

Efficient Management of Wireless IoT Hydroponic Systems Using Multi-Node and Hybrid Wi-Lo Communication

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Abstract

Hydroponic gardening requires less room than soil-based cultivation and it provides precise control over environmental factors. The specific challenges of hydroponic systems with IoT can include the management of systems that receive and transmit large amounts of data especially in limited Wi-Fi coverage zone or Wi-Fi dead zone and analysing data wirelessly to assess the system's performance. This project aims to design and investigate an IoT-based hydroponic system that makes use of several multi-hop nodes for effective administration and communication. In this project involve with multi-node communication and each node connected to many sensor nodes. Each nodes will collect data from sensor and send to Wi-Lo transceiver where the data will transfer wirelessly via Wi-Fi direct and Lora technology. The combination of these two techniques will form new network topology. The goal is to wirelessly connect all the nodes and establish communication in an appropriate topology in the hydroponic system. The multi-nodes communication system enables effective decision-making and problem-solving by facilitating real-time data sharing and cooperation. An investigation will be done at Line-of-sight and Non-Line of-Sight conditions. Based on the investigation, it is recommended that to avoid data loss, Wi-Fi direct node-to-node transmission should occur within a maximum range of 50 meters for 100% data reliability, while LoRa transmission can effectively cover within range of 150 meters.

Keywords: Internet-of-Things, LoRa, Wi-Lo, Node to Node Communication, Hydroponic System

Introduction

Agriculture, the foundation of human civilization, enables the production of high-quality food for the people. As previously stated, hydroponic systems do not need soil to grow plants

(Mendon, 2022). A nutrient-rich water-based solution, in which the water is combined with the prescribed solutions for the plant to thrive, provides all the nutrients that plants need to survive (Lakshmi, 2020). Therefore, there are several hydroponic systems or techniques that allow plants to thrive either directly in the nutrient-rich water-based solution or in a non-soil medium. A hydroponic system using Internet of Things (IoT) technology may enable users to remotely monitor and manage various system components, enabling more accurate and efficient plant development.

Developing a hydroponic system with IoT technology requires the best and most efficient network to store data, control and monitor the system wirelessly. To monitor and control hydroponic plants in that area needs more than one sensor node. Data must therefore travel farther to reach its destination, increasing latency and resulting in slower speeds for the end user. This area is usually short of Wi-Fi coverage, is a location within a wireless LAN where Wi-Fi does not work, usually as a result of radio interference or range problems (Abdul, 2022)(Quamara, 2018). In addition, due to the large area, it involves many sensor nodes to cover the hydroponic area. If not using wireless communication, more wired connections are needed for each sensor or actuator connection to cover the hydroponic area. This can take up more space and is untidy because of the many wired connections for each sensor. High installation and replacement expenses are one drawback of a wired connection. Inefficient network topology is another issue that requires additional spending. This is due to the fact that using Lora in a small area will result in higher costs than using Wi-Fi direct.

An approach for moving data from one node to another has been documented in a few publications. According to a method presented by (Samijayami, 2020), data is transferred from sensor nodes using ZigBee. A raspberry pi equipped with a ZigBee module receives the data from the sensor nodes and sends it to a PC node where it is received and analyzed. The paper by (Fajri, 2022) approach involves creating and implementing a hydroponic smart farm system in the Bireuen Regency using web-based Internet of Things (IoT) technology. The incorporation of IoT into the idea of the hydroponic system design enables the monitoring and management of many elements of the hydroponic plants. The primary focus of the article (Rathod, 2021)(Aarif, 2022) is the development of an IoT network based on LoRa technology for hydroponic farm monitoring. These characteristics are measured using a variety of sensors, and the real-time data gathered from the sensors is sent to a gateway through LoRa. Moreover, the authors of this research (Yusuf, 2022) have created a system that blends IoT with hydroponic vertical gardening. The system builds a dashboard for real-time monitoring and management of environmental parameters using parts like the ESP32, MQTT broker, and Adafruit IO. In this study (Rahmadya, 2020), the authors evaluate the effectiveness of an automated hydroponic system using two different wireless sensor network techniques: cluster-based and multihop-based. The simulation was run with Symphonics, an OMNET++-based simulator.

