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Experimental and Case studies of Long-distance Multi-hopping Data Transmission Techniques for Wildfire Sensors Using the LoRa-Based Mesh Sensor Network

Jarun Khonrang, Mingkwan Somphruek, Pairoj Duangnakhorn, Atikhom Siri, and Kamol Boonlom

***Abstract*—This study proposes the LoRa-Based Mesh Sensor Network without relying on LoRaWAN connection sending the communication data in the form of Star-to-Star, it can be sends the data in the form of peer-to-peer without the gateway. In the case that a longer distance is needed, the system is connected by a means of multi-hop presenting the hardware and software model through the use of low voltage power. Then, the testing is done using point to point and the received signal is measured by a gauge and compared with the model in accordance with the theoretical principle.**

***Keywords*—LoRa-Based Mesh Sensor; Wireless Internet of Things Technology (WIoT); Wildfire Sensor**

I. INTRODUCTION

NOWADAYS, Wireless Internet of Things (WIoT) [1][2] becomes an essential solution and widely used in society. Moreover, it is applied more and more in industry, commerce and customer service through collecting data from different instruments equipped in different points of the network. Thus, transmitting data in a long distance is quite limited from some instruments having the limitation of using the power and the law involving law enforcement. In the past, some kinds of technology could not respond to the use of long-distance data. Consequently, technology of Wireless Internet of Things (WIoT) [3] can send data in a long distance for many kilometers and consume low power such as technology of LoRa, LoRaWAN, SigFox and technology of NB-IoT [4][5]. However, LoRa Technology is a popular one as the reasons mentioned earlier. Above of all, it is an unlicensed technology which does not pay for the service resulting in the consumer's and the researcher's popularity.

LoRa technology is a physical layer working with chirp spread spectrum (CSS) radio modulation with integrated forward error correction (FEC) for enabling robust long-range communications on unlicensed industrial, scientific and medical (ISM) frequency bands. Therefore, LoRa has becomes a physical equipment which is widely accepted [8].

The LoRaWAN network consists of architectural components which are terminal gateway equipment and distant network server. All these components are connected to their data in topology form of star-of-stars type which the terminal equipment communicates with one gateway or more by LoRa as a physical layer. Also, in each gateway can send the frame of LoRaWAN to the server network using the backhaul interface type with higher-throughput such as WIFI or 5G network shown in Fig. 1. Then, the application connected to the server can make use of data collected at best.

One of the strongest limitations of LoRaWAN is topology which is permitted to communicate directly in the single-hop type between the terminal equipment and the gateway [5][6]. Furthermore, in the case that collecting or changing the data from remote area difficult to reach, this method is appropriate for the solution most.

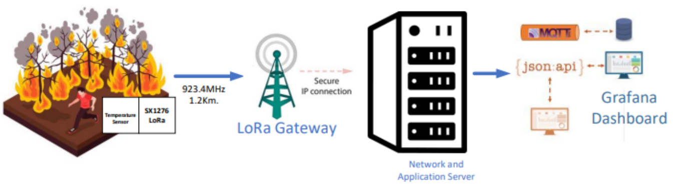

Fig. 1. Demonstrated an overview of the operation of a wildfire detection system based on LoRa technology

From the studies, it is clearly seen that the mesh network and multi-hop communication on LoRa architecture which the terminal equipment can function as a relay node to expand the network and improve the equipment's energy consumption [6][7]. It is still believed that this kind of development is in the middle stage which can be improved in the higher one and can take the advantage of the multi-hop communication on LoRa architecture to be applied for the sensor system or sending data in a remote location.

In this research, the studies of long-distance multi-hopping data transmission techniques for wildfire sensors using the LoRa-based mesh sensor network is applied in sending data but in a real situation the wildfire point is very far from the gateway area which is farther than 10 kilometers. This will have an effect on the sensor equipment which cannot send the data to the gateway and cannot cover the focused area in case of using star

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of stars topology network. Thus, choosing this approach may not be suitable but this problem can be eliminated when using topology model.

