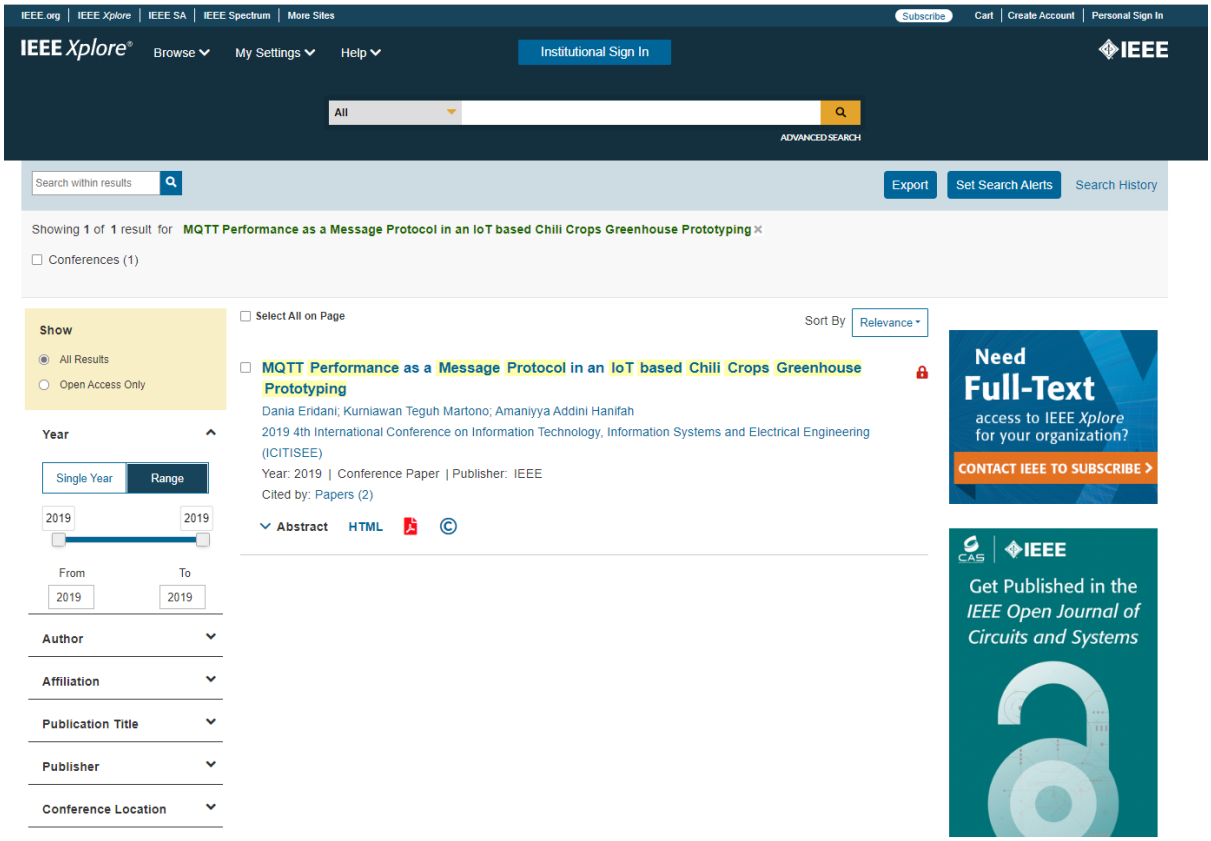
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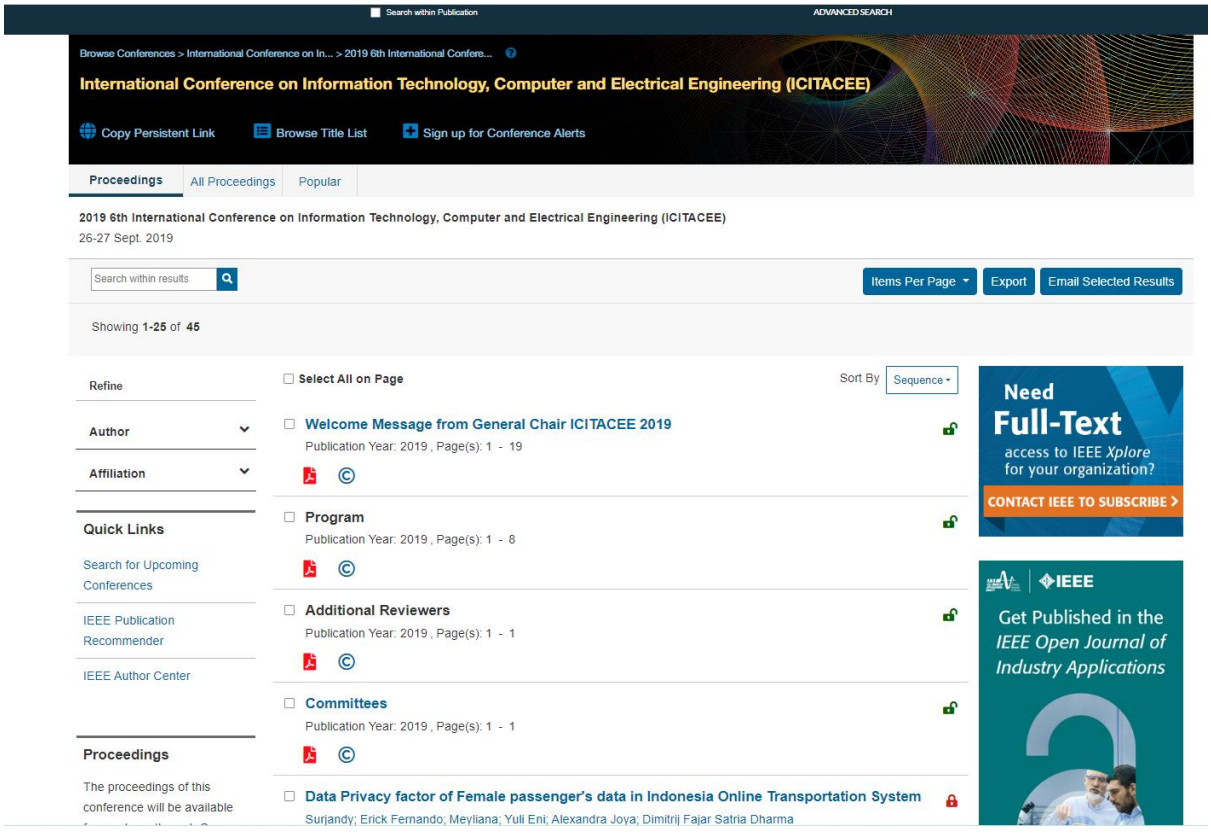
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# MQTT Performance as a Message Protocol in an IoT based Chili Crops Greenhouse Prototyping