The goal of this project is to create a multi-node wireless communication system that will allow wireless monitoring, control, and operation of a hydroponic system through the use of Internet of Things technology. Designing a multi-node sensor that is integrated with several sensors is part of the development process to track important characteristics including temperature, humidity, pH, TDS, and water level. The establishment of an effective communication protocol enables smooth data flow between the nodes and the master node.

BLYNK App, an Internet of Things application system, is made to collect and show data from the end nodes. The Arduino IDE software is used in the data gathering process to program the ESP32 hardware, and Data Streamer Excel is used to capture the data that is received. Peer-to-peer communication was investigated, including node are counted, data loss between nodes, and range in both line-of- sight and non-line-of-sight circumstances. The outcomes of these inquiries were documented, offering significant perspectives on the system's functionality in many scenarios.

Methodology

The process of developing an automated hydroponic system with a sustainable network architecture involves three main phases which are developing, validation, and investigation. The process of developing a hydroponic system starts with a thorough analysis of which sensors such as pH, temperature, and humidity sensors are necessary for keeping an eye on the system. After determining which sensors to use, attention turns to building the hardware of the system. In order to create the communication infrastructure, this entails building sensor nodes that are individually outfitted with the designated sensors and integrating a LoRa Gateway with Wi-Fi-LoRa (WiLo) transceivers. In order to guarantee perfect data transfer, the validation step that follows is essential for figuring out the maximum number of slave nodes that may connect to the master node. After these parameters are set, the automated hydroponic system design process begins, building the network architecture according to the results of the previous stages.

Next, in order to confirm successful receipt from individual sensors, a comprehensive inspection of the data received by every node is carried out throughout the system building. The next research stage examines packet loss that occurs between Wi-Fi nodes in both line-of- sight and non-line-of-sight circumstances. Network improvement and performance optimization are made possible by an understanding of the causes and extent of packet loss. Evaluation of the packet loss and received signal strength indicator (RSSI) between LoRa transmitters and the LoRa gateway is also included in the research. Data transfer from the LoRa Gateway to the BLYNK app enables visualization and monitoring, ensuring that every component is operating as it should. Finally, the user interface is refined to offer a user-friendly platform for keeping an eye on the functioning of the hydroponic system.

The hardware system is made up of three separate circuits: the LoRa Gateway, the hybrid Wi-Fi-LoRa (Wi-Lo) Transceiver, and the multi-node based on ESP32. In order to ensure that the entire system operates smoothly and in line with the project's goals, each of these systems has its own set of components and needs. Figure 1 shows the block diagram of multinode communication for hydroponic design system. The system consists of 3 nodes that are used to collect data from sensors, one Wi-Fi-LoRa (Wi-Lo) transceiver and LoRa Gateway. All this nodes, Wi-Lo transceiver and gateway are designed and built in Wireless Broadband and Networking Lab (WiBNet UTeM).

The circuit diagram for Node 1 is presented in Figure 2. Node 1 is designed to collect data from pH sensor while Figure 2 depicts Node 2 which connect to a humidity/temperature sensor and water level sensor. Figure 3 represent circuit layouts for Node 3 connect to a relay for on/off water pump. This relay will control the incoming A & B fertilizer depend on pH value. Figure 4 shows circuit diagram of design Wi-Lo (WiFi-LoRa) Transceiver which receive data

from Nodes via Wi-Fi direct and transmit to LoRa for long range communication. Moreover, the LoRa Gateway circuit design which connect to the internet concluding the project's thorough hardware configuration.