Multi-hop communication on LoRa architecture, generally called mesh topology can send data farther than before through multi-hop approach but it has the advantage of data propagation delay. However, this research presents a solution model consisted of LoRa software and hardware by installing three sensor nodes which can communicate in the form of peer-to-peer between the LoRa terminal equipment while still keeping the function of multi-hop and mesh network as mentioned earlier and then sending data to gateway consisting of Lora model which is connected to the internet network of WIFI technology [8][9]. The equipment used in this research was designed by choosing LoRa model from the producer which is Semtech No. SX1276 having working frequency area at 920-925MHz and the highest transmission power at +14dBm [10][11] connected to microcontroller processing unit, an 8-bit sized Arduino nano in reading the data value gained from the sensor metering the heat temperature from wild fire. However, from testing result, it showed the use of setting the signal transmission value of LoRa at different values such as modulating bandwidth of sending data will result in network coverage and data propagation delay.

II. Designed Research methodology

LoRa-Based Mesh and Multi-Hop Networking

Physical layer of LoRa has a parameter which can determine many of its values including FS, numbers of entering mistake codes, header types, preamble length and bandwidth [1]. As we know, LoRa radios can communicate in the form of point-to-point and can be used in LoRaWAN network which involves with the communication with centre- mixed station. In this study, the different ways on the construction of mesh network of LoRa node is claimed. This kind of network is a network communicating each other if being in a distance directly or indirectly through a middle node level. For example, if node 1 require to transmit a message to node 2 which is very long distances from node 2, the message will be controlled its way automatically via the middle node which is presumably a node 3. However, one of the first work pieces involves with the use of LoRa's capability in creating the general IoT mesh and multi-hop network claimed which is called LoRa blink having a protocol supporting multi-hop communication. The architect used is consisted of the nodes used many LoRa which sink each other. Then, the terminal end of the message is created from the node. This study shows that the packet delivery ratio that can be improved by the use of Mesh network which the star topology is basically considered.

Analysis of LoRa propagation in rural environment

Environment is another factor should be considered since the path loss, the shadowing and the multipath fading are parameters important for the characteristics of the signal channel of wireless communication system. Thus, in the rural environment, the environment of the rural areas surrounded by forest has the feature of shadowing and multipath fading which has a great effect on the propagation performance of the radio link. From the analysis of the propagation performance in the rural areas having a forest may have an effect on the distance and the signal level receiving. By a parameter indicating PT which is the power of transmission by the signal instrument while GT and GR are the rate of signal expansion of the antenna both sides; a transmitter and a receiver, and LP is the path loss attenuation, PR is the received power by the value of PR can be calculated from equation (1).

$$P_R\big|_{dBm} = P_T\big|_{dBm} + G_T\big|_{dB} + G_R\big|_{dB} - L_P\big|_{dB} \quad (1)$$

In general, there are no specific path loss models for LoRa technology used to estimate the value of . However, $L_P\big|_{dB}$ there are many evidently simulated propagation models gained from measuring by using different standards and frequencies, and in different propagation conditions. Some people use them for frequency area accepted for LoRa in Europe, for example, Erceg model which can be used with the expected result in order to compare with the experiment measurement in different distance of 100 meters [2]. However, Erceg model will sometimes evaluate the distance too high in urban environment. In terms of simulated Lee propagation model, it can be applied both area-to-area model and point-to-point model. The enforcement of Lee's propagation model [3] is efficient which will occur immediately when the suitable variable is determined for each city. In Thailand, particularly, cities in remote areas are different from the cities which Lee's propagation model designs will not have a correlation value for Lee's simulation model. When managing the signal transmission between 100 to 1,500 MHz in urban area in the evident form of Okumura-Hata (O-H) model [3] is particularly developed for the wireless system which can be used to communicate in the environment by the path loss L_P can be assessed as equation (2) [4].

