QoS analysis of WSN (Wireless Sensor Network) using node MCU and accelerometer sensors on bridge monitoring systems

D Junesco1,*, E Supriyanto2, A Hasan1 and M Mukhlisin3
1 Faculty of School of Graduate Studies, Management and Science University, Shah Alam, Malaysia
2 Department of Electrical Engineering, Politeknik Negeri Semarang, Semarang, Indonesia
3 Department of Civil Engineering, Politeknik Negeri Semarang, Semarang, Indonesia

*devanjunesco@gmail.com

Abstract. Based on the planning guideline of Health Monitoring System of Bridge Structure of Kementrian Pekerjaan Umum dan Perumahan Rakyat, one of the main components needed in bridge health monitoring system is a communication system. The application of the WSN (Wireless Sensor Network) function to perform monitoring can be used to create a more practical system. Based on the system, required hardware that can be integrated with the software and can connect on wireless. Proposed methods using WSN (Wireless Sensor Network) on devices, then do testing on connectivity to obtain network quality and data sensor. Data sensor will be uploaded on the cloud can be accessed from various places that connected to the Internet network thus forming an IoT (Internet of Things) based system with using Message Queue Telemetry Transport (MQTT) protocol. Experiments carried out in two ways of connectivity, point-to-point and star topology to determine the network quality of each device, which is Node MCU and MiFi modems. Network quality parameters can be known by looking at the value of packet loss, delay, jitter, and throughput. In the results, the MQTT Protocol applied to build IoT system. In addition, proposed methods that used in this research has a great quality network with packet loss <25 ms. However, there’s a big gap between serial data and online data that makes MQTT protocol is not suitable for monitoring systems that require fast data transfer.

1. Introduction
Bridges play a vital part in the economy of the country, as they facilitate the movement of goods and people around. These structures are subject to deterioration over time due to the continuous use and exposure to deicing salts, vibration, humidity, temperature variations, etc. The closure of a bridge due to extensive damage or failure may affect millions of people monetarily, or even cause loss of life in some cases. Hence it is important to evaluate the condition of the structure in order to avoid any failure and plan maintenance actions without disrupting its operations [1]. Indonesia as an archipelago has a unique topography in the form of lands separated by waters and rivers. This condition makes Indonesia need bridges as one of the important infrastructures in supporting the economy in Indonesia [2]. Maintaining the safety and reliable service of a large bridge over its relatively long life requires obtaining continuous and reliable data regarding its structure, including the damage caused by the temperature
gradient, cracking, fatigue, corrosion, of structures and the decrease of load capacity of the bridge, etc. which all should be carefully evaluated [3]. Technology development is very fast and has been widely applied in various fields. In the field of telecommunications, for example, the speed of data access and information is now a mandatory requirement for every society of the country. Development of infrastructure development and public facilities have also started to utilize telecommunication technology, one of them in the monitoring system of infrastructure development. As mentioned in [4], modern health monitoring systems usually consist of six general components:

- Sensor systems and data acquisition;
- Communication system;
- Data processing and analysis system;
- Data storage;
- Diagnostics (e.g. damage detection and algorithm models);
- Retrieval of required information.

To overcome this, the Internet of Things (IoT) can be used, which would provide flexibility to monitor structures (building, bridge) from anywhere [5]. The IoT brings new opportunities for our society. Yet, most of the existing Structural Health Monitoring (SHM) systems are not connected to the IoT. SHM is a system to monitor the structural health of buildings and bridges [6]. With the advancement of modern technology, structures like buildings, bridges, etc. are getting structurally complicated, and safety has become an issue. Structural Health Monitoring (SHM) with the Internet of Things (IoT) can help improving security and safety [7]. In Bridge-based Wireless Monitoring Systems usually use WSN (Wireless Sensor Network) where WSN is a network consisting of node sensors equipped with equipment such as memory, processor, ADC, and batteries. The small form of WSN has the disadvantage of limited energy and bandwidth so that the right topology is needed [8].

Based on the planning guideline of Health Monitoring System of Bridge Structure of Kementrian Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia, this research focus on one of the main components needed for health monitoring system of the bridge structure, which is communication system. It is important to build a communication system that connected between sensors nodes are to be able to detect damage at each point of laying node sensor. Proposed method and devices are used to find the Quality of Service of the device itself to build WSN. Network analysis using QoS (Quality of Service) is defined as a mechanism or way that allows services to operate according to their own characteristics in the IP (Internet Protocol) network. Packet loss, delay, jitter, and throughput will be tested on this research as a measurement parameter of QoS. Data analysis that performed, will be compared with IEEE802.11b/g/n which is a standard provision of wireless networks. The network quality parameters generated from the node sensor network under test will be analyzed using QoS standards based on TIPHON.