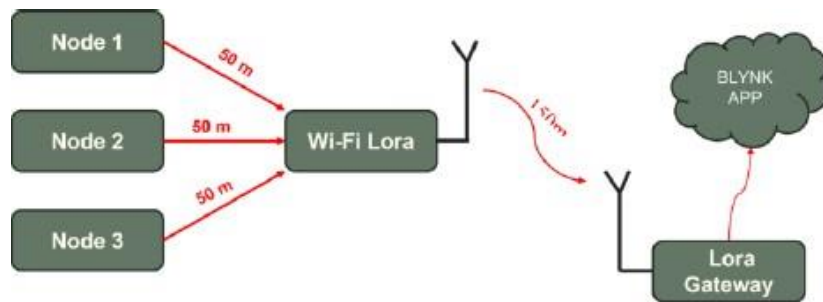


Figure 1: Block diagram of multi-nodes with hybrid Wi-Lo hydroponic systems

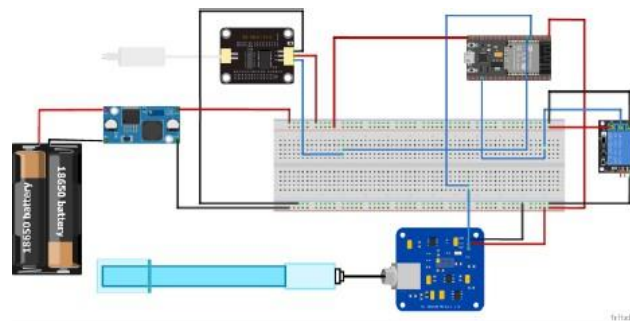


Figure 2: Circuit diagram for Node 1 connected to pH sensor.

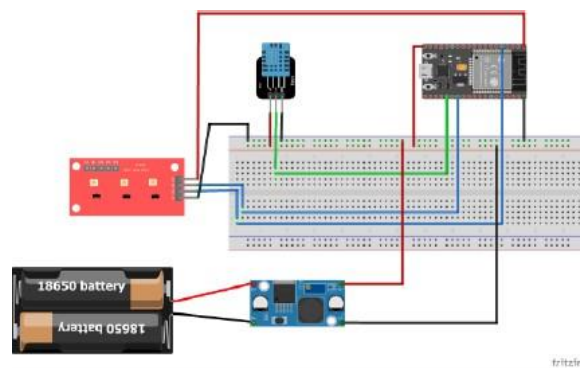


Figure 3: Circuit diagram for Node 2 connect to water level sensor and DHT11

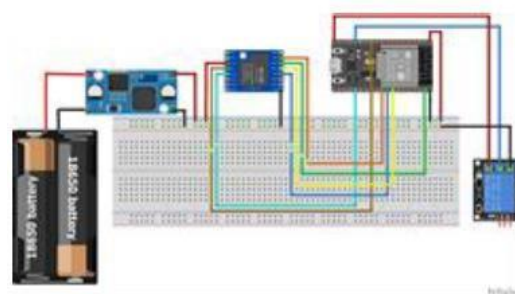


Figure 4: Circuit diagram for Node 3 to relay

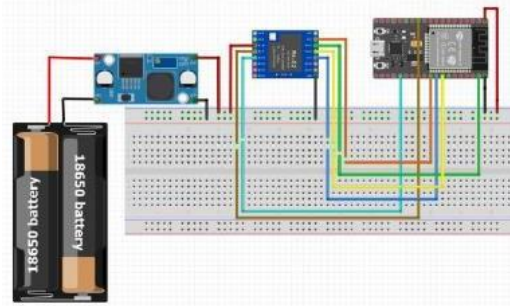


Figure 5: Circuit diagram for Wi-Lo Transceiver for long range communication.

Developing a wireless communication system with several nodes to manage an Internet of Things (IoT) hydroponic system effectively requires integrating multiple software tools to guarantee smooth data gathering, processing, and display. In this case, the construction and operation of the system are greatly aided by the usage of programs like the Blynk App, Microsoft Excel (Data Streamer), and the Arduino IDE.

Finding & Results

This chapter focuses on presenting the results obtained from the methodology described previous section. Figure 6 shows the whole circuit system was designed for testing purposes based on the schematic design.