1st Dania Eridani
*dept. of Computer Engineering*
*Diponegoro University*
Semarang, Indonesia
dania@ce.undip.ac.id

2nd Kurniawan Teguh Martono
*dept. of Computer Engineering*
*Diponegoro University*
Semarang, Indonesia
k.teguh.m@live.undip.ac.id

3rd Amaniyya Addini Hanifah
*dept. of Computer Engineering*
*Diponegoro University*
Semarang, Indonesia
amaniyya@gmail.com

***Abstract*—MQTT is an open source message protocol ideally used in machine-to-machine or Internet of Things. MQTT designed for limited devices, low bandwidth, and high latency system. MQTT provided with transmission assurance by using the QoS level in publish and subscribe mechanism. The aim of this research is to check the MQTT performance as an implementation of monitoring and controlling system. The system used in this research designed to be able to automate a greenhouse prototyping system and also to monitor and control greenhouses remotely. The case of this system is to automatically control and monitor chili crops in the greenhouse prototyping. This system used Wemos D1 R2 board as a control center, SHT11 sensor, YL-69 sensor, 16x2 LCD, RTC, relay, and Level-0 QoS MQTT communication protocol. The parameter used to check the MQTT performance are delay, throughput, and packet loss. The result showed that MQTT protocol is suitable for transmitting data in Internet of Things system. The average QoS parameter result changed based on the transmission speed in each network and the use of level 0 QoS on MQTT protocol.**

***Keywords— Greenhouse Prototyping, Internet of Things, Level 0 QoS, MQTT***

## I. INTRODUCTION

IoT or Internet of Things used to connect the real world physical devices. Many systems in various field built based on IoT. Application that often built using IoT is a monitoring and controlling system. IoT also support the monitoring and controlling system in agriculture, like greenhouse [1] [2]. Monitoring the vital parameter of greenhouse now is possibly done by building a monitoring system based on IoT [3] [4]. By using greenhouse, people can create the best environment to have plantation, people can monitoring and control the environment used for the plantation. The common parameters must be monitored in greenhouse system are temperature, humidity, soil moisture, light, and PH level. The parameters used varies depend on the crops planted in the greenhouse.

### *A. MQTT (Message Queuing Telemetry Transport)*

MQTT or Message Queuing Telemetry Transport is a message protocol that ideal for use in many situations such as for Machine to Machine (M2M) and Internet of Things (IoT) system [5]. MQTT use publish and subscribe mechanism to support data-centric communication. This publish and subscribe mechanism have been widely used due to scalability [6].

