet loss value and a greater success rate. This can be seen in Tables 4. and 5. The difference is caused by a barrier, wherein in the LOS condition, there is no barrier, while in the NLOS condition, it is blocked by concrete. So from the above discussion, the room divider is one-factor affecting packet loss and success rate. In addition, testing at a distance of 8 m, more precisely in the second and third experiments, had a more significant packet loss value and a lower success rate than the 1st experiment. This is because the second and third experiments used nodes sensor 3, where the XBee module on sensor node three is experiencing a decrease in reliability, which affects the data transmission process.

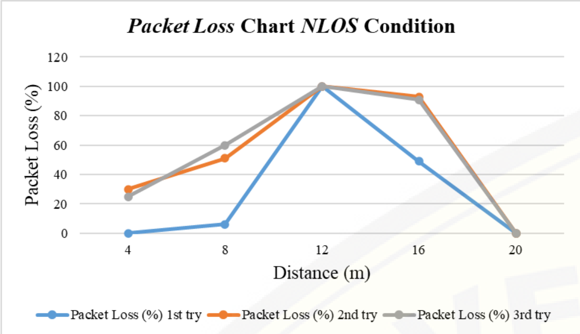


Figure 9. *Packet Loss* Test Graph *NLOS* Condition

Testing packet loss at a distance of 4 m, carried out three times, had packet loss in the range of 0-30%. Furthermore, packet loss has increased at a distance of 8 m, which is in the range of 0-50%. Then the test at a distance of 16 m packet loss increased again, which is 50-90% range. This result happened because the distance between the sensor node and the coordinator node is getting farther away. However, testing at a distance of 12 m, packet loss is 100%. This error occurred because, at that distance, XBee could not send data due to the shape of the building. While testing at a distance of 20 m, the coordinator could not find the presence of the router. So from Figure 9, the graph shows how distance affects packet loss. The farther the distance between the sensor node and the coordinator node, the greater the packet loss. Vice versa, the closer the distance between the sensor node and the coordinator node, the smaller the packet loss.

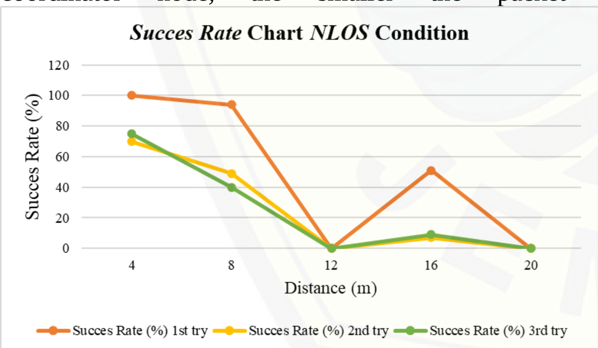


Figure 10. *Succes Rate* Test Graph *NLOS* Condition

The success rate test at a distance of 4 m, carried out three times, had a success rate in the 70-100% range. Furthermore, testing at a distance of 8 m success rate decreased, which was in the range of 40-90%. Then the test at a distance of 16 m, the success rate decreased again, which was in the range of 10-50%. This error happened because the distance between the sensor node and the coordinator node was getting farther away. However, testing at a distance of 12 m has a success rate of 0%. This result happened because, at that distance, XBee could not transmit data due to the shape of the building. While testing at a distance of 20 m, the coordinator could not find the presence of the router. So from Figure 10. the graph can be analyzed that distance affects the success rate. The farther the distance between the sensor node and the coordinator node, the lower the success rate. Vice versa, the closer the distance between the sensor node and the coordinator node, the greater the success rate..

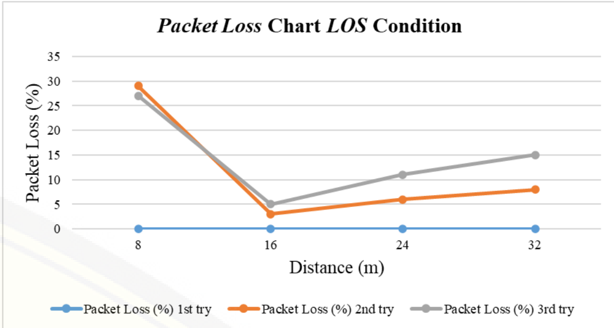


Figure 11. *Packet Loss* Test Graph *LOS* Condition

Testing packet loss at a distance of 8 m, carried out three times, had packet loss in the range of 0-30%. Furthermore, testing at a distance of 16 m, packet loss has decreased in the range of 0-5%. Then the test at a distance of 24 m and 32 m packet loss increased, which is in the range of 10-15%. This error results from the distance between the sensor node and the coordinator node getting farther away. In addition, testing at a distance of 8 m, more precisely in the second and third experiments, has a packet loss value more significant than in the 1st experiment. This is because in the second and third experiments using sensor node three, the XBee module on sensor node three is experiencing a decrease in reliability. So from Figure 11. the graph can be analyzed that distance affects packet loss. The farther the distance between the sensor node and the coordinator node, the greater the packet loss. Vice versa, the closer the distance between the sensor node and the coordinator node, the smaller the packet loss.