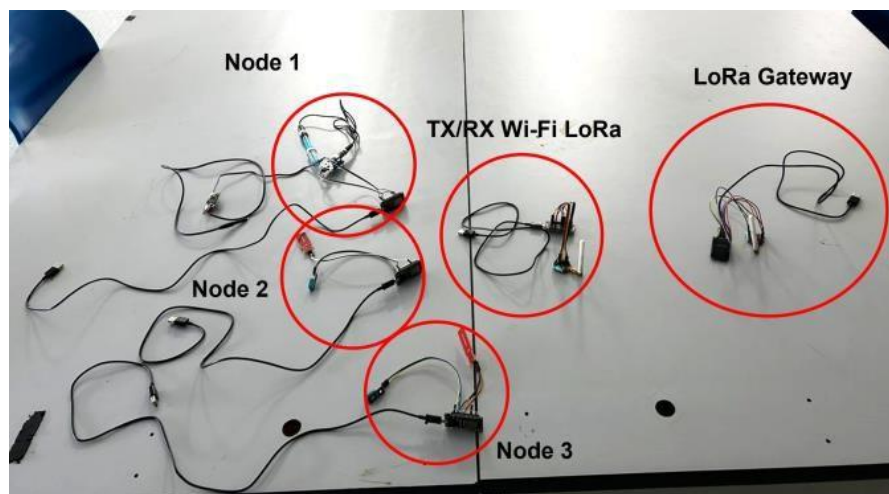


Figure 6: Hardware System Design

By gathering data from their corresponding sensors, these nodes serve as data sources. The Wi-Lo transceiver, a central hub that acts as the master node, receives the data from these nodes through Wi-Fi direct from microcontroller ESP32 and retransmits it over LoRa SX1278 communication module. Importantly, every single one of these nodes and the Wi-Lo is situated in a Wi-Fi dead zone. This is relevant due to usually the place of farm situated far from Wi-Fi coverage. On the right side, the Lora Gateway which will be positioned away from these parts and in an office area with stronger Wi-Fi coverage (approximately 200m apart). The LoRa gateway connect data to Blynk through MQTT protocol. Users may see and manipulate the data they get by using the Blynk app as a human interface.

Maximum Number of Nodes Data Transmission

An experiment was conducted, as shown in Figure 6, to test communication between nodes using Wi-Fi Direct technology on a microcontroller. On the left side is the multi-node (up to 5 nodes) that acts as the transmitter and on the right side is the receiver. All data from nodes transmit simultaneously to the receiver and observation on Arduino IDE.

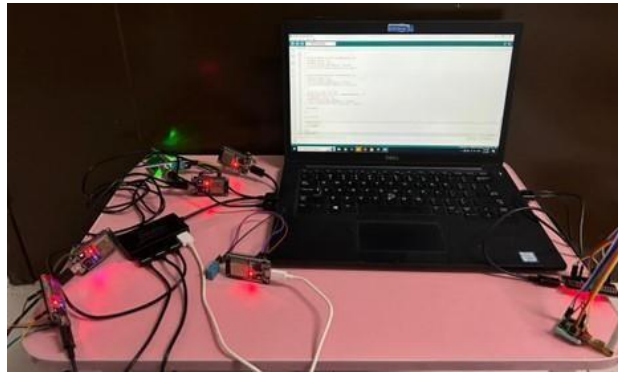


Figure 6: Wi-Fi Direct Data Transmission

Based on Figure 7 and Table 1, it can be concluded that there was no packet loss for any of the system nodes. The graph illustrates the packet loss for each node, showing the values for the amount of packet loss experienced during a specific time period or set of conditions. The results indicate that, under the given circumstances, none of the nodes (Nodes 1 through 5) experienced packet loss. This suggests a reliable communication environment where all nodes successfully transmitted data without encountering data loss issues.