MQTT supports several level of Quality of Services (QoS) to ensure that all of the data published received, by using level QoS 0 (at most once), QoS 1 (at least once), and QoS 2 (exactly once). The higher the QoS level the higher of the complexity process [7]. MQTT better used to transfer sensors data, and it is enable to build a system on this protocol. Building a system using MQTT protocol also has advantages in mobile environment compare to the HTTP protocol. It is really possible to build a system in cellular network using MQTT protocol [8]. MQTT protocol also better than HTTP in QoS, faster response and throughput, security, and lower battery and bandwidth usage [5] [9] [10].

According to [11], there is a correlation between packet loss and delay to the QoS MQTT level used. The use of QoS level 2 produces the biggest delay compared to the other QoS levels, and the smallest delay results generated with the use of QoS level 0. Compare to the packet lost parameter, the smallest packet loss comes from QoS level 2 and the largest comes from QoS level 0.

There is also research that examines MQTT communication using NodeMCU board [12]. The research stated that the MQTT protocol is suitable for all cases defines above but speed of transfer information is less than the serial connection because it depends on the speed of Wi-Fi. It stated that this protocol never lost the data while it connected with Wi-Fi and it saves the data in a queue.

### *B. Wemos D1 R2*

Wemos D1 R2 is a microcontroller board based on ESP-8266 that integrated with Wi-Fi module. This board can be used to develop Internet of Things project. Wemos D1 R2 can be seen as in Fig. 1.

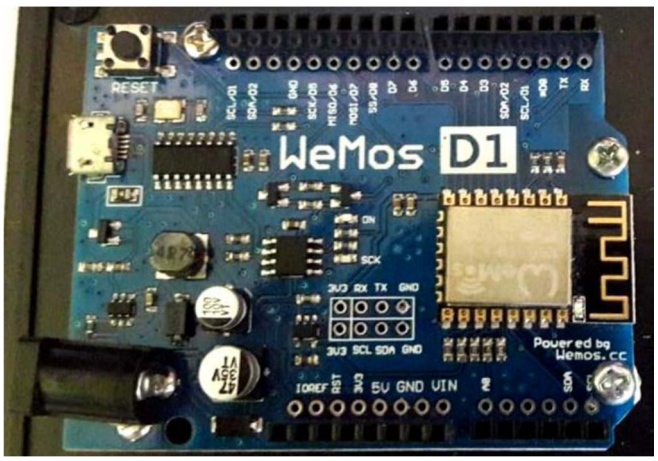


Fig. 1 WeMos D1 R2

Based on [13], Wemos using Tensilica L106 as the microcontroller integrated with ESP8266EX as a Wi-Fi module. It has 11 digital GPIO pin, 1 analog pin, 3.3V operational voltage and 68.6mm x 53.4mm board size. It also supported with flash memory and SRAM. As on [14], there are various others wireless development board that can be used to develop an IoT project as a comparison for Wemos D1 R2. It can be seen that Wemos D1 R2 also suitable to be used as an IoT project.

Based on the previous research, this paper contain the analysist of MQTT performance in the use of greenhouse monitoring and control system in various network bandwidth. The parameters used based on parameters suitable for developing chili crops. The MQTT implemented in Wemos D1 R2 board.

## II. Research Method

This research discuss the performance of MQTT protocol in Wemos D1 R2 board using delay, throughput, and packet loss as the parameters checked. The system used in this research designed to be able to automate a greenhouse prototyping and also to monitor and control greenhouses remotely. The case of this system is to automatically control and monitor chili crops in the greenhouse prototyping.

The method of this research consist of requirement analysist, hardware and software design, hardware and software implementation, and testing and analysist. The requirement analysist result are:

- The greenhouse prototype must be able to read all the parameter monitored.
- The greenhouse prototype must be able to put the data read by the sensors to display.
- The greenhouse prototype must be able to send all the parameters status using MQTT protocol to the MQTT broker.
- The greenhouse prototype must be able to read the message from the MQTT broker.
- The greenhouse prototype must be able automatically control the watering system, the plantation lamp, and the fan using the parameters read by the sensors.

The parameters used as a threshold in this system showed in Table I.

TABLE I. Chili Crops Parameters [15]

| ***Parameters*** | ***Threshold*** |
|---|---|
| Temperature | 25-27 $^0$C |
| Humidity | 60-80% RH |

Based on the result in [11], MQTT protocol used in this research is Mosquitto for broker and using Level 0 QoS for publish and subscribe mechanism. The QoS level 0 implemented in the system can be seen in Fig. 2. The design of the system used in this research shown in Fig. 3.

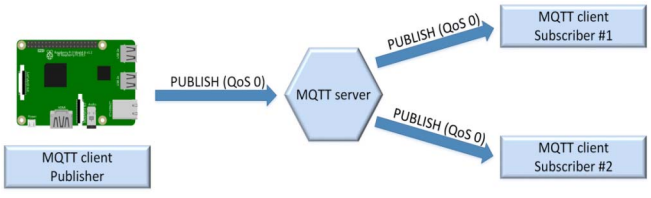


Fig. 2. QoS Level 0 mechanism [16]

The component used as the input to sense the temperature is SHT 11 and the humidity is YL-69. The component used as the output are water pump as the watering component, lamp and fan as the component to control the temperature, and LCD to display the status of the parameters controlled in the system. This method limited in making the greenhouse prototyping monitor and control system in one node only.

