# Enhancement of Packet Delivery Ratio during Rain Attenuation for Long Range Technology

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***Abstract*—Countries with tropical climates experience various weather changes throughout the year. The weather can drastically change from extremely hot and humid to a complete downpour in a twenty-four-hour cycle. Different atmospheric conditions such as atmospheric gas attenuation, cloud attenuation, and rain attenuation can cause interruption of electromagnetic signals and weaken the radio signals. The amount of attenuation is mostly depending on the raindrops. Rate of attenuation by rain depends on the composition, temperature, orientation, shape and fall velocity of raindrops. In this paper, we measure the effect of different atmospheric attenuations, particularly due to rain for non-line-of-sight environments and proposed a LoRa (Long Range) based wireless mesh network to enhance packet delivery ratio (PDR). We experimented with the LoRa based wireless network by taking the packet delivery ratio at different times of the day when there was no rain and performed some experiments while raining. The experiments conclude that PDR is affected by different volumes of rain where PDR decreases significantly from 100% when it was not raining and decreases to 89.5% when it rains. The results also show that the LoRa device can successfully transmit up to 1.7km in a line-of-sight environment and around 1.3km in a non-line-of-sight environment without rain. The results show the effect of atmospheric attenuation to LoRa wireless network and become a consideration factor when designing any LoRa applications for outdoor deployment.**

***Keywords—LoRa; packet delivery ratio; wireless mesh network; atmospheric attenuation; rain attenuation***

## I. Introduction

Internet of Things (IoT) is a fast-growing communication model to connect millions of devices to make our everyday life easier. IoT is related to sensors, wireless technology, cloud server services and possibly the applications. The main function of IoT is to identify each object digitally. An IoT system consists of processors, sensors, and communication of hardware collection. IoT devices connect to other devices or IoT gateway to collect the sensor data and act on the information they receive. In this present world, IoT is related to consumer segment, wearable devices, health care, smart buildings, smart city, and agriculture. It is expected that there will be 50.1 billion users of IoT by the year of 2020[1]. Bluetooth, WiFi, and Zigbee are the wireless communication technology that allows devices to transmit data wirelessly in a short-range compared to LoRa technology for a longer range [2-3]. LoRa uses low power consumption and highly secured data transmission [4]. Lora WAN is based on the low power wide area network (LPWAN) protocol. In LoRa technology, LoRa enables the connection between the end device and LPWAN to deliver data. LoRa offers to compile features for IoT applications. This technology can utilize in public, private and hybrid networks. Key features of LoRa technology are long-range, low power, secured data transmission, high capacity and low cost [5]. It is also easy to install, extremely economical and very flexible to implement. LoRa uses the license-free radiofrequency. It uses 169MHz, 433MHz, 868MHz, and 915MHz [6] bands and can transmit data more than 10km in rural areas.

Data packet that is transmitted between the sender and receiver occasionally failed to reach its specific destination causes packet loss [7]. For high priority data [8], any packet loss requires retransmission and thus requires more energy.

Earth atmosphere is one of the factors that can cause signal attenuation. Atmospheric attenuation is the discontinuation of the power of electromagnetic radiation due to weather or atmospheric variation [9]. There is no effect on millimeter-wave because of multipath. But some causes of the earth's atmosphere can affect the millimeter wavelengths. Like rain attenuation, gaseous absorption, cloud attenuation can affect the millimeter wavelengths. Any discontinuation of signals can create packet loss.

In this paper, we proposed a LoRa-based wireless mesh network [10] to improve the packet delivery ratio and to measure the effect of different atmospheric attenuations, particularly due to rain for non-line-of-sight environments. The testbed is also used to evaluate the maximum distance for LoRa data transmission during different line-of-sight and non-line-of-sight environments. We experimented with our LoRa based wireless network by taking the packet delivery ratio when there was no rain and performed at different timings of a day and some experiments while raining.