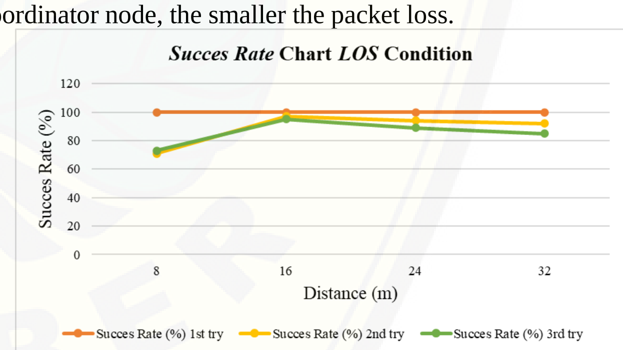


Figure 12. *Succes Rate* Test Graph *LOS* Condition

The success rate test at a distance of 8 m, carried out three times, had a success rate in the 70-100% range. Furthermore, testing at a distance of 16 m success rate has increased, which is in the range of 90-100%. Then the test at a distance of 24 m and 32 m, the success rate decreased, which was in the range of 70-100%. This result could happen because the distance between the sensor node and the coordinator node was getting farther away. In addition, testing at a distance of 8 m, more precisely in the second and third experiments, has a lower success rate than the 1st experiment. The reason is that in the second and third experiments using sensor node three, the XBee module on sensor node three is experiencing a decrease in reliability. So from Figure 12, the graph shows that distance affects the success rate. The farther the distance between the sensor node and the coordinator node, the lower the success rate. Vice versa, the closer the distance between the sensor node and the coordinator node, the greater the success rate.

D. Testing of *Delay*

Table 6. *Delay* Test Result *NLOS* Condition

Distance (m)	Delay (s) Experiment		
	1st	2nd	3rd
4 (5th floor)	1,26	3,02	1,85
8 (4th floor)	1,44	3,4	3,37
12 (3rd floor)	Lost	Lost	Lost
16 (2nd floor)	1,88	11,4	13,7
20 (1st floor)	Lost	Lost	Lost

The placement of nodes in the delay test is the same as placing nodes in the RSSI test. In Table 6. the 4 m distance test in the second and third experiments had a higher delay when compared to the 1st experiment. In addition, this also happened to the 8 m and 16 m distance tests. This delay occurred because the environmental conditions between the first and second experiments differed at the testing time. The conditions in the 1st experiment were with a surrounding open environment and the conditions in the second and third experiments were with a closed environment. So from the above discussion that the surrounding environmental conditions affect delay, which is one of the characteristics of wireless transmission media.

Furthermore, at a distance of 12 m, it cannot transmit data due to the shape of the building. In addition, the delay is also affected by packet loss, while at a distance of 12 m (3rd floor), it cannot transmit data. Then at a distance of 20 m, the same thing as a distance of 12 m, which cannot transmit data, but this is because the coordinator cannot find the router..

Table 7. *Delay* Test Result *NLOS* Condition

Jarak (m)	Delay (s) Experiment		
	1st	2nd	3rd
8	1,25	2,4	2,21
16	1,23	1,29	1,31
24	1,22	1,4	1,41
32	1,26	1,38	1,49

The placement of nodes in the delay test is the same as placing nodes in the RSSI test. The test was carried out at a distance of 8 m, 16 m, 24 m, and 32 m, and the RSSI value was obtained, which can be seen in Table 7. In Table 7. the delay obtained when compared to the NLOS condition, the LOS condition has a minor delay. This can be seen in Tables 6. and 7. The difference is caused by a barrier, wherein in the LOS condition, there is no barrier, while in the NLOS condition, it is blocked by concrete. So from the discussion above that, the room divider is one of the factors that affect delay. In addition, testing at a distance of 8 m, more precisely in the second and third experiments, had a more significant packet loss value and a lower success rate than the 1st experiment. This packet loss occurred because the second and third experiments used node sensor 3, where the XBee module on sensor node three is experiencing a decrease in reliability.