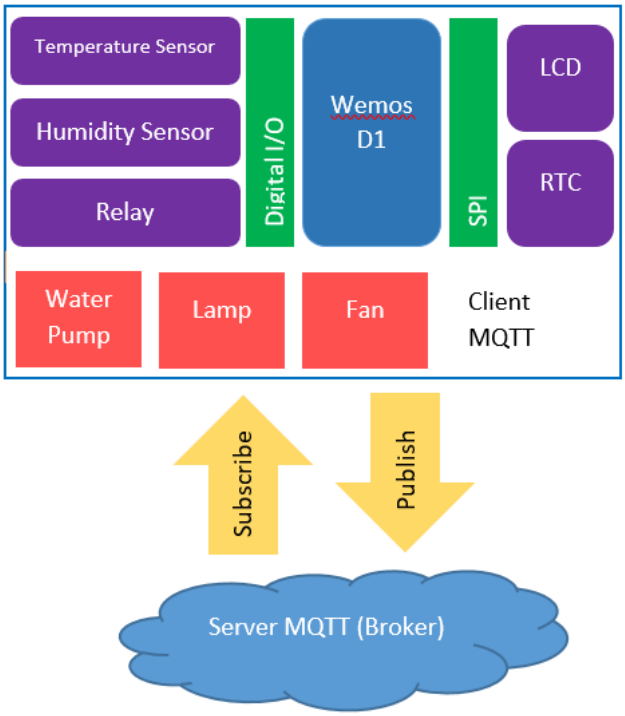


Fig. 3. System Design

Based on [11] to check the performance of MQTT protocol is done by comparing the the QoS parameter like delay and packet loss in the 3 QoS level of MQTT protocol. Here in this research, the testing mechanism method used is by checking the QoS parameter such as delay, throughput, and packet loss using only QoS level 0 on the system network to analyze MQTT performance in the various network bandwidth.

## III. Implementation

The components in the system united in a 68.6 mmX53.4 mm board using Wemos D1 R2 board as shown in Fig. 4. The board then connected to relay, sensors, adaptor, 16x2 LCD, and electric socket. The system then put in 300mmX200mm box as shown in Fig. 5

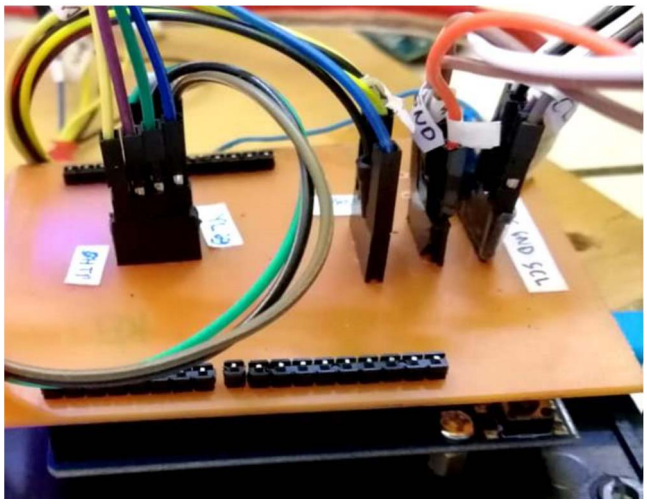

Fig. 4. System Board

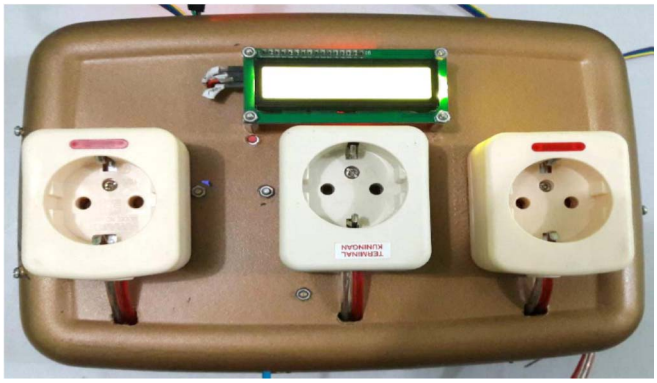

Fig. 5. System Box

After the implementation, the next step of this research is testing the MQTT QoS Level 0 by checking the delay, throughput, and packet loss as the MQTT performance parameters.

## IV. Testing and Analisyst

This test aims to determine the Quality of Service parameters of the MQTT used can run well. This system itself uses QoS MQTT level 0. This test done by sending and receiving several messages. The test done by using 3 different network specification. Network A has ± 6.64 Mbps download and ± 7.49 Mbps upload rates. Network B has ± 1.44 Mbps download and ± 4.21 Mbps upload rates. Network C has ± 4.71 Mbps download and ± 5.53 Mbps upload rates.