## II. Related Works

Previous studies have been focusing on the packet delivery and some outdoor applications of LoRa technology. In [11], LoRa wireless mesh network system is used to monitor a large-area IoT sensor. They use 20 LoRa devices with mesh network topology deployed in 800*600 meters' area. A gateway was installed to collect data from each end node in 1-minute intervals. The LoRa wireless mesh network module used Nuvoton nano100LE3BN, ARM M0 microprocessor and Semtech SX1278 LoRa RF 430MHz transceiver with a 1.9dBi gain helical antenna. Nodes and gateways are powered by a 5-

V USB adapter. This system achieves an average packet delivery ratio of 88.84%.

In [12], the transmitter and receiver module RFM95W transceiver hope RF was used in high and low frequency. This unit is integrated with SX1276 which enables the comparison between frequencies and wireless transmission. The network was set up in a suburban/rural area to measure the performance in line-of-sight and non-line-of-sight environments. The effects of the spreading factor (SF) and bandwidth (BW) were tested on the Received signal strength indication (RSSI) value. Omni-directional 3dbi antenna was used. The transmit power was set to 23dBm. The result shows the minimum RSSI value recorded is -98dBm under a line-of-sight environment at a distance of 1.17km. The maximum RSSI value of -80dBm is in 20m distance. The research concludes that the topical climate has a big impact on radio signal attenuation.

In [13], researchers have proposed two approaches like nodes with modified IoT applications, which retransmit the lost data and another one is to help the neighbouring nodes to transmit data to solve and increase the success rate of massage delivery in LoRaWAN. They designed a network setup of 3.54dBi antenna with the RN2483 LoRa module. The gateway uses the IC880A LoRa concentrator with an 8dBi antenna. 8 sensor boxes are using the RN2483 module installed on the rooftop of a building. This network setup reduces the data loss rate from 100% to 25.51% by applying this IoT application-based node that retransmits the lost data and helps the neighbour to transmit data.

In research work [14], they designed a network set up to monitor and track mental disorder persons using LoRa technology. The end device is installed on the patient's body and the gateway is installed in the hospital and other public locations. The gateway is connected with several end devices and to the server. All end nodes are monitored from the server. The system is designed for line-of-sight and non-line-of-sight environments. The end device consists of LoRa shield, Arduino UNO, GPS sensor, WiFi module and set of batteries. The gateway is connected with an application server. They used a mobile application for monitoring by a medical officer. The result of this research shows that the increase of RSSI value and power consumption of the system depends on the distance of end nodes and gateway.

Research in [15], developed a remote monitoring system of radio data infrastructure that uses LoRa technology. The researcher used LoRa module RF1276, Arduino MEGA board, GPS module for tracking and SD card to save data on the transmitter side. The LoRa module RF frequency is 867MHz, RF factor is 2048 and RF bandwidth is 125KHz. The LoRa module connected with a whip antenna using the 867MHz band. The receiver side contained LoRa RF1276 module connected with the gateway and internet, which store the data in the Dataino server with latitude and longitude tracker included. After considering the communication power, cost, security, and bandwidth, the network system built in this research is a better option to deploy in a remote monitoring system, agriculture, smart home, and wireless sensor network.

Research [16], create a LoRa wireless technology-based network system to control the drip irrigation system. For the end device, researchers used LoRa module RA-02, Atmega 328p microcontroller, D-size battery and low-dropout voltage regulator to control the power for MCU. Researchers used the same components for master node and end-nodes but the master node was added with an extra WiFi module so that it can transmit signals or data to the controller. In the controller PC, there was a GUI application for controlling all the end devices and master devices. Implementation of this proposed system gives a cost-effective solution for the drip irrigation system with a reliable radio link that covers a large area and has long-time power backup.

## III. Proposed Mesh Network

This section shows the proposed network model and the description of the physical components and software used in the project. A LoRa compatible temperature and humidity sensor DHT11 is attached to the end node for measuring temperature. Nodes are deployed at different locations, taking the reading at different weather conditions with different line-of-sight and non-line-of-sight environments. The temperature reading is sent from an end node to a master node which is then forwarded the data to a gateway. The network is built with LoRa RFM 915MHz shield, Arduino UNO board, 915MHz SMA antenna, 5V power supply is required to power this network. We show the flow chart of this proposed network in Fig. 1.