$$\begin{aligned} L_P\big|_{dB} = {} & 69.55 + 26.16\log_{10} f + \\ & \left(-13.82\log_{10} h_T - a(h_R)\right) + \\ & \left(44.9 - 6.55\log_{10} h_T\right)\log_{10} d \end{aligned} \quad (2)$$

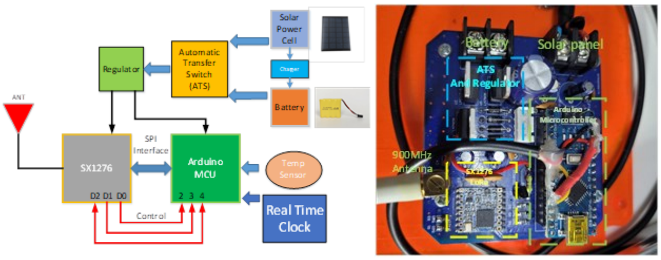
By knowing that operating frequency (f) which is the MHz high of the transmitter and the receiver: hT and hR showing its unit in meter and the distance between the transmitter and the receiver showing its unit in kilometer by the correction parameter occurs from the area type and considers its value from equation (3) [4].

$$a(h_R) = 3.2\left[\log_{10}(11.75 . h_R)\right]^2 - 4.97 \quad (3)$$

III. The experiment and the measurement

Hardware Equipment and Transmission Setups

The node equipment of sensor metering the heat temperature from wild fire is consisted of the microcontroller, sized 8 bits connected to SPI interphase and LoRa model No. SX1276 which works as a wireless LoRa model transmitting and receiving distant data with frequency 920-925 MHz and in the permitted areas in Thailand as determined by the National Broadcasting and Telecommunication Commission (NBTC). Its transmission power is +14dBm or 25 mill watt and the microcontroller is connected to an infrared IR thermocouple to check the heat occurring when the wild fire happens and the power distribution system from the solar cell in the form of direct current (D.C.) with 12 volts and 5 Watts and the storage battery with 12 volts and 8 Amperes. Then, this system is connected to micro grid system in choosing the distribution source automatically, distributing the power to the microcontroller and LoRa Sx1276 module and coming along with the battery management circuit which is easier when working with LoRa as shown in Fig. 2a and Fig. 2b.



(a) (b)

Fig.2. Design micro grid system (a) the diagram block of a sensor metering the heat temperature from wild fire (b) the real- built circuit of a sensor metering the heat from wild fire.

Moreover, the designed board is suitable for Mesh network due to its better calculation from Arduino nano which supports the small calculation while consuming very low energy. The efficiency of CPU will come along with RISC architecture with 2Kbytes internal SRAM and 32K bytes of in-system self-programmable flash program memory. The LoRa module will have library Radiohead supporting the value setting of several signal transmissions on SX1276 which is different in bandwidth (BW), coding rate (CR) and spreading factor (SF) which CR means the proportion of bit transmitting the real data and SF means number of bits per signal while BW means the differences between above and under the frequency occupied by the chirp. In terms of spread-spectrum modulation technique, Chirp is a sign signal having the increasing frequency when the time is over.

The setting of measurement value is created by one receiver and more than one signal transmitters according to different tests as shown in Fig 3. The heat sensor metering node from wild fire is consisted of the same instruments including microcontroller with the same bit number which are Arduino nano and LoRa module No. SX1276 connected to the monopole-typed antenna with the signal expansion rate G=3.16dB Satel ISM antenna 900MHz model. At the same time, the software for testing each time is developed by Arduino IDE.

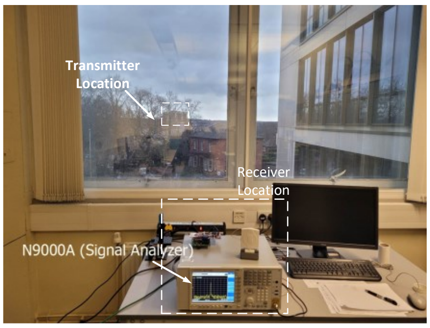


Fig.3. Showing the measurement of the signal level testing of the LoRa module via spectrum analyzer between TX location and RX location.