The test are carried out for 1 day per network and 10 sample data are taken for each message sent from the system to the broker (publish) and 10 sample data for each message received from the broker to the system (subscribe). Messages received and sent are 1 character or 8 bits.

### *A. Delay*

Delay is the time difference between the sending point to the receiving point. Delay obtained from the difference between the time messages sent and the time it received. Delay obtained from the time difference between the timestamp on the serial monitor and the MQTT server time. Table II-III are the result of the delay testing while publishing messages.

TABLE II. Result of Delay Parameter in Publish Testing using Network A

| No | *Timestamp* | *Server* | *Delay* (s) |
|---|---|---|---|
| 1 | 08:08:16.685 | 08:08:17.509 | 0,824 |
| 2 | 09:08:47.315 | 09:08:47.509 | 0,194 |
| 3 | 10:08:17.976 | 10:08:18.509 | 0,533 |
| 4 | 11:08:48.714 | 11:08:49.509 | 0,795 |
| 5 | 12:08:19.322 | 12:08:19.510 | 0,188 |
| 6 | 13:08:52.667 | 13:08:53.512 | 0,845 |
| 7 | 14:08:23.314 | 14:08:23.510 | 0,196 |
| 8 | 15:08:53.935 | 15:08:54.511 | 0,576 |
| 9 | 16:08:24.614 | 16:08:25.511 | 0,897 |
| 10 | 17:08:55.336 | 17:08:55.511 | 0,175 |

TABLE III. Result of Delay Parameter in Publish Testing using Network B

| No | *Timestamp* | *Server* | *Delay* (s) |
|---|---|---|---|
| 1 | 08:25:53.389 | 08:25:53.802 | 0,413 |
| 2 | 09:25:53.503 | 09:25:54.267 | 0,762 |
| 3 | 10:25:53.506 | 10:25:53.843 | 0,337 |
| 4 | 11:25:53.522 | 11:25:53.855 | 0,333 |
| 5 | 12:25:53.556 | 12:25:53.878 | 0,322 |
| 6 | 13:25:53.554 | 13:25:53.843 | 0,287 |
| 7 | 14:25:53.584 | 14:25:53.834 | 0,25 |
| 8 | 15:25:53.620 | 15:25:53.869 | 0,249 |
| 9 | 16:25:53.634 | 16:25:53.872 | 0,238 |
| 10 | 17:25:53.623 | 17:25:53.836 | 0,213 |

TABLE IV. Result of Delay Parameter in Publish Testing using Network C

| No | *Timestamp* | *Server* | *Delay* (s) |
|---|---|---|---|
| 1 | 08:13:51.719 | 08:13:51.972 | 0,253 |
| 2 | 09:13:51.738 | 09:13:52.051 | 0,313 |
| 3 | 10:13:51.775 | 10:13:52.044 | 0,269 |
| 4 | 11:13:51.811 | 11:13:52.045 | 0,234 |
| 5 | 12:13:51.831 | 12:13:52.117 | 0,281 |
| 6 | 13:13:51.857 | 13:13:52.137 | 0,28 |
| 7 | 14:13:51.892 | 14:13:52.171 | 0,279 |
| 8 | 15:13:51.927 | 15:13:52.289 | 0,362 |
| 9 | 16:13:51.960 | 16:13:52.298 | 0,338 |
| 10 | 17:13:51.991 | 17:13:52.262 | 0,271 |

The average delay generated during transmission (publish) on network A is 0.5223 seconds, on network B is 0.304 seconds, and on network C is 0.288 seconds. The delay comparison of publish testing between the 3 networks shown in Fig. 6.

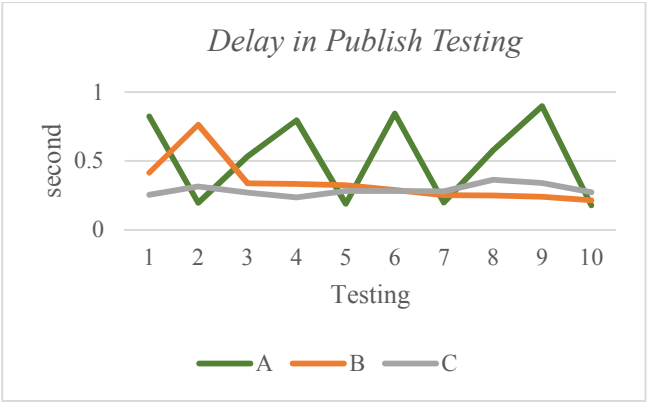


Fig. 6. Delay in Publish Testing

Table V-VII are the result of the delay testing while subscribing messages. The comparison of delay parameters on subscribe testing between the 3 networks shown in Fig. 7.