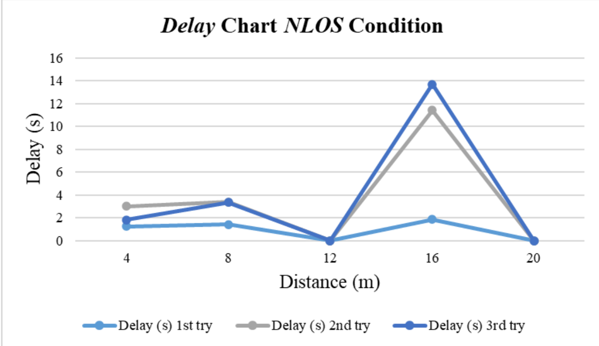


Figure 13. *Delay* Test Graph *NLOS* Condition

The test for delay at a distance of 4 m and 8 m, carried out three times, had a delay in the range of 1-3 s. Then testing at a distance of 16 m has increased, which is in the range of 2-12 s. This delay is caused by the distance between the sensor node and the coordinator node getting farther away. However, testing at a distance of 12 m cannot transmit data due to the shape of the building. While testing at a distance of 20 m, the coordinator could not find the presence of the router. So from Figure 13. the graph can be analyzed that the distance affects the delay. The farther the distance between the sensor node and the coordinator node, the greater the delay. Vice versa, the closer the distance between the sensor node and the coordinator node, the smaller the delay.

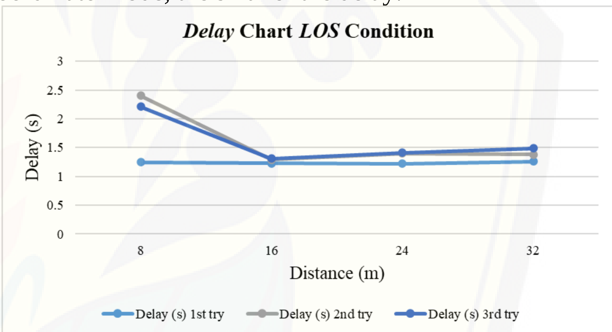


Figure 14. *Delay* Test Graph *LOS* Condition

The delay evaluation at a distance of 8 m, carried out three times, had a delay in the range of 1, 25-2.5 s. Furthermore, testing at a distance of 16 m, 24 m, and 32 m delay decreased in the range of 1.25 -.1.5 s. However, in Figure 14, it can be seen that the one with the highest delay is at a distance of 32. This result happened because the distance between the sensor node and the coordinator node is getting farther away. In addition, testing at a distance of 8 m, more precisely in the second and third experiments, has a delay value more significant than in the 1st experiment. This result happened in the second and third experiments using sensor node three. The XBee module at sensor node three is experiencing a decline in reliability. So from Figure 14. the graph can be analyzed that the distance affects the delay. The farther the distance between the sensor node and the coordinator node, the greater the delay. Vice versa, the closer the distance between the sensor node and the coordinator node, the smaller the delay.

IV. Conclusion

From testing the prototype of a multi-story building monitoring system using a vibration sensor based on a wireless sensor network using the ZigBee protocol at the Biotechnology-Engineering Laboratory Building, Faculty of Engineering, University of Jember. The result shows that the method used is a wireless sensor network using the ZigBee protocol with a mesh topology that works quite well. This can be proven by the maximum distance traveled is 16 m, with an RSSI of -84 dBm.

The signal quality of this research uses RSSI, delay, and packet loss parameters. The results of the RSSI test on the distance, namely, the farther the distance between the transmitter and receiver, the smaller the RSSI value, which means the signal is of poor quality. Vice versa, the closer the distance between the transmitter and receiver, the greater the RSSI value, which means the signal is good quality. This is proved at a distance of 4 m RSSI average of -75.7 dBm and a distance of 16 m RSSI average of -81.7 dBm. In addition, the delay test results are directly proportional to the distance. This is proved at a distance of 4 m, the average delay is 2.04 s, and at a distance of 16 m, the average delay is 8.9 s. Then, the packet loss test results are directly proportional to the distance, but at the success rate, the distance is inversely proportional. This can be proven at a distance of 4 m, the average packet loss is 18.33% with an average success rate of 81.77%, and at a distance of 16 m, the average packet loss is 77.67% with an average success rate of 22.33%.

For further research, the energy consumption for each node should be analyzed because one of the main challenges for wireless sensor networks is energy scarcity. Another thing that can be considered is increasing the number of nodes at least one floor of one node so that the data transmission process and signal quality are much better.

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