In this study, LoRa shield is used as a transmitter module with Arduino compatible device where it can transmit data for a long-range. The data rate for our network is taken as 50kbps. For the second part of this network, the master node is responsible for receiving data from the end node and sends it to the gateway. The master node also consists of the same components as the end node but without the temperature sensor. A gateway collects data from the master node and sends them to an application server. Gateway is connected to the application server through the USB port of Arduino UNO. In Fig. 2 the network architecture is shown.

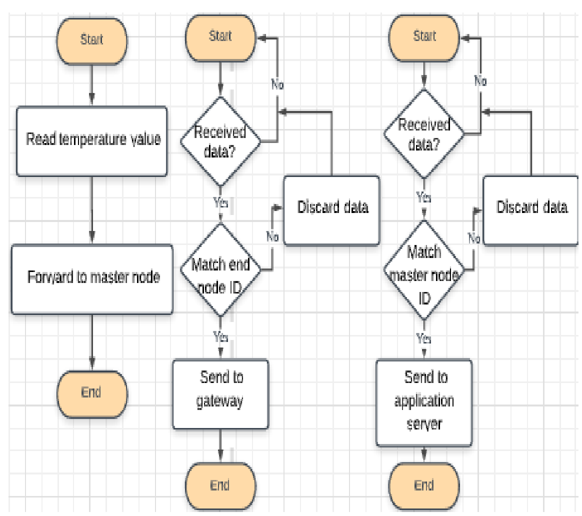


Fig. 1. Flow Chart for End Node, Master Node and Gateway.

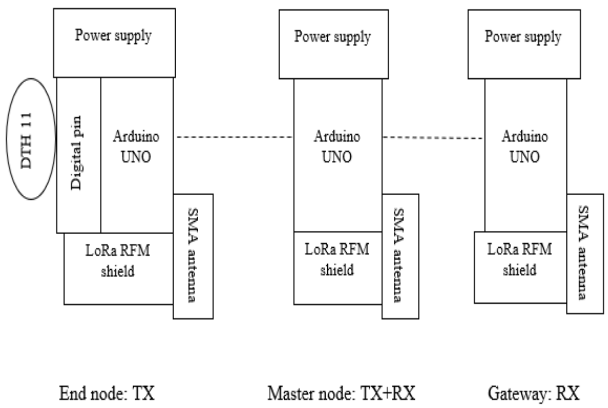


Fig. 2. The Proposed Network Diagram.

To visualize the data, we have taken the Arduino IDE application as our application server. All the data that the gateway received is displayed in the serial monitor of the Arduino IDE application. An example of a serial monitor is shown in Fig. 3.

In this research, PDR is taken to measure the performance evaluation. High PDR value indicates a smaller number of packet loss. To calculate the PDR value, the following equation is used:

$$Packet\ Delivery\ Ratio\ (PDR) = \frac{\text{Total packets received}}{\text{Total packets sent}} * 100 \qquad (1)$$

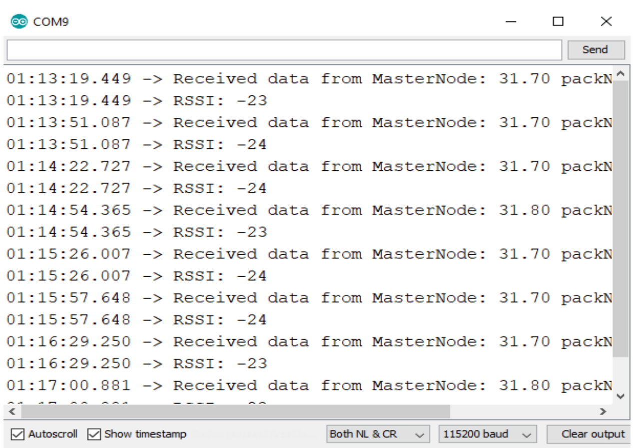


Fig. 3. Serial Monitor Graphical user Interface.