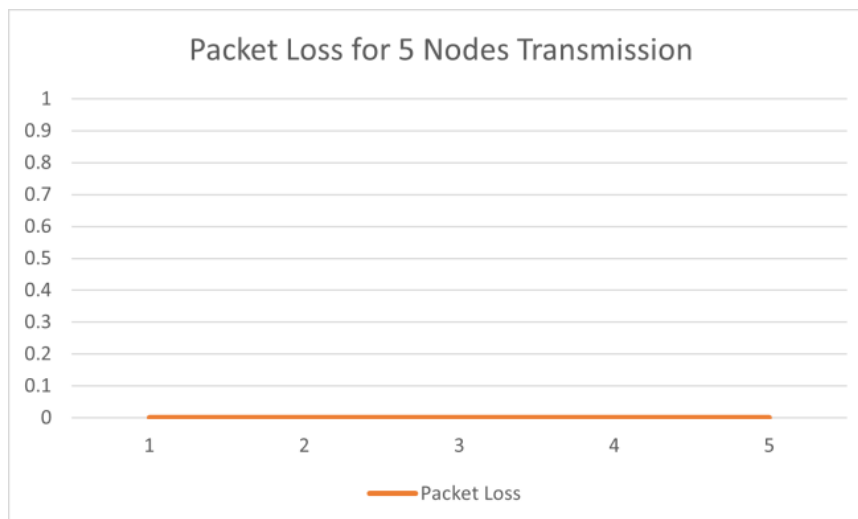


Figure 7: Wi-Fi Direct Transmission Packet Loss

Table 1
Number of Packet Loss in ESP32 Wi-Fi Direct Transmission

Node	Total Packet Loss
Node 1	0
Node 2	0
Node 3	0
Node 4	0
Node 5	0

Time Delay Data Transmission

Another experiment that was conducted are on delay interval parameter on Wi-Lo transceiver for transmitting data. The delay interval was set by 1 second, 5 seconds, and 10 seconds before transmit new data and packet loss counted on LoRa gateway as receiver. Figure 8 and Table 2 shows the packet loss counted when transmit 100 packet data with interval delay of 1s, 5s and 10s.

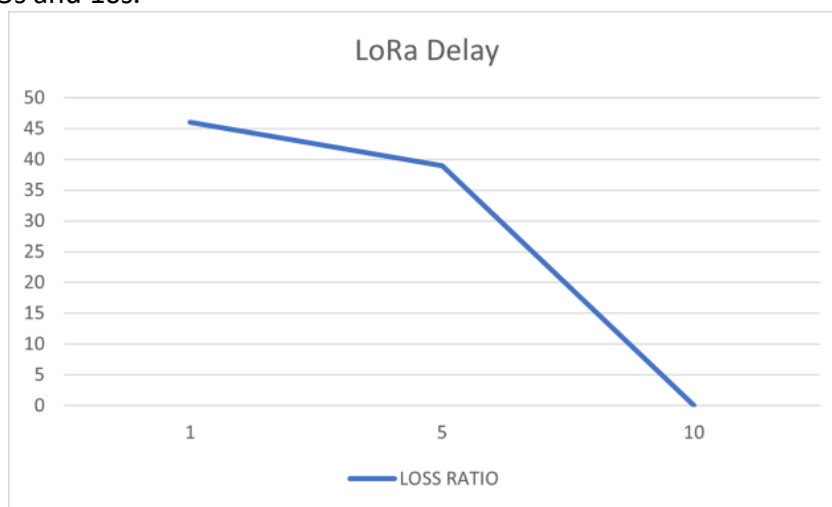


Figure 8: Packet Loss VS Time Delay

Table 2
Total Packet Loss with Time Delay

Time Delay (s)	Number of Packet Loss
1	46
5	39
10	0

Based on Figure 8, the link between packet loss and time delay in a LoRa (Long Range) communication system is seen in this graph. Data is sent from a Wi-Lo transmitter to a LoRa gateway, which serves as the receiver, in this arrangement. The transmitter's time delay settings were adjusted to a certain second. A total of 46 packet loss instances were noted with a 1- second time delay, suggesting that some sent packets were not received. This is due to data at the gateway take some time to finish process before it can process another receive packet of data. Reducing packet losses to 39 by extending the delay to 5 seconds significantly increased the dependability of data delivery. Surprisingly, a 10-second delay produced flawless outcomes with no packet losses, highlighting the benefits of longer delays for dependable and consistent data transfer.

Line of Sight and Non-Line of Sight Packet Loss for Node-to-Node Wi-Fi Direct

Another experiment was conducted on distance between nodes effect to packet loss using Wi-Fi direct technology. This experiment considers for both Line of Sight (LOS) and Non-Line of Sight (NLOS) scenarios and focuses on the packet loss during ESP32 Wi-Fi direct data transfer. This is important in planning Node-to-Node communication arrangement. The results show in Figure 9 and Table 3 show how Non-Line of Sight (NLOS) and Line of Sight (LOS) situations affect the dependability of data transmission.