2. Related works

In Satria et al. [9], experiments have been conducted using the MQTT protocol on Smart building. In the experiment parameter that used were delay, overhead, and packet loss. The experiment was conducted to find out Quality of Service (QoS) from MQTT. The virtual sensor was used to build a WSN based system. The experiment was done with change in the number of sensor used from 10, 100, and 1000. All of the data produce on the experiment was totally good with 0 packet loss, average overhead under 1 byte, and average delay under 1 second. Furthermore, on Wulandari [10] Quality of service analysis on internet network has been carried out at the UPT Loka Uji Teknik Pertambangan Jampang Kulon on the indoor area and provide a good result without any packet loss.

The great potential of Wireless Sensor Network is being seen in industrial, consumer and commercial application. The wireless technology is becoming one of the most prominent areas of research [11]. MQTT (Message Queue Telemetry Transport), an open protocol designed by IBM, was originally intended for unreliable networks with restricted resources such as low bandwidth and high-latency. MQTT consists of one broker server and two kinds of clients that are called Publisher (Publish client)
and Subscriber (Subscribe client). Broker server acts as an intermediary for messages sent between Publish client and Subscribe client for the interesting topic. When the Publish client issues a topic and sends a message to the Broker server, the Subscribe client selects the topics which it finds interesting [12].

3. Proposed methods
Based on the related works that have been described in this research, microcontroller that integrated with sensor was made, a system with accelerometer sensor and node MCU ESP8266 or called as node sensor. Node sensors are set to connect wirelessly and form a wireless sensor network. Furthermore, node sensors are set to connect with internet to upload the data on cloud which is form an Internet of Things (IoT) system using MQTT protocol. In this research, the experiment carried out on bridge to test network quality that produce from node sensor. The draft and general overview of the bridge monitoring system is shown on Figure 1.

![Figure 1. Design of SHM system.](image)

3.1. Hardware
This system works on several nodes connected to the sensor access point. At each node sensor, it consists of Node MCU that connected to the accelerometer sensor and forms the M2M (Machine to Machine) component. The accelerometer sensor is used as sensor data generator which can indicates that on the network that have been made using Node MCU and access point there is transmitted data. The data sensor that generated by the accelerometer sensor will be processed and transmitted via Node MCU which connected to the access point which will connect directly to the internet network. The data transmitted will directly uploaded to the cloud internet using MQTT protocol. Each node sensor placed at different places to generate different quality of network. The detail of node sensor can be seen on Figure 2.
The node sensors that are formed have several units: the microcontroller unit, the transceiver unit, the battery unit, and the sensor unit. This research uses Node MCU ESP8266 as microcontroller and also receiver device on node sensor. Node MCU ESP8266 already has a wireless module with Wi-Fi 802.11b/g/n, so it can directly transmit and receive data wirelessly. Node MCU ESP 8266 works at 32-bit resolution. In this paper, structural vibrations are sampled by accelerometer sensors. Accelerometer sensor used in this research is ADXL 345 which is has affordable price. In addition to low-cost but also has the low-power output of 3 axes X, Y, and Z with measuring range ± 16 g. The Node MCU and accelerometer work on a 3.3 volt. The sensor output of ADXL 345 is digital data. The minimum resolution that can be read by the accelerometer sensor is 4mg / LSB (Least Significant Bit).

3.2. Software

![Flow diagram of the proposed system](image-url)
3.3. QoS (Quality of Service)
Quality of Service referred to in this research is network quality parameter that becomes indicator which shows that node sensor has good or bad performance in producing quality network with a certain distance in the bridge monitoring system applications.

3.3.1. Packet loss

\[
PL = \frac{(\text{packet data sent} - \text{packet data received}) \times 100}{\text{Packet data sent}}
\]

Packet Loss is a parameter that describes a condition that shows the total number of packets lost. It can occur due to collision and congestion on the network and this affects all applications because retransmission will reduce the overall network efficiency even though the amount of bandwidth is sufficient for the application.

3.3.2. Delay/ Latency

\[
\text{Average Latency} = \frac{\text{total time to send packet}}{\text{total packet received}}
\]

Delay/latency is defined as the length of time required by the data packet to arrive at the destination. Latency is the time it takes data to travel from distance to destination. Latency can be affected by distance, physical media or long processing time.