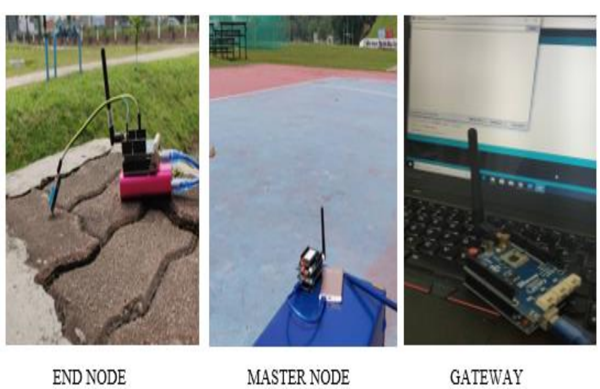


Fig. 4. Distribution of Nodes.

We have chosen different weather and location to deploy our network and carried out the experiments. Data received by the gateway is calculated to obtain the number of packet losses using the expression in (1). All data are visualized in the serial monitor of the gateway. The PDR results show the effects on data transmission in different weathers and locations.

Fig. 4 shows an example of locations where devices were installed at different places for the experiments. The figure shows the distribution of node, master node, and gateway.

## IV. Results and Discussion

In this study, four types of experiments were conducted at different times of the day and different weather such as with and without rain. Four categories of experiments are performed as follows: 1) to measure PDR in a non-line-of-sight environment; 2) to measure PDR in a line-of-sight environment; 3) to measure PDR during rain and without rain; and 4) to measure maximum distance with the highest successful data transmission in mesh and star network.

*1) PDR in Non-line-of-sight:* We have tested our proposed LoRa based network by sending 38 data packet and a duration of 20 minutes is allocated to measure the PDR value in the non-line-of-sight environment. The network was installed in different places with obstacles between the devices. Experiments were conducted at 9.00 am, at 1.00 pm, 9.00 pm and 1.00 am with cloudy weather without rain. The distance between nodes and gateway were varied between 100m, 200m, 300m, and 400m. The experiments were performed with data sent from the end node to the master node which then forwarded to the gateway. The results show that the PDR value when we vary the distances from 100m to 400m remains 100%. We performed another experiment to verify our results by repeating the experiment with the same setup as before but on different days only at 400m area and the time recorded was 10.30 am. Fig. 5 shows the results of PDR value remain 100% on a different day at 10.30 am. Experiment results show that there is no difference in PDR for this experiment as well and verified the stability of our proposed network in a non-line-of-sight environment.

*2) PDR in Line-of-sight:* The experiments to measure PDR in a line-of-sight environment were conducted by sending 38 data packet and in 20 minutes. This network was installed in different places without any obstacles. Experiments were performed at 9.00 am, 1.00 pm, 9.00 pm and 1.00 am without rain. Distance variations from node to gateway were varied between 100m to 400m area. The experiments were conducted by data sent from the end node to the master node which then forwarded to the gateway. Data transmission of this network was visualized and collected from an application server. When we vary the distance from 100m to 400m the results show that the PDR value remains 100%. To verify the results, we performed another experiment with the same setup as before but on different days only at 400m area and the time recorded was 11.30 am. PDR value remains the same 100% shown in Fig. 6. The experiment results show that there is no difference in PDR for this experiment as well. It verified the stability of our proposed network in a line-of-sight environment.

*3) PDR during rain and without rain:* To collect the PDR value during rain, we have tested our proposed LoRa based network in different amounts of rain. We observe closely the weather forecast to prepare for the experiments. Collecting the PDR values during rain is the most challenging phase in our experiments because the rain does not always occur according to the weather forecast. The experiments took more than three months to catch for rain. We repeat the same process in the experiment by sending 38 data packet and a duration of 20 minutes is allocated to measure PDR. We installed our devices in 200m area of non-line-of-sight and all the devices were placed under a roof to prevent rain from damaging the devices. This network was installed in a place with obstacles between them. The experiments were conducted in different amounts of rain. During the experiment time duration, the rain intensity was measured by a rain gauge. Captured rain intensities were 2.4mm, 3.1mm, 6.2mm, 10.7mm, 12mm, 21.1mm, 22.3mm, 29mm, 41mm, and 45mm. Table I shows the scale of measure the rain intensity.