TABLE I
SHOWING THE DETERMINATION OF PARAMETER FOR LORA MODULE IN TESTING THE MEASUREMENT BY SPECTRUM ANALYZER

LoRa Module SX1276 Configuration	Transmitted power (Tx power, dBm)	14 dBm
	spreading factor (SF)	10
	Bandwidth (BW, kHz)	125 kHz
	Frequency (MHz)	923.2 MHz
	Antennas gain (dBi)	3.16 dBi
Spectrum Analyzer Configuration	Center frequency (CF,MHz)	923 MHz
	Resolution bandwidth (RBW,kHz)	10 kHz
	Video bandwidth (VBW,kHz)	30 kHz
	Sweep time(ms)	5 ms
	Span(kHz)	500 kHz

In basic testing, the installation of the stable-typed measurement by the signal staying at the stable position and the receiver at different positions of the sensor node at point 1,2 and 3 respectively as shown in Fig 4.

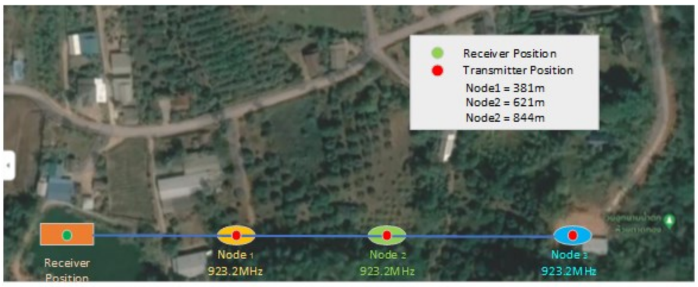


Fig.4. Showing the position of the transmitter node1, node 2 and node 3 respectively, and RX receiver with the correlative distance for point-to-point measurement.

The distance between the transmitter and the receiver is 381 meters for the Node1 about 621 meters for Node 2 and 844 meters for Node 3 while the receiver is placed at the height of 30 meters from the ground. For all positions, the transmitter is located at the same eye sight level to the receiver. The distance between the transmitter and the receiver is equivalent to the highest distance between two nodes of network which is difficult to be used in the rural areas.

The receiver module is programed in order to give data beneficial to the signal quality consisted of receiving the signal strength of the indicator (RSSI) of the package, the ratio of signal to disturbing signal (SNR) and the mean of the signal strength indicator receiving. The analyzed data is consisted of a block of 1,000 packages and the position of the signal transmitter, the value setting and the value setting for the receiver and the transmitter shown in Table uI.

The measurement result is compared with the theorical efficiency gained from Okumura-Hata model shown in Table II.

TABLE II
SHOWING THE COMPARISON RESULT WITH THE THEORICAL EFFICIENCY GAINED FROM OKUMURA-HATA MODEL

Transmitter Position	Node1	Node2	Node3
Distance (m)	381	621	844
Signal to Noise Ratio (SNR) (dB)	1	-1	-6
Received Signal Strength Indicator (RSSI) (dB)	-92	-112	-120
Receiver Power (dBm)	-93	-103	-116
Okamuru-Hata Rx power (dBm)	-88	-97	-103

From measurement testing, the possibility of measuring the negative value of SNR is done when the signal power level is lower than the disturbing sound according to the LoRa determination by the negative value for SNR indicating the ability in receiving the power signal which is lower than the receiver noise floor. This can occur when the range of the communication distance is too far from each other or having the high disturbing signal because the outside environment is the main factor to cause this problem. In terms of RSSI package, the value decreases as expected when the distance has the increasing value. However, most of the packages received are correct. In reality, from the distance of Node 1 and Node 2, the RSSI value is in a higher level than the SX1276 module determination which is able to receive the packet data correctly whereas Node 3 has the distance more than 800 meters causing the package to have the losing rate more than other nodes because the RSSI value is very low and sometimes the data reverse is lower than the determination of SX1276 module.