3.3.3. Jitter

\[
\text{Jitter} = \frac{\text{Total Varian Delay}}{\text{total packet received}}
\]

Jitter is a variation of Delay, where there is a difference of delay in the packets sent in the same data flow stream. Jitter is commonly called delay variation, closely related to latency, indicating the amount of delay variation in data transmission on the network. Delay queue on the access point can cause jitter.

3.3.4. Throughput

\[
\text{Throughput} = \frac{\text{Packet data received}}{\text{Total time to send packet}}
\]

Throughput is the number of successful packets sent at certain time intervals. Measurement at throughput is by dividing the speed (rate) of effective data transfer with a certain time interval (s) and measured in units of bps (bits per second) and mbps (megabits per second).

This research purpose to determine the performance of Node MCU as microcontroller and transceiver at node sensor and also to know accelerometer acceleration sensor data can detect parameter change on bridge by using serial monitor and by using MQTT protocol. Testing is divided into two methods with point-to-point connectivity and with star topology with Line of Sight (LoS) condition. With applying star topology, expected to show network quality data generated when there are collisions and congestion of data that indicate by looking packet loss, delay, and jitter quality.

4. Results and data analysis

4.1. Using point-to-point connectivity

In the experiment, point-to-point network quality obtained by adjusting the distance at the node sensor and access point as far as 10 m, 20 m, 30 m, up to 100 meters on the overpass bridge which is a hollow concrete bridge type. In point-to-point testing, data retrieval is done with 2 different devices, using Node MCU ESP8266 as transmitter and Mi-Fi modem. The testing repeated 5 times to get valid result. On point-to-point connections require only one node sensor and access point only. Overpass bridge can be seen on Figure 4.
Here the result of the test that have been done by applying point-to-point connectivity, the data obtained can be seen on Table 1. Which is the result from using Node MCU ESP8266 device as access point, and Table 2. which is the result from using Mi-Fi device as access point. As mentioned before, the testing is done with Line of Sight.

Based on point-to-point connection using Node MCU ESP8266 as access point, at the farthest distance of testing the result of network quality that is not too bad. Based on TIPHON index, packet loss with percentage less than 25% included on average quality of network. Furthermore, the result of delay, jitter, and throughput is very good at all. But, there’s anomalies when tested at a distance of 60 meters to 70 meters. When testing at a distance of 60 meters and 70 meters, sometimes surge of packet loss occurs. The surge sometimes effecting the result of throughput and sometimes it works normally. The index for all network quality test system category are given as in appendix.

Overall, based on point-to-point connection using Mi-Fi as access point, the quality of network produced is better than using Node MCU ESP8266. The anomalies that occur on Node MCU test, also happened in testing using Mi-Fi but need to be considered on packet loss testing. When on 80 meters the quality of packet loss was increased, but the numbers of delay, jitter, and throughput constantly decreasing. From the result, it can be analyzed that Mi-Fi have the ability to reconnect quickly and the quality of the throughput will continue to constantly decreased. That affected by the distance that causes the delivery and receipt time to take longer time.

**Table 1.** The result of point-to-point connection (Node MCU ESP8266).

| Length (meters) | Packet Loss (%) | Delay (ms) | Jitter (ms) | Throughput (mbps) |
|-----------------|-----------------|------------|-------------|------------------|
| 10              | 0               | 1.188      | 0.008       | 4.843            |
| 20              | 0               | 1.92       | 0.015       | 5.632            |
| 30              | 0               | 2.006      | 0.019       | 4.005            |
| 40              | 0.4             | 2.704      | 0.200       | 4.603            |
| 50              | 2.8             | 3.454      | 0.577       | 1.97             |
| 60              | 6.8             | 4.893      | 0.757       | 1.8539           |
| 70              | 1.6             | 3.396      | 0.411       | 1.3801           |
| 80              | 2.4             | 3.363      | 0.304       | 1.5              |
| 90              | 12.4            | 4.033      | 0.713       | 1.5064           |
| 100             | 22              | 7.640      | 2.321       | 0.3986           |
| Length (meters) | Packet Loss (%) | Delay (ms) | Jitter (ms) | Throughput (mbps) |
|---------------|-----------------|------------|-------------|-------------------|
| 10            | 0               | 3.078      | 0.0054      | 10.381            |
| 20            | 0               | 3.742      | 0.0121      | 8.606             |
| 30            | 0               | 4.03       | 0.0621      | 6.94              |
| 40            | 0               | 4.384      | 0.0270      | 6.0278            |
| 50            | 2               | 4.289      | 0.0212      | 5.691             |
| 60            | 3.8             | 4.925      | 0.0474      | 2.737             |
| 70            | 4               | 4.879      | 0.0445      | 1.826             |
| 80            | 3               | 5.109      | 0.0905      | 1.2612            |
| 90            | 4               | 7.180      | 0.5036      | 0.6541            |
| 100           | 17.8            | 9.788      | 0.9577      | 0.4753            |

Based on the test data of connections that have been done, on each QoS parameters generated from both devices can be seen in Figure 5 until Figure 8.