PDR values in rain are shown in Fig. 7. Results show that the gradual increase of rain increases the amount of packet loss gradually. It shows the decrease of PDR value from 100% to 89.50% as the rain increased from light to heavy rain.

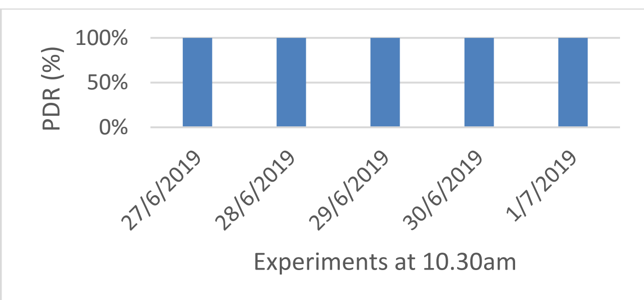


Fig. 5. PDR in 400m Non-Line-of-Sight.

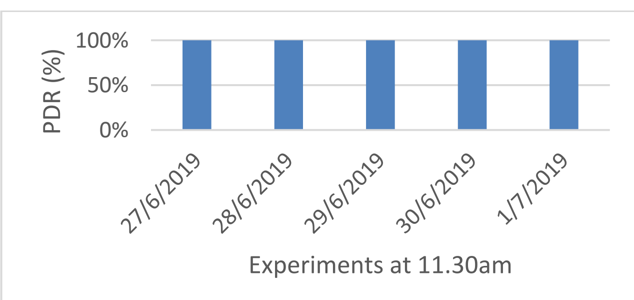


Fig. 6. PDR in 400m Line-of-Sight.

TABLE. I. RAIN INTENSITY MEASUREMENT SCALE

| | Rain amount in mm | Category |
|---|---|---|
| 1 | 1-10 | Light rain |
| 2 | 11-30 | Moderate |
| 3 | 30-60 | Heavy |
| 4 | >60 | Very heavy |

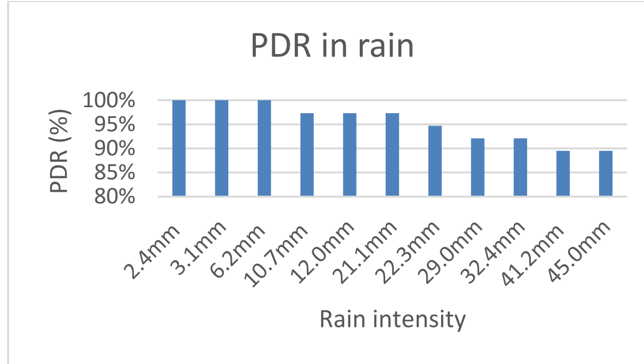


Fig. 7. PDR in Rain at 200m with Mesh Network.

We have installed our network at the same place where we installed our network during rain experiments to measure the PDR value without rain. We repeat the same process of sending 38data packets in a time duration of 20 minutes. Experiment results show that the PDR remains 100%. We repeat the experiments with the same setup but vary the distance between the end node, master node, and gateway to verify the results. The distance between devices varied between 100m to 400m area without rain. The experiment results are shown in Fig. 8. Results show that PDR value remains100% in every distance and there is no change in PDR.

We did the same experiments during rain with star network and deployed our devices in the same location and environment as installed during mesh network experiments. We conducted the experiments with the same amount of data packets and time duration. For these experiments, we used the end node and gateway with stat network configuration. The end node was installed at 200m and the gateway was installed at 0m and the data was visualized in the application server. Rain intensity was captured by a rain gauge and it was able to catch the rain of 3.2mm, 5.7mm, 6.1mm, 15.6mm and 23.1mm during experiments. Results show that the value of PDR starts decreasing with the increase of rain. It shows that the star network drops more packets with less intensity of rain. In Fig. 9 PDR in a different amount of rain at 200m with the star network is shown.

From the collected results of PDR value during rain and without rain, with different time, day, location and network, it proves that the different type of rain intensities attenuates the radio signal and affects the signal transmission process. The difference between experimental results of mesh and star network show that mesh network can provide better PDR value even in the high intensity of rain. In Fig. 10, the PDR value of mesh network in a different amount of rain from 2.4 mm to 45.0 mm and the PDR value of star network in a different amount of rain from 3.2 mm to 23.1 mm is shown.

*4) Maximum distance with highest PDR:* Our proposed network was built with the mesh network where all nodes sent data to their immediate node. To get the maximum distance of successful data transmission in line-of-sight and non-line-of-sight environments, we have deployed our network at different distances without rain. We started our experiments from a

500m distance by sending 38 data packets within 20 minutes of time duration and increased the distance gradually until the network starts dropping the PDR value from 100%. We have found that in a non-line-of-sight environment, this network can transfer the highest successful data of 100% PDR until 1.3 km from the end node to the gateway. During the experiment gateway was installed at 0 m, the master node was installed at 650 m and the end node was transmitting data from 1.3 km. In the line-of-sight environment it can provide 100% PDR value up to 1.7 km where the end node was at 1.7 km, the master node was at 850 m and gateway was installed at 0 m. After this distance, the PDR value starts decreasing. Results show that in 1.4 km of non-line-of-sight the PDR value decreases to 92.1% and in line-of-sight PDR drops to 97.3% in 1.8 km. Fig. 11 shows the highest successful transmission range in both environments and in Fig. 12 the device setup during the experiments is shown. In Fig. 13, the PDR value in different distances and PDR dropping points of this network and the maximum distance coverage with the highest successful PDR value in line-of-sight and non-line-of-sight is shown.

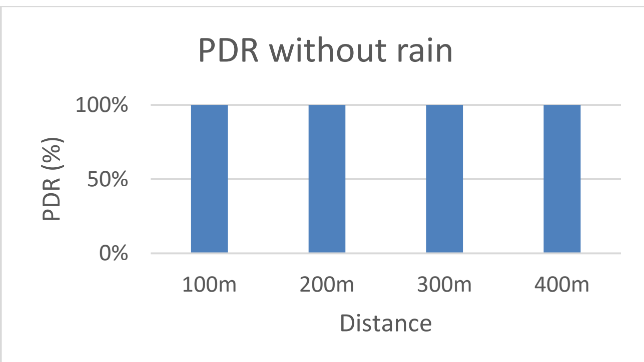


Fig. 8. PDR in without Rain.

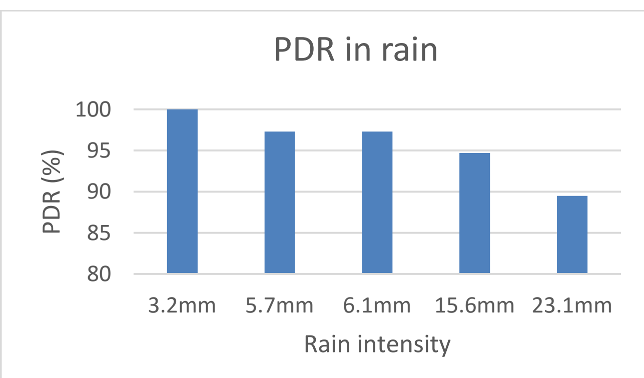


Fig. 9. PDR in Rain at 200m with Star Network.

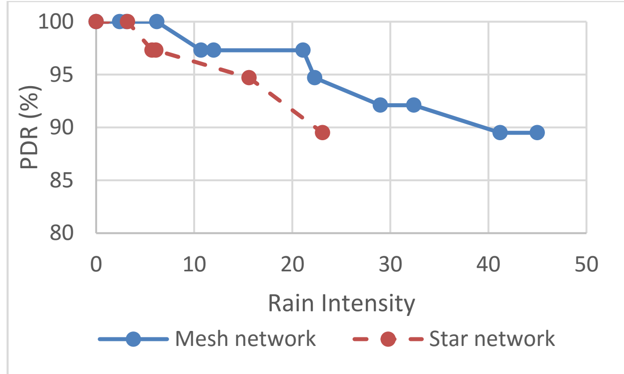


Fig. 10. PDR in different Rain Intensity.

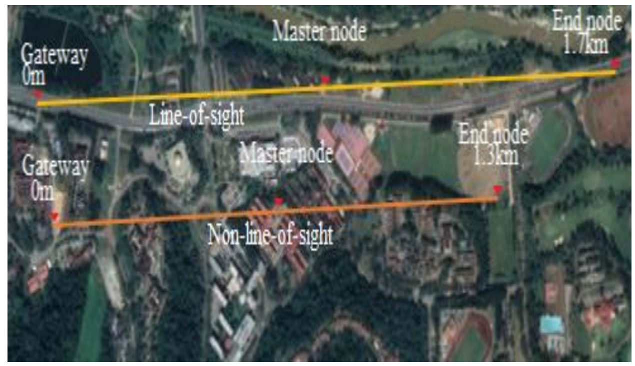


Fig. 11. Highest Successful Transmission Range.

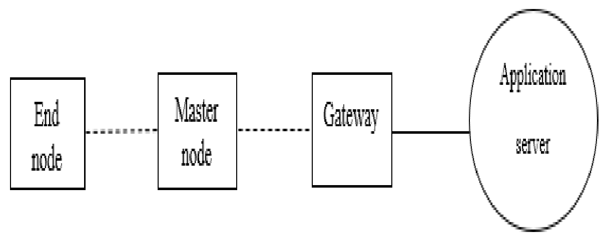


Fig. 12. Device Setup in the Mesh Topology.

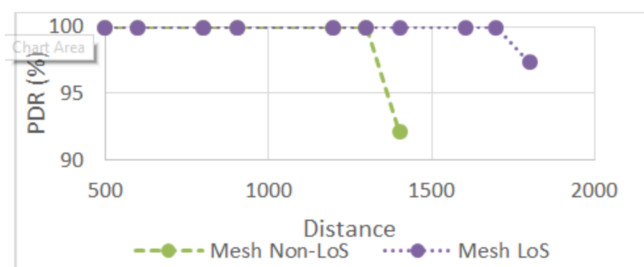


Fig. 13. PDR in Maximum Distance.

The main aim of this star network experiment is to measure the maximum distance of successful data transfer by the star network topology to compare it with the network that we have proposed, which is performing with a mesh network topology. For these experiments, we used the end node and gateway. Data received by gateway ware viewed in the Arduino IDE serial monitor. Experiments were conducted in line-of-sight and non-line-of-sight environments without rain. We started our experiments from a 200 m distance by sending 38 data packets within 20 minutes of time duration and increased the distance gradually until the network starts dropping the PDR value from 100%. Results from the experiments show that the maximum distance of successful data transfer value of PDR remains 100% unlit 500 m in a non-line-of-sight environment where the gateway was installed at 0 m and end node was transmitting data from 500 m, but when the distance increase to 600 m the PDR value decreases to 92.1%. In the line-of-sight environment, the maximum distance of receiving 100% PDR value is 800 m where the gateway was at 0 m and the end node was at 800 m. But in 900 m the PDR drops to 94.7%. In Fig. 14, we have shown the maximum successfully transmission range between nodes and gateway in both line-of-sight and non-line-of-sight environments and in Fig. 15 the device setup during experiments is shown. In Fig. 16, the experiment results and the dropping point of PDR for star network are shown.


Fig. 14. Highest Successful Transmission Range.

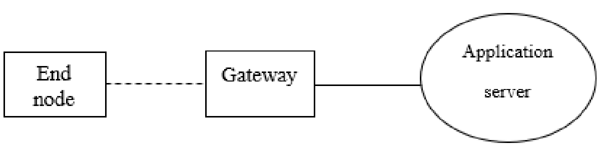


Fig. 15. Device Setup in the Star Topology.