TABLE V. RESULT OF DELAY PARAMETER IN SUBSCRIBE TESTING USING NETWORK A

| No | *Timestamp* | *Server* | *Delay* (s) |
|---|---|---|---|
| 1 | 08:49:57.305 | 08:49:57.007 | 0,343 |
| 2 | 09:04:23.461 | 09:04:23.143 | 0,318 |
| 3 | 10:19:12.020 | 10:19:11.438 | 0,582 |
| 4 | 11:34:44.126 | 11:34:43.779 | 0,347 |
| 5 | 12:49:39.999 | 12:49:39.680 | 0,319 |
| 6 | 13:04:40.941 | 13:04:40.608 | 0,333 |
| 7 | 14:19:46.005 | 14:19:45.398 | 0,607 |
| 8 | 15:34:04.223 | 15:34:03.892 | 0,331 |
| 9 | 16:49:29.162 | 16:49:28.832 | 0,330 |
| 10 | 17:04:28.337 | 17:04:28.025 | 0,312 |

TABLE VI. RESULT OF DELAY PARAMETER IN SUBSCRIBE TESTING USING NETWORK B

| No | *Timestamp* | *Server* | *Delay* (s) |
|---|---|---|---|
| 1 | 06:26:14.029 | 06:26:13.678 | 0,351 |
| 2 | 07:34:35.036 | 07:34:34.699 | 0,337 |
| 3 | 08:38:36.457 | 08:38:36.112 | 0,345 |
| 4 | 09:44:51.613 | 09:44:51.335 | 0,278 |
| 5 | 10:04:41.233 | 10:04:40.875 | 0,385 |
| 6 | 11:06:58.266 | 11:06:58.008 | 0,258 |
| 7 | 12:08:18.023 | 12:08:17.745 | 0,278 |
| 8 | 13:13:08.859 | 13:13:08.587 | 0,272 |
| 9 | 14:13:13.624 | 14:13:13.332 | 0,292 |
| 10 | 15:14:05.707 | 15:14:05.340 | 0,367 |

TABLE VII. RESULT OF DELAY PARAMETER IN SUBSCRIBE TESTING USING NETWORK C

| No | *Timestamp* | *Server* | *Delay* (s) |
|---|---|---|---|
| 1 | 06:00:32.734 | 06:00:32.436 | 0,298 |
| 2 | 07:04:07.776 | 07:04:07.498 | 0,278 |
| 3 | 08:04:08.898 | 08:04:08.628 | 0,27 |
| 4 | 09:13:52.643 | 09:13:52.034 | 0,509 |
| 5 | 10:25:44.903 | 10:25:44.619 | 0,284 |
| 6 | 11:13:08.469 | 11:13:08.255 | 0,214 |
| 7 | 12:20:16.835 | 12:20:16.479 | 0,356 |
| 8 | 13:52:49.271 | 13:52:48.978 | 0,293 |
| 9 | 14:57:58.722 | 14:57:58.384 | 0,338 |
| 10 | 15:59:21.830 | 15:59:21.566 | 0,264 |

The average delay generated during transmission (subscribe) on network A is 0.3822 seconds, on network B is 0.3163 seconds, and on network C is 0.3104 seconds.

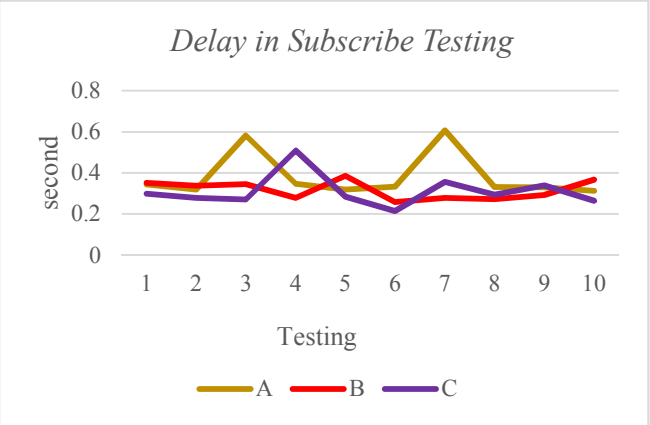


Fig. 7. Delay in Subscribe Testing

The test results found that the delay influenced by internet connections like download and upload speeds, it seen from the comparison of three different network speeds and the presence of outside interference can inhibit network connections in accordance with previous studies [12]. Delay time also influenced by the presence or absence of data that collides into or out of the broker or into the broker.

## *B. Throuhput*

Throughput is the average speed of data received by a node in a certain time interval. This throughput test conducted at the time of sending data and receiving data. Test sending messages (publish) and receiving data (subscribe) by sending each of 1 characters or 8 bits of message. Table VIII-X are the results of throughput testing while publishing messages.