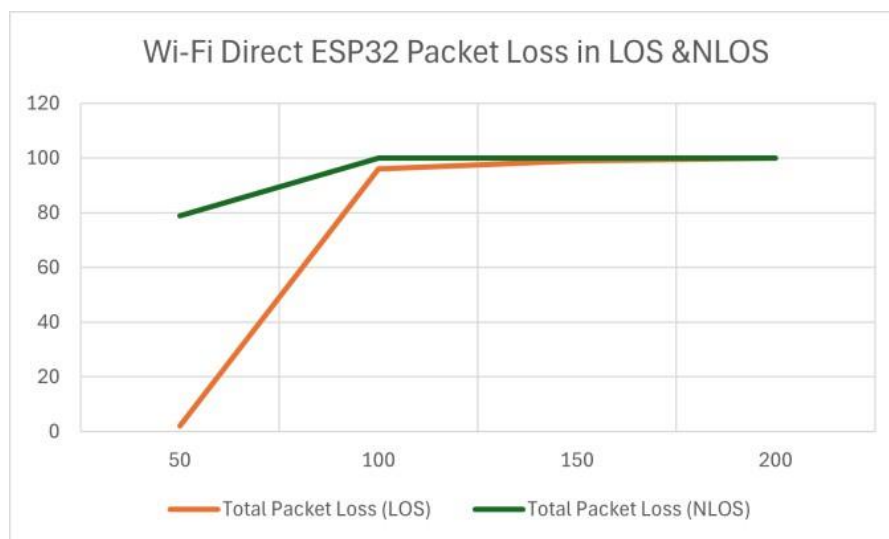


Figure 9: Packet Loss vs distance (m) for LOS &NLOS

Table 3

Result of Total Packet Loss in Non-Line of Sight and Line of Sight

Distance (m)	Packet Loss in (NLOS)	Packet Loss in (LOS)
50	79	2
100	100	96
150	100	99
200	100	100

With just two occurrences, the data loss in the LOS scenario where the transmitter and receiver are in direct line of sight is quite small at 50 meters. However, when distance rises, it becomes much larger, reaching 96, 99, and 100 losses at 100m, 150m, and 200 m, respectively. In contrast, packet loss is worse in the non-line-of-sight (NLOS) situation, where obstructions may impede the direct line of sight. At 50 meters, packet loss is as high as it gets 79 packer loss, with 100 occurrences of data loss at 50 meters, 150 meters, and 200 meters.

Line of Sight and Non-Line of Sight Packet Loss for LoRa Data Transmission

Next experiment was conducted on investigation how distance affected to packet loss on LoRa module data transmission by Line of Sight (LOS) and Non-Line of Sight (NLOS) circumstances. In this arrangement, both LOS and NLOS scenarios are considered, with a Lora module on Wi-Lo transceiver transmitting data to a LoRa Gateway receiver. Using the SX1278 transceiver chip to facilitate connection between the Lora Wi-Lo transceiver and the LoRa Gateway receiver, the default configuration for LoRa communication was established with a

Spreading Factor of 7 (SF7), balancing data rate and range. The number of lost packets and RSSI value during Line of Sight (LOS) and Non-Line of Sight data transmission for LoRa modules at various distances is displayed on the graph as shown in Figure 10 and Table 4.

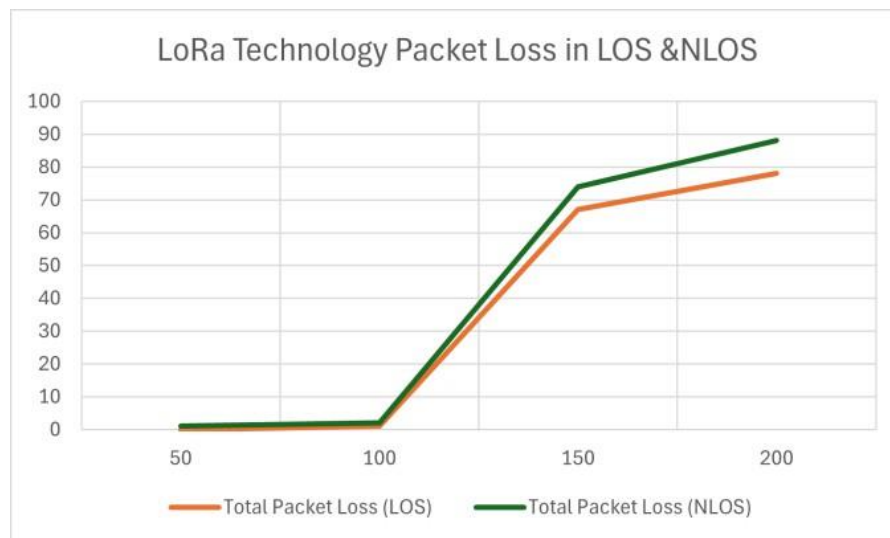


Figure 9: Packet Loss in LOS & NLOS Condition for Transmission Using LoRa Table 4: Result of Total Packet Loss in LOS & NLOS

Distance (m)	Packet Loss (LoS)	Packet Loss (NLoS)
50	0	1
100	1	3
150	67	74
200	78	88

There were no dropped packets at 50 meters, suggesting a dependable connection and good data transfer. One packet was dropped as the distance increased to 100 meters, indicating a generally reliable communication relationship. Nevertheless, the number of lost packages grew to 67 at 150 meters and to 78 at 200 meters as the distance increased. These losses show that when the distance increases, data transmission reliability decreases, and more packets have trouble getting to the recipient. Next in NLoS, one packet was dropped at 50 meters, indicating a relatively small loss in the non-line-of-sight communication channel. Three packets were dropped as the distance reached 100 meters, suggesting a marginal increase in the difficulty of the data reaching the recipient. But the number of missing data dramatically jumped to 74 at 150 meters, and to 88 at 200 meters.

The received signal strength during LoRa module data transmission at different distances and under both Line of Sight (LoS) and Non-Line of Sight (NLoS) situations is represented by the RSSI values in the graph as shown in Figure 11 and Table 5.

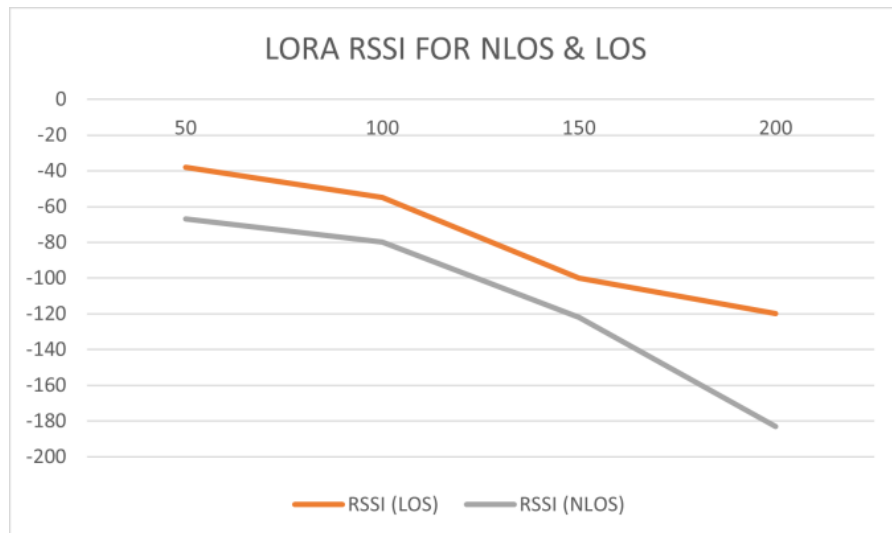


Figure 10: RSSI Result for Both Condition LoS and NLoS for Transmission using LoRa Table 5: RSSI Value in Line of Sight and Non-Line of Sight Condition

Distance (m)	Received Signal Strength Indicator (RSSI) Value	
	LOS	NLOS
50	-38	-67
100	-55	-80
150	-100	-122
200	-120	-183

The RSSI values are comparatively high in the line-of-sight (LoS) situation, when the transmitter and receiver have a direct line of sight. The RSSI score is -38 at 50 metres, which indicates a strong and powerful signal. The RSSI value at 100 meters is -55, which is little weaker than at 50 metres but still indicates a strong signal. However, the RSSI values further decline to -100 and -120, respectively, when the distance rises to 150 and 200 metres, showing a steady deterioration of the signal intensity. The RSSI values are lower in the NLoS scenario than in the LoS scenario due to the possibility of obstructions obstructing the direct line of sight. The RSSI score of -67 at 50 metres indicates a signal that is a little weaker than in the LoS scenario. The RSSI readings continue to drop to -80 and -122 when the distance grows to 100 and 150 meters, respectively, suggesting a further weakening of the signal. The RSSI number sharply decreases to -183 at 200 metres, demonstrating the strong influence of obstructions on signal strength. Push Data to IoT Platform Blynk The Blynk app facilitates real-time monitoring and visualization dashboard of the received data, with updates occurring every 10 seconds as shown in Figure 12.

