Multinode LoRa-MQTT of Design Architecture and Analyze Performance for Dual Protocol Network IoT

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***Abstract*—LoRaWAN networks and large places do not support Wi-Fi for multiple points. An architecture that offers dual networks to alter their supporting networks is needed for IoT device installation. The novelty in this research is that designing an architecture for multimode LoRa-MQTT with a mechanism for testing LoRa data transmission with different delays and Wireshark for testing Wi-Fi network QoS on MQTT is necessary. This hour-long LoRa network experiment shows that the End-Node can only receive one data at a time. One data set will be received if several data sets are obtained due to conflict. The second experiment showed data barely reached 70%. The signal strength or RSSI, and the node that sent the data initially decide the data received from a given node, some seconds apart, towards tested QOS with excellent packet loss, 21 ms delay, 50,616 bytes/s throughput, and 0.1426 jitter. Avoid data conflicts and loss by utilizing fewer nodes or adding end nodes in this experiment. The network service is excellent. According to this study, LoRa and MQTT can work well together. This approach could solve Internet of Things communication concerns, especially in large places that are LoRaWAN-inaccessible and Wi-Fi networks are limited.**

Keywords*—*LoRa; MQTT; multinode; QOS; LoRaWAN

I. Introduction

Improvements in telecommunications technology are currently developing rapidly, and new telecommunications systems are starting to emerge, such as the LoRa (Long Range) protocol [1]-[3] and also MQTT [4],[5], which are used in various fields. LoRa is currently believed to be a telecommunications technology that can be used for long-distance communications because LoRa uses CSS (Chirp Spread Spectrum) modulation technology [6], which makes it possible to send low-power and long-distance data. LoRa is often used in IoT (Internet of Things) devices [7]-[9] to send data from node to node. The advantage of LoRa is that it uses non-licensed frequencies such as the AS920-923 standard, which is the LoRa frequency standard in Asia ranging from 920MHz to 923MHz so that any user can freely use this frequency.

LoRa is a technology located at the physical layer network for limited node-to-node long-distance communication [10]. It cannot be used for open networks such as Wi-Fi or GSM [11], [12], which allows data to be sent to servers. An open network is important for the Internet of Things so that users can monitor or control IoT devices. So, LoRaWAN [13] is a solution because LoRaWAN works at the data link layer [14]. LoRaWAN allows IoT devices to send data to servers and already has been tested with a multi-client model [15]. However, the LoRaWAN network remains limited in its capabilities due to incomplete implementation across all sites, For the future, LoRaWAN must be able to be combined with cross-communication technology at different frequencies, for example at 2.4 GHz, with a large bandwidth it is possible to transfer data well such as traffic light data [16] which requires video in the data transmission process, and also Face Recognition [17] which is based on images. Some techniques such as doing split images when transmitting data are also still a challenge using LoRa's limited bandwidth. LoRaWAN Technology must also continue to be improved in terms of server security, for now, LoRaWAN Server uses AES [18] as server security, In the future, LoRaWAN technology will continue to be developed along with the development of telecommunication systems such as Lacuna Space which uses LPWAN Satellite LEO technology in its development.

Moreover, if the Internet of Things device is configured for the LoRaWAN network, this must be considered since it may provide difficulty. The site of the Internet of Things device installation lacks functionality for the LoRaWAN network. Moreover, such a broad area only facilitates the Wi-Fi network for many places. This research proposes a solution to the location issue that is incompatible with the LoRaWAN network. Moreover, a limited number of locations have Wi-Fi access. On the other hand, MQTT is usually used to communicate media of the Internet of Things. This solution is realized by integrating LoRa and MQTT to facilitate data transmission between the user and the server, or vice versa. Two communications are needed, namely LoRa and Wi-Fi [19], to send data to the MQTT broker.

The main contribution of this work is to demonstrate and analyze the LoRa-MQTT multi-node communication technology. In this research, the design of architecture LoRa-MQTT on multi-node IoT devices to send and receive data so that users can monitor data in real-time [20] and control [21] the devices installed on the IoT device. Apart from that, LoRa and Wi-Fi networks that use the MQTT protocol [22] will be analyzed using Wireshark [23] to determine the quality of service (QoS) [24]-[26] on the system. As a result, the percentage of end-node data reception sent by multi-nodes will be calculated later. Other than that, measurements will be taken of the data received by the MQTT Broker to know the system's reliability in the end.