TABLE VIII. RESULT OF THROUGHPUT PARAMETER IN PUBLISH TESTING USING NETWORK A

| *No* | *Message* | *Delivery Time (s)* | *Troughput (bit/s)* |
|---|---|---|---|
| 1 | 8 bit | 0,824 | 9,71 |
| 2 | 8 bit | 0,194 | 41,24 |
| 3 | 8 bit | 0,533 | 15,01 |
| 4 | 8 bit | 0,795 | 10,06 |
| 5 | 8 bit | 0,188 | 42,55 |
| 6 | 8 bit | 0,845 | 9,47 |
| 7 | 8 bit | 0,196 | 40,82 |
| 8 | 8 bit | 0,576 | 13,89 |
| 9 | 8 bit | 0,897 | 8,92 |
| 10 | 8 bit | 0,175 | 45,71 |

TABLE IX. RESULT OF THROUGHPUT PARAMETER IN PUBLISH TESTING USING NETWORK B

| *No* | *Message* | *Delivery Time (s)* | *Troughput (bit/s)* |
|---|---|---|---|
| 1 | 8 bit | 0,413 | 19,37 |
| 2 | 8 bit | 0,762 | 10,50 |
| 3 | 8 bit | 0,337 | 23,74 |
| 4 | 8 bit | 0,333 | 24,02 |
| 5 | 8 bit | 0,322 | 24,84 |
| 6 | 8 bit | 0,287 | 27,87 |

| | | | |
|---|---|---|---|
| 7 | 8 bit | 0,25 | 32,00 |
| 8 | 8 bit | 0,249 | 32,13 |
| 9 | 8 bit | 0,238 | 33,61 |
| 10 | 8 bit | 0,213 | 37,56 |

TABLE X. RESULT OF THROUGHPUT PARAMETER IN PUBLISH TESTING USING NETWORK C

| *No* | *Message* | *Delivery Time (s)* | *Troughput (bit/s)* |
|---|---|---|---|
| 1 | 8 bit | 0,253 | 31,62 |
| 2 | 8 bit | 0,313 | 25,56 |
| 3 | 8 bit | 0,269 | 29,74 |
| 4 | 8 bit | 0,234 | 34,19 |
| 5 | 8 bit | 0,281 | 28,47 |
| 6 | 8 bit | 0,28 | 28,57 |
| 7 | 8 bit | 0,279 | 28,67 |
| 8 | 8 bit | 0,362 | 22,10 |
| 9 | 8 bit | 0,338 | 23,67 |
| 10 | 8 bit | 0,271 | 29,52 |

From the results of throughput testing by sending data of 1 Byte or 8 bits, the average value of throughput on network A is 23.74 bps. The average throughput on network B is 26.57 bps. While on the network C, the average throughput value is 28.21 bps. The throughput comparison in publish testing shown in Fig. 8.

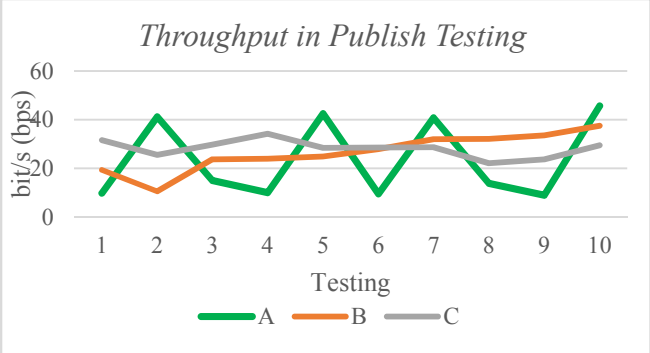


Fig. 8. Throughpit in Publish Testing

Table XI-XIII are the results of throughput testing while subscribing messages.

TABLE XI. RESULT OF THROUGHPUT PARAMETER IN SUBSCRIBE TESTING USING NETWORK A

| *No* | *Message* | *Delivery Time (s)* | *Troughput (bit/s)* |
|---|---|---|---|
| 1 | 8 bit | 0,343 | 23,32 |
| 2 | 8 bit | 0,318 | 25,16 |
| 3 | 8 bit | 0,582 | 13,75 |
| 4 | 8 bit | 0,347 | 23,05 |
| 5 | 8 bit | 0,319 | 25,08 |
| 6 | 8 bit | 0,333 | 24,02 |
| 7 | 8 bit | 0,607 | 13,18 |
| 8 | 8 bit | 0,331 | 24,17 |
| 9 | 8 bit | 0,33 | 24,24 |
| 10 | 8 bit | 0,312 | 25,64 |