The total value of the receiving power from the receiver is compared with the theorical value O-H model appeared at the end of Table II. Thus, it is clearly seen that the power value gained is higher than all measured values which had been done before. This is because the simulated model has not been yet developed but just considering the feature of the CSS modulation which is used for LoRa. Moreover, in this study, point-to-point connection in O-H model does not consider the wave reflection occurring from the environment.

The next experiment is the delivery time assessment evaluated in the laboratory. In case of single or two-hop communication model of LoRa-based mesh network as shown in Table 3. This study shows the parameter value, Bandwidth frequency and SF (spreading factor) value which has different values and in every case the CR value is set at 4/5 whereas BW and SF values are different. Setting the values of signal transmission may be chosen by BW and SF. This study chooses the best possibility as shown in Table III.

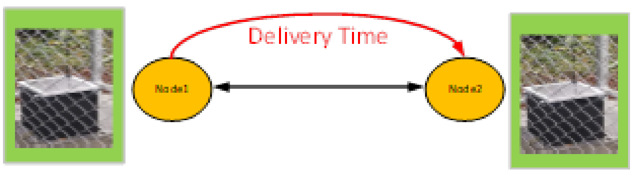


Fig.5. Single-hop delivery time

TABLE III
SETTING THE VALUES OF TRANSMISSION AND DELIVERY TIME FOR SINGLE – HOB COMMUNICATION BETWEEN NODE CENTER POINT 1 AND NODE CENTER POINT 2 AS SHOWN IN FIG.5, AND TWO-HOP BETWEEN NODE CENTER POINT 1 AND NODE CENTER POINT 3 AS SHOWN IN FIG.6

			Delivery Time (ms)	
transmitting configuration	BW (kHz)	SF	Single-hop	Two-hop
Maximum Band	250	7	495 ± 87	835 ± 103
Medium_LSF	125	7	649 ± 196	1,334 ± 424
Medium_HSF	125	10	5,329 ± 51	10,746 ± 85
Minimum Band	56	10	6,692 ± 85	13,410 ± 223

In the experiment, setting the value each time can evaluate the delivery time value. When sending the data having payload, size 240 bites and the highest payload value which SX1276 receiver and transmitter modules can be done at 255 bites which is a 4 bite- Radiohead header. The maximum payload which can be transmitted is 251 bites. It can choose the small-sized message which is 240 bites and when the Radiohead header is included the total size is 244 bites. However, for sure, Radiohead header can be checked and can increase at the maximum of 11 bites. In case, it is needed to enter the payload code, although this part is not used in the experiment but it is needed just in the case that the message size cannot avoid leading to the single-way signal transmission as shown in Fig.5 and Fig.6 which show the setting network value having the three highest nodes; node 1, node 2 and node 3 respectively of LoRa-based mesh which are considered in single-hop and two-hop communication models as shown in the Fig.6. In case of two-hop communication, node 2 can determine correctly the route of sending and receiving data between node 1 and node 3. The delivery time calculation means the difference between the last bite time of the message. It can be explained in details that node 2 or node 3 (depending on testing) is at application and time when application class at node 1 sends out the message, it is sure that the clock time of node is synchronized but propagation times are not important.

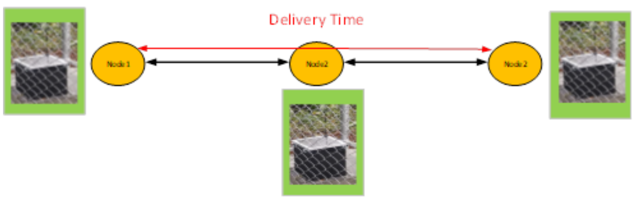


Fig.6. Two-hop delivery time

From the experiment result in Table 3, the delivery time value having the mean and the validity values at 95%. It shows that the SF value plays an important role when the more the SF is higher the more the delivery time is. Considering in other important values, the delivery time value of two-hop communication is about two times of single–hop communication which means that in over all the delivery time value is occupied by the required value in sending and receiving through LoRa module. It is estimated that how many delivery times in the case of m-hop and m>2 in single-hop communication.