II. Method and Architecture Design

This section presents the architectural design for multimode and end-node, an IoT device consisting of an ESP32 and LoRa microcontroller [27],[28]. Two programming settings are applied to each node, namely to send data from node to end node and receive data from end nodes. Likewise, the end-node has two settings, namely receiving from each node, then the end-node will publish the data to the MQTT-broker [29]-[31]. During the publishing process, the network will be tested using Wireshark to see the quality of service on the network. Quality of service consists of packet loss, the total number of packets lost from all the data left, as in Eq. (1). Then delay is the time required for data to cover the distance from origin to destination, as in Eq. (2). Next, throughput is the actual bandwidth measured in units. A specific time is used to transfer data of a certain size, such as Eq. (3) Jitter is a variation of delay caused by the queue length in data processing and reassembly of data packets at the end of transmission due to previous failures such as Eq.(4) Delay variations will refer to all samples in Wireshark. The second setting is to subscribe to data by the end node, and the end node will send the data to the node according to the address. As shown in the block diagram in Fig. 1. In carrying out the multi-communication technique of LoRa end-nodes, a method is needed so that there is no redundancy in transmission which causes packet errors [6] such as ADR, LBT, LR-FHSS, etc, This is an essential solution.

Furthermore, Eq. (1)-Eq. (4) are the basic formulas used in making the analysis in this research and finding the right results from the LoRaWAN analysis by comparing the theoretical and practical results so that it becomes the right solution during the process of transmitting data analysis.

$$Packet\ loss = \frac{(Packet\ transmitte - Packet\ Received)}{Packet\ transmitte} x100 \quad (1)$$

$$Delay = \frac{Total\ Delay}{Total\ Packets\ Received} \quad (2)$$

$$Throughput = \frac{Packet\ Received}{Time\ Transmitted} \quad (3)$$

$$Jitter = \frac{Total\ Delay\ Variation}{Total\ packets\ received - 1} \quad (4)$$

This research uses six nodes as IoT devices that will send data to the end nodes. Each node, including end nodes, has an address and channel, as shown in Fig. 1. The address of each node is different; each LoRa can be set using numbers ranging from 0 to 65535 and the same channel; this channel represents the frequency used. In this research, channel 72 is used, which represents the 922MHz frequency. Each node has the same program contents: the destination address, destination channel, and data. Data nodes consist of two types, namely analog data and digital data. Analog data represents data from sensors, and digital data represents data from actuators, which only consists of 1 and 0 or 1 for active and 0 for inactive. Address settings, channels, and examples of programming content, along with examples of data with semicolon separators sent by each node, can be seen in Table I.

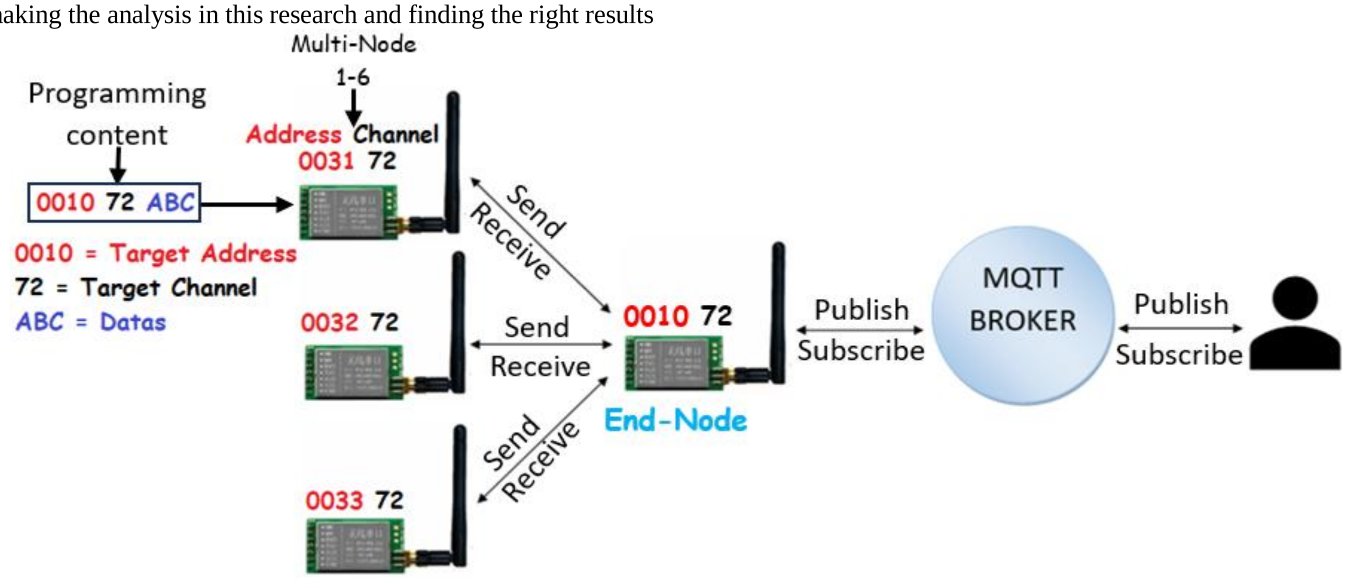

Fig. 1. The design architecture of multinode LoRa-MQTT.

TABLE I. CONFIGURATION OF LORA NODES

Node Name	Address	Channel	Target Address	Target Channel	Programming Content	Information
Node 1	31	72	10	72	0, 10, 72, 10;20;30	Key = 0 (NOT USE) Target Address=10 Target Channel=72 String Data = 10;20;30
			10	72		
Node 2	32	72	10	72		
			10	72		
Node 3	33	72	10	72		
			10	72		
Node 4	34	72	10	72		
			10	72		
Node 5	35	72	10	72		
			10	72		
Node 6	36	72	10	72		
			10	72		
End-Node	10	72	31, 32, 33, 34, 35. 36	72	From 10;20;30 to be [data1=10;data2=20;data3=30]	convert string data to JSON

The data flow process from multi-node to end-node to the user is as follows:

1) Data is sent from each node to the end node in the form of string data type using the LoRa network with 10 addresses and 72 channels or 922MHz frequency.

2) Then, the data will be converted into JSON from the end node.

3) Next, it is published to the MQTT Broker using a Wi-Fi network with the topic smartfarm/Address_Node/sensors with the information in Table III.

4) Users will subscribe to data from MQTT Broker on the same topic as number 3.

Next, the user process sends command data to move the actuator on the node as follows:

1) The user will send data in JSON form to the MQTT broker with the topic smartfarm/Address_Node/actuator with the information in Table III.

2) Then, subscribed by the end-node on the same topic as number 1.

3) Then, the end node converts the JSON data to String.

The end node sends data to the user's destination node according to the Addess_Node on the topic.

III. RESULT AND DISCUSSION

This section presents the results and analysis of several experiments, which are divided into two. The first is an analysis of LoRa communications, which explains the results of experiments sending data from multi-node to end-node with variations in delay, and the second is an analysis of the quality of service on Wi-Fi networks with the MQTT protocol using Wireshark.

A. LoRa Communication Analysis

Define abbreviations and acronyms the first time they are This section presents an analysis of the experiment of sending data from six nodes to the end node. Several experiments have been carried out, namely sending data simultaneously at one time and sending data with different time delay variations at each node, as in Table II and detail conflict in Table IV.

In the first experiment, each node sends data to the end node with the same delay, namely 1 second. Only node 1 is sent during the sending process, and only data from one node can be received. This is due to data reception conflicts with other nodes. The data received from a particular node depends on the node that sent the data first with a difference of a few seconds and the signal strength or RSSI (Receive Signal Strength Indicator), as shown in Fig. 2.

TABLE II. RESULT AND ANALYZES OF VARIATION DELAY FOR SENDING DATA

No Experiment	Delay settings	Information data received by the end-node					
		Node 1	Node 2	Node 3	Node 4	Node 5	Node 5
1	Node 1,2,3,4,5,6 = 1 second	Data Received	no data	no data	no data	no data	no data
2	Node 1 = 3 minutes Node 2 = 5 minutes Node 3 = 7 minutes Node 4 = 9 minutes Node 5 = 11 minutes Node 6 = 13 minutes	Data Received with note : Data reception conflict 13 times in 1 hour with other nodes	Data Received with note : Data reception conflict 6 times in 1 hour with other nodes	Data Received with note : Data reception conflict 3 times in 1 hour with other nodes	Data Received with note : Data reception conflict 7 times in 1 hour with other nodes	Data Received with note : Data reception conflict 2 times in 1 hour with other nodes	Data Received with note : Data reception conflict 1 times in 1 hour with other nodes
3	Node 1 = 13 minutes Node 2 = 14 minutes Node 3 = 15 minutes Node 4 = 16 minutes Node 5 = 17 minutes Node 6 = 18 minutes	Data Received with note : There is no conflict within 1 hour, but after more than 1 hour there will be a conflict in receiving data with other nodes					

TABLE III. MQTT TOPIC INFORMATION

No	Topic of MQTT	Information
1	smart farm/Address_Node/sensors	Topic for data from nodes (analog or digital data). If the data is from Address 30 then Address_Node=30
2	smart farm/Address_Node/Threshold	Topic for threshold data for sensor values to move actuators. If the data is from Address 30 then Address_Node=30
3	smart farm/Address_Node/actuator	Topic command data from the user. If the user's destination is address 30 then address_Node = 30

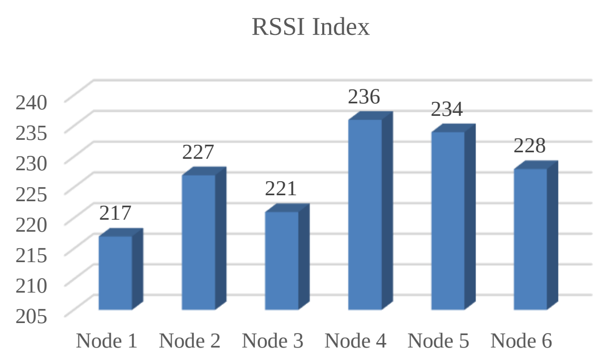

Fig. 2. RSSI Index from node 1 to node 6.

Each node was given different data transmission delay variations in the second experiment. Within 1 hour, there were quite frequent reception conflicts. The data received by the end node will depend on the split-second difference and RSSI. From the result of the experiment, using the Greatest Common Factor (GCF), can identify which nodes are going through conflict along with which minutes as shown in Table IV, and the percentage of receiving data is 70%.

In the third experiment, delay variations were given from node 1 to node 6, starting from 13 to 18 minutes. Within 1 hour of sending data to the end node, there was no conflict in receiving data; however, after more than 1 hour, there was a conflict in receiving data, and conflicts occurred more frequently over time because the time interval delay is much longer. This multi-node system cannot communicate data at the same time. To avoid conflict in the receiver, future studies can set each node to send data separately between milliseconds and seconds.

B. Analyzes Network of MQTT Protocol

Furthermore, when the end node receives data in the string type from each node, it will convert the string data into JSON and immediately send it to the MQTT Broker. This section will present network analysis with the MQTT protocol using Wireshark to capture network data with uplinks and downlinks, as in Table V. This experiment was carried out to see the network stress level by sending data every five seconds with a data load of 118 bytes. Then, the Wireshark capture results will be processed to produce Quality of Service as in Table VI, which consists of delay, throughput, packet loss, and jitter using Eq. (1) - Eq. (4).

Moreover, from the perspective of the ITU G.1010 standard, Table VI provides an overview of the quality of service on the network that was utilized to access the MQTT Broker on the smart farm server. Because there is no packet loss, the delay value in this table falls into the category of very good. This indicates that there is no loss of data during the transmission process from the end node to the MQTT Broker. After that, the delay is considered to be very good because it is still less than 150 milliseconds; this is because the network conditions are good and the weather conditions are sunny.

The next step in the research process is to conduct experiments with a variety of weather conditions to enhance the architectural architecture of the LoRa-MQTT protocol. Therefore, the jitter is satisfactory because it is less than 75 milliseconds; it would be ideal if the jitter were zero milliseconds. In addition to this, it is essential to conduct research with two end nodes for every six nodes to get a better understanding of the design and reduce the number of data conflicts.

TABLE IV. DETAIL CONFLICT OF NODE WITHIN 1 HOUR OBSERVATION

Number of Send Data	Node1 (3 min)	Node 2 (5 min)	Node 3 (7 min)	Node 4 (9 min)	Node 5 (11 min)	Node 6 (13 min)	Conflict
1							
2							
3	x						
4							
5		x					
6	x						
7			x				
8							
9	x			x			+
10		x					
11					x		
12	x						
13						x	
14			x				
15	x	x					+
16							
17							
18	x			x			+
19							
20		x					
21	x		x				+
22					x		
23							
24	x						
25		x					
26						x	
27	x			x			+
28			x				
29							
30	x	x					+
31							
32							
33	x				x		+
34							
35		x	x				+
36							
37							
38							
39	x					x	+
40		x					
41							
42	x		x				+
43							
44					x		
45	x	x		x			+
46							
47							
48	x						
49			x				

50		x					
51	x						
52						x	
53							
54	x			x			+
55		x			x		+
56			x				
57	x						
58							
59							
60	x	x					+
Total Data Sent	**20**	**12**	**8**	**6**	**5**	**4**	**55**
Total Data Receive	**39**						
Percentage of Receive	**7.090.909.091**						

C. *Analyzes Network of MQTT Protocol*

When the end node receives data in the string type from each node, it will convert the string data into JSON and immediately send it to the MQTT Broker. This section will present network analysis with the MQTT protocol using Wireshark to capture network data with uplinks and downlinks, as in Table V. This experiment was carried out to see the network stress level by sending data every five seconds with a data load of 118 bytes. Then, the Wireshark capture results will be processed to produce Quality of Service as in Table VI, which consists of delay, throughput, packet loss, and jitter using Eq. (1)-(4).

TABLE V. UPLINK AND DOWNLINK FROM ENDNODE TO MQTT BROKER SMARTFARM SERVER

No.	Time	Source	delay
1	18:42:26,477690000	10.72.0.121	00:00:05,044
2	18:42:31,521880000	10.72.0.121	00:00:05,004
3	18:42:36,526048000	10.72.0.121	00:00:05,049
4	18:42:41,574734000	10.72.0.121	00:00:05,067
5	18:42:46,641786000	10.72.0.121	00:00:05,046
6	18:42:51,687533000	10.72.0.121	00:00:05,061
7	18:42:56,749428000	10.72.0.121	00:00:05,023
8	18:43:01,772036000	10.72.0.121	00:00:05,068
9	18:43:06,839599000	10.72.0.121	00:00:05,025
10	18:43:11,864858000	10.72.0.121	00:00:05,068
11	18:43:16,932637000	10.72.0.121	00:00:05,052
12	18:43:21,985399000	10.72.0.121	00:00:05,018
13	18:43:27,002951000	10.72.0.121	00:00:05,004
14	18:43:32,007443000	10.72.0.121	00:00:05,050
15	18:43:37,057111000	10.72.0.121	00:00:05,008

TABLE VI. VALUE AND CATEGORY FOR PACKET LOSS, DELAY, THROUGHPUT, AND JITTER

	Packet Loss	Delay	Throughput	Jitter
Value	0%	21ms	50.616 bytes/s	0.1426ms
Category	Very Good	Very Good	No Category	Good

From the perspective of the ITU G.1010 standard, Table 6 provides an overview of the quality of service on the network that was utilized to access the MQTT Broker on the smartfarm server. Because there is no packet loss, the delay value in this table falls into the category of very good. This indicates that there is no loss of data during the transmission process from the end node to the MQTT Broker. After that, the delay is considered to be very good because it is still less than 150 milliseconds; this is because the network conditions are good and the weather conditions are sunny.

The next step in the research process is to conduct experiments with a variety of weather conditions to enhance the architectural architecture of the LoRa-MQTT protocol. Therefore, the jitter is satisfactory because it is less than 75 milliseconds; it would be ideal if the jitter were zero milliseconds. In addition to this, it is essential to conduct research with two end nodes for every six nodes to get a better understanding of the design and reduce the number of data conflicts.

IV. CONCLUSION

The issue is that the IoT device's location lacks compatibility with the LoRaWAN network, and extensive areas require Wi-Fi network connectivity for many position points. The research defines the multi-node LoRa-MQTT architecture and conducts a performance comparison of the two protocols. An experiment was conducted in the LoRa network to transmit data from six nodes to the end nodes with differing delays. The results of this experiment, conducted over one hour of observation, indicate that the End-Node can receive just one data packet at a time. If multiple data points are received, a conflict will occur, resulting in the reception of only one data point. The second trial revealed that the data obtained scarcely attained 70%. The data obtained from a certain node is contingent upon the initial node that transmitted the data, with a few seconds of interval, in addition to the signal strength or RSSI. The subsequent part of the research involves identifying a mechanism, modulation, adjustment of delay, or procedure that facilitates data transmission. Contemplate employing a queueing method. In the investigation of the MQTT protocol network, there is 0% packet loss classified as very excellent, a delay of 21ms also categorized as very good, a throughput of 50,616 bytes/s, and a jitter of 0.1426 classified as good. This study demonstrates that the integration of LoRa with the MQTT protocol can yield a highly successful solution. This concept can address Internet of Things obstacles, including communication problems in extensive platforms that lack LoRaWAN accessibility, with Wi-Fi networks available only at certain locations.

Future Research

LoRaWAN technology that is developing at this time, not only setting the Multi-Communication and transmission analysis process using MQTT but needs development from the Terrestrial Communication side to Non-Terrestrial Communication before data is received on the LoRaWAN Server. This is used in the future to reduce Packet Error and the presence of obstacles and Interferences.

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