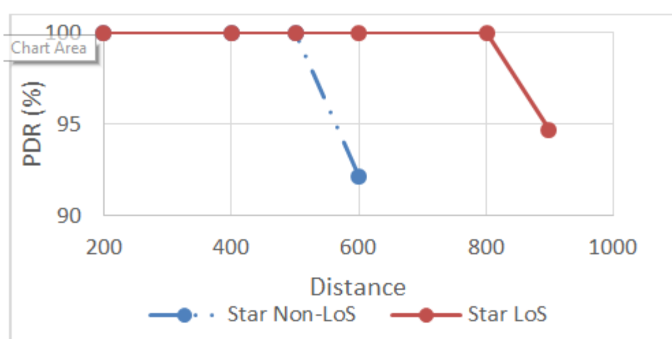


Fig. 16. PDR in Maximum Distance.

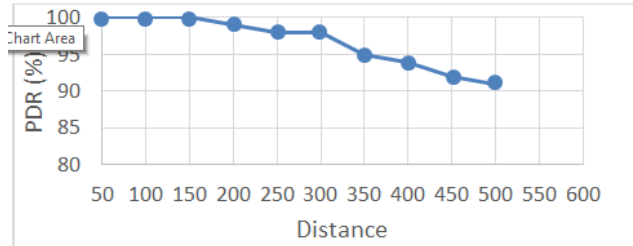


Fig. 17. PDR in the Maximum Distance for ZigBee.

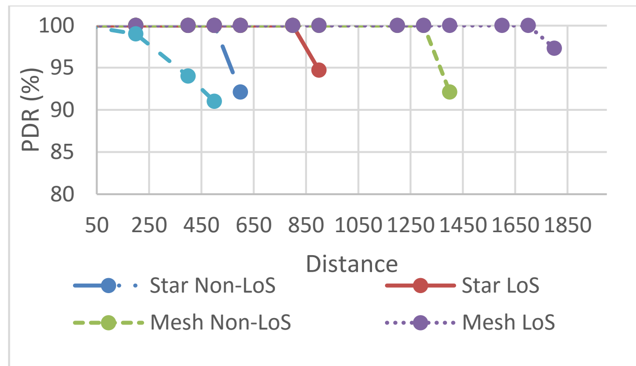


Fig. 18. PDR Value Comparison.

We make a comparison between our experiment with research done in [17] where the work designed and implemented data transmission by using Zigbee technology. The experiments show that when the distance increases, the packet loss rate also increases. The experiments started from 50 m distance and increase to 150 m where PDR was 100% but from 200 m PDR start decreasing. When the distance increased to 500 m the PDR decreases to 91%. In Fig. 17, the PDR of Zigbee in the different distances is shown.

Experiment results of the mesh network, star network, and ZigBee technology gives a clear indication that mesh topology covers longer distance than star topology or ZigBee technology in both line-of-sight and non-line-of-sight environments. Our proposed Mesh network provides better performance with a longer distance. In Fig. 18, the PDR comparison between LoRa based mesh and star network and a network based on Zigbee in the different distance is shown.

## V. Conclusion

LoRa technology has become one of the most preferred wireless technology comparing to Zigbee, WiFi, and Bluetooth due to longer transmission range and low cost. However, data transmission during rain causes attenuation to radio signals. In this research, we proposed the LoRa-based mesh network to improve the packet delivery ratio in tropical climate experiencing rain and to provide the effects of atmospheric attenuation in the signal transmission process. The experiment results collected from different locations, during rain and without rain at various distances, shows that mesh network shows better performance with longer transmission distance compared to star network. The network behaves differently during different amounts of rain but it still shows that it can perform better than the star network in any weather conditions. One significant result obtained from the experiment shows that the PDR decreases significantly from 100% to 89.5% by the effects of atmospheric attenuation. On the contrary, this network can successfully transmit data up to 1.7 km in line-of-sight and 1.3 km in non-line-of-sight environments with a 100% PDR value. The research concludes that atmospheric attenuation should be taken into consideration when designing any LoRa applications for outdoor deployment.

The future work can focus on processing a big volume of data received by the gateway, in the cloud. Our research is implemented on a fixed node for all end, master and gateway nodes. The enhancement can be done by having the end node as mobile nodes and see the mobility effect to the PDR.

## Acknowledgment

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