TABLE XII. RESULT OF THROUGHPUT PARAMETER IN SUBSCRIBE TESTING USING NETWORK B

| *No* | *Message* | *Delivery Time (s)* | *Troughput (bit/s)* |
|---|---|---|---|
| 1 | 8 bit | 0,351 | 22,79 |
| 2 | 8 bit | 0,337 | 23,74 |
| 3 | 8 bit | 0,345 | 23,19 |
| 4 | 8 bit | 0,278 | 28,78 |
| 5 | 8 bit | 0,385 | 20,78 |
| 6 | 8 bit | 0,258 | 31,01 |
| 7 | 8 bit | 0,278 | 28,78 |
| 8 | 8 bit | 0,272 | 29,41 |
| 9 | 8 bit | 0,292 | 27,40 |
| 10 | 8 bit | 0,367 | 21,80 |

TABLE XIII. RESULT OF THROUGHPUT PARAMETER IN SUBSCRIBE TESTING USING NETWORK C

| *No* | *Message* | *Delivery Time (s)* | *Troughput (bit/s)* |
|---|---|---|---|
| 1 | 8 bit | 0,298 | 26,85 |
| 2 | 8 bit | 0,278 | 28,78 |
| 3 | 8 bit | 0,27 | 29,63 |
| 4 | 8 bit | 0,509 | 15,72 |
| 5 | 8 bit | 0,284 | 28,17 |
| 6 | 8 bit | 0,214 | 371,38 |
| 7 | 8 bit | 0,356 | 22,47 |
| 8 | 8 bit | 0,293 | 27,30 |
| 9 | 8 bit | 0,338 | 23,67 |
| 10 | 8 bit | 0,264 | 30,30 |

From the results of throughput testing by receiving 1 Byte or 8 bits data from MQTT broker, the average value of throughput on network A is 22.6 bps. Network B throughput is 25.77 bps. While on the network C, is 27.03 bps. The throughput comparison in Subscribe testing shown in Fig.9. The difference in the value of throughput at the time of publish and subscribe is due to the bandwidth of the download and upload speeds by the network connection and the amount of messages sent or received.

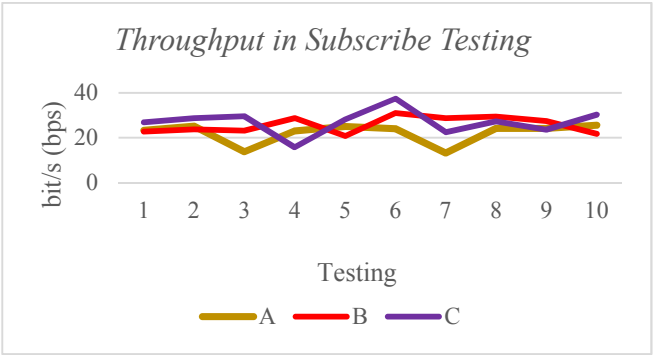


Fig. 9. Throughpit in Subscribe Testing

### C. Packet Loss

Packet loss is the number of packets lost in a data packet shipment. This time the test is done by sending a message to the broker (publish) and receive messages from the broker (subscribe) for 60 seconds in a row to flood the server. Table XIV is the result of packet loss testing.

TABLE XIV. RESULT OF PACKET LOSS PARAMETER IN PUBLISH AND SUBSCRIBE TESTING

| No | Type | Network | Duration (s) | Packet Send | Packet Received | *Packet loss* (%) |
|---|---|---|---|---|---|---|
| 1. | *Publish* | A | 60 | 208 | 206 | 3,33 |
| 2. | *Subscribe* | A | 60 | 129 | 124 | 8,33 |
| 3. | *Publish* | B | 60 | 356 | 352 | 6,67 |
| 4. | *Subscribe* | B | 60 | 486 | 481 | 8,33 |
| 5. | *Publish* | C | 60 | 449 | 448 | 1,67 |
| 6. | *Subscribe* | C | 60 | 171 | 162 | 15 |

From the test results obtained, the packet loss when publishing messages on network A has a ratio of 3.33%, on network B 8.33%, and on network C 1.67%. Whereas when subscribing to a message, packet loss is 8.33% on network A, on network B has a 8.33% packet loss ratio, and on network C is 15%. It can be seen from the results of research that the value of packet loss at the time of subscribe mechanism is greater than publish one. The result is quite different comparing to [12], which showed that there is any packet lost in the publish and subscribe mechanism done in MQTT protocol using HIveMQ that connected to WiFi. This possibly because of the system or microcontroller is executing other programs, so that there are packets that do not reach the system. This can also be due to network congestion. and at the using of QoS level 0, there is no guarantee the message will actually be sent.

## V. CONCLUSION

The use of MQTT protocol in chili crops greenhouse prototyping is able to send sensor readings to the MQTT broker so that they can be monitored remotely. It also able to receive control messages from the MQTT broker to activate the pump, fan and lights properly. Things that affect delay, throughput, and packet loss are the differences of internet connection, data transmission speed of each network and the characteristics of QoS level 0 on MQTT.

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