In the experiment, the delivery time values are calculated for single-hop communication and two-hop one, and for the highest efficiency of the distance from 200 meters to 1,200 meters as shown in Fig.7 which shows the environment through the satellite of Google Maps used in testing all transmission value settings. From the experiment result in Fig.8, it indicates that the setting of transmission values leads to testing the different single-hop communications. The change of the communication efficiency and the delivery time can be seen from Fig.3, for example, Maximum Band for delivery times has the time period at around 500 ms but the communication value decreases rapidly (less than 0.5 after 300 meters). It seems that the best efficiency testing is Medium HSF having the efficiency more than 0.9 at 800 meters and the delivery time value is 5.3 seconds but it still depends on the feature of the application. Thus, it can be concluded that whenever the bandwidth is increased which is compared with SF (spreading factor). As a result, the delivery time value used in data transmission decreases while the transmission distance has more values. However, when bandwidth is made narrower which can see from a case study of Minimum band with bandwidth size 56 kHz and having SF (spreading factor) at 10, the highest distance is 1.2 kilometers while the delivery time value has its value more than 80 seconds which the difference is clearly seen. At the same time, when increasing the number of nodes to two-hop, it can be clearly seen that the delivery times are twice as high as compared to single-hop communication shown as Fig.9 and Fig.10. Moreover, the Fig.11 illustrate the wildfire temperature sensor was installed in the location test also Fig.12 shows the LoRa gateway device used in the research.

Fig.7. The testing place for calculating the delivery time value.

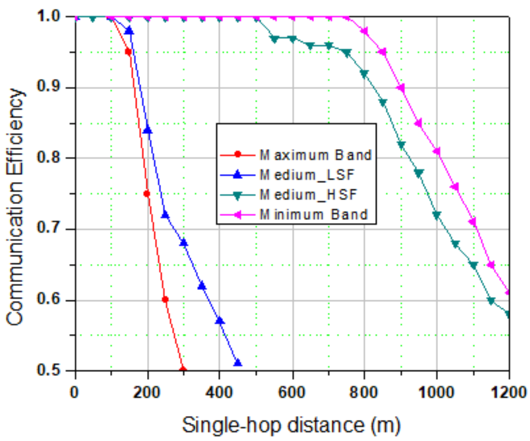


Fig.8. Show the efficiency of Single-hop communication in different distance.

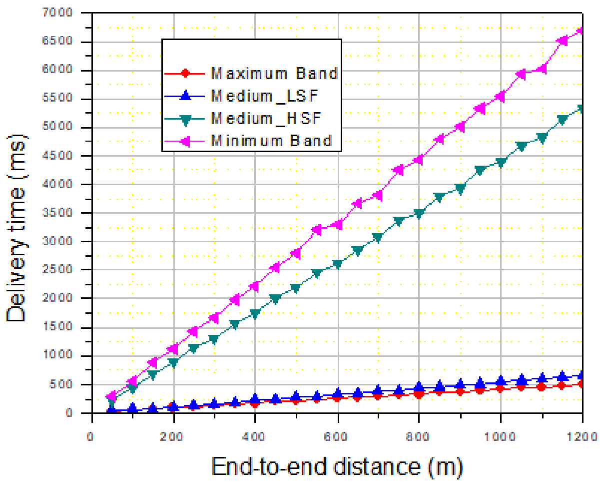


Fig 9. Showing the delivery time value of the single-hop communication in different distances.