4.2. Using star topology

In the test using a star topology, all of five node sensors are connected with one access point. Sensor nodes are placed in each different place, N1 at a distance 20 meters, N2 at a distance 40 meters, N3 at a distance 60 meters, N4 at a distance 80 meters, and N5 at a distance 100 meters. When applying star topology Mi-Fi is only the device that used for access point. That caused by Node MCU ESP8266 can’t
handle and serve more than 4 node sensors at the same time. Distribution of IP Address from each node sensors can be seen on Table 3.

Table 3. Address on each node sensor.

| Node Sensor | IP Address  |
|-------------|-------------|
| N1          | 192.168.1.102|
| N2          | 192.168.1.104|
| N3          | 192.168.1.103|
| N4          | 192.168.1.105|
| N5          | 192.168.1.101|

IP Address and placement of node sensors was doing in randomly. Node Sensors was turned on at the same time then get the IP Address by randomly and sequentially along with the connection of node sensors. Network quality that generated from this experiment can be seen on Table 4. And shown on Figure 10, until Figure 12.

Table 4. Network quality data on star topology.

| Node Sensor | Packet Loss (%) | Delay (ms)  | Jitter (ms) |
|-------------|-----------------|-------------|-------------|
| N1          | 3.8             | 7.026       | 0.25406     |
| N2          | 0               | 5.556       | 0.23274     |
| N3          | 9.2             | 6.61957     | 0.34254     |
| N4          | 22.4            | 7.32232     | 0.3688      |
| N5          | 2.4             | 6.77276     | 0.31191     |

When using star topology, packet loss value is not only affected by distance, but also the number of node sensors and the connected node sensor sequence proved by the packet loss of N5 is only 2.4% compared to the packet loss of N4 of 22.4%. Based on that, Mi-Fi modem still using the SISO system (Single Input Single Output) it is proven by looking on IP Address the data services run in alternating ways and the first connected priority. However, the overall value of the resulting network quality is quite good that is marked with a packet loss value of not more than 25%.

4.3. Sensor accelerometer

After performing the connection test, a sensor test is performed which becomes an indicator of the system that has been made to work optimally on the bridge monitoring system. The result of comparison of sensor data output between raw data and online data using MQTT protocol is very much different which can be seen in figure 9 until 11.

![Figure 9. Output data sensor of accelerometer axis X.](image-url)
Based on the test, MQTT protocol is very good at publishing and subscribing sensor data transmitted. But, MQTT protocol still unable to compensate for the very short vibration detection speed of the ADXL345 accelerometer sensor. There’s a big gap between serial data and online data. With the same setting that node sensor can take more than 100 data in one second to improve the detection of vibration, in serial data all of the data was recorded alternately between X, Y and Z axis. However, transmitting and uploading data to the cloud will certainly make this data can be subscribed and seen by anyone anywhere connected to the internet but it still not efficient for a sensor that produces data very quickly and very much.

5. Conclusion
On protocol MQTT, transmitting and uploading needs a time for the process that caused delay at the time of reading online data on MQTT Dashboard. In addition, sensor data requires ACK (acknowledgment) or the correction of the sensor data transmission process that has effect on the transmitted data does not collide and there is no error data but it will impact on the time required in the transmission of sensor data that will become progressively longer. Accelerometer sensor can offset and represent vibrations that occur on the bridge in the event of a vibration caused by a vehicle engine that occurs very briefly. Anyway, to build a health monitoring system on the bridge there are still complex problems. This research still has many limitations such as this research is only based on the point of view of telecommunications engineering without comparing with civil engineering data so that it is still not perfect to called as SHM. Need further research that comparing when it LoS (Line of Sight) and nLoS (non-Line of Sight) and also vibration sensor data itself. Furthermore, tests the quality of the network from the MQTT broker itself and radiation pattern are needed to find out more about the anomalies that happen on the bridge.
Acknowledgment
Thanks to Mr Sudarmono from Politeknik Negeri Semarang, for supporting and helping by giving the bridge prototype as the object of this project.

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