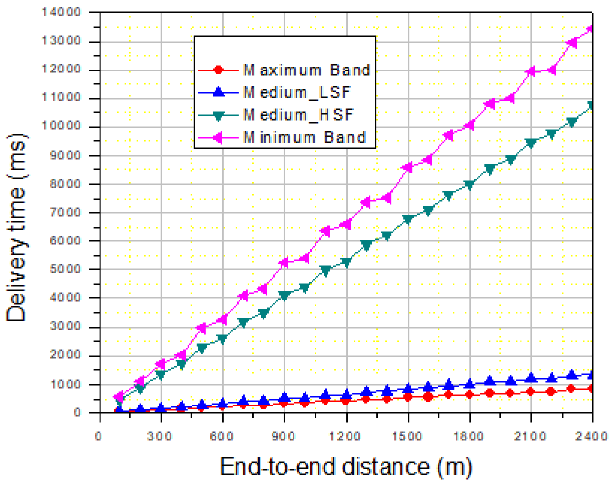


Fig.10. Showing delivery time value of the two-hop communication model in different distances

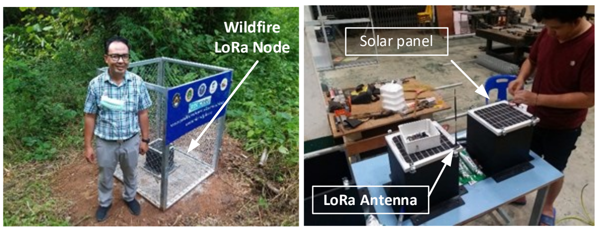


Fig.11. Showing the sensor instrument metering the heat from wild fire which is equipped for testing the heat from wild fire.

Fig.12. Illustrates the LoRa wildfire gateway which is located in Maechan districts.

IV. Conclusion and Discussion

LoRa technology is wireless technology which can send data in a distance and consumes low energy although it sends the data with low data transmission rate. This study explains the testing of the point-point propagation and the ability of the data receiving system both receiving power and package error rate in the distance 800 meters. This indicates that LoRa can be used in the environment having signal disturbance in a countryside or in a forest area. Simultaneously, the data transmission of single-hob LoRa is tested in order to evaluate the communication efficiency value of the system by adjusting bandwidth frequency value and SF value. From the experiment it can be concluded that when bandwidth data is increased whereas the SF value is low the distance gained is short which is around 300 meters while delivery value is around 500 meters. Meanwhile the bandwidth size is made narrower and SF value is made higher, the highest distance gained is 1200 meters while the delivery time value is low which is around 6692 meters. At the same time, when the bandwidth is made narrow but the SF value is high. When two-hop communication is experimented in different distances in order to test its efficiency, the delivery time value is at 835 meters and bandwidth frequency at 250 kHz followed by the lowest frequency bandwidth at 56 kHz having delivery time value at 13,410ms.

From the experiment, it showed that the design and construction which connects to LoRa technology of Mesh Sensor Network to sensor the heat from wild fire cannot connect to Star-to-Star as the distance in the forest is too far to send the data. Thus, two-hop module is efficiently applied for data transmission, environment and industry in the future.

V. Recommendations from this Study

From the design and the experiment on status data transmission of metering sensor the heat from wild fire through LoRa-Based Mesh Sensor Network, although it is beneficial to the application in increasing the more distance of sending the data when compared with Star-to-Star module but the researcher can see some points to be developed for its efficiency in transmitting the data through LoRa-Based Mesh Sensor Network as two reasons.

1. Whenever the more distance is needed, the system has to increase more transmission power but LoRa module has its limitations in sending data not more+20dBm. Thus, to increase the transmission power rate by increasing the antenna expansion rate higher which can make the sensor node receives and transmits the data better, for instance, the researcher chooses the Monopole antenna with the signal expansion rate at 3dBi, if the expansion rate of the antenna with size 6dBi is increased, the power value is two times gained as a theory.

2. The placing position of the sensor node is the main part to the data transmission distance. If the installation has the problems with the waves, for example, thick forest can reduce the signals and the distance gained will be reduced. Therefore, in installation, the appropriate position is considered. Another point is that the choosing of bandwidth frequency is important in sending the data if we need to send the data farther, the bandwidth chosen is made narrower which may result in delivery time value higher even though delivery time is not the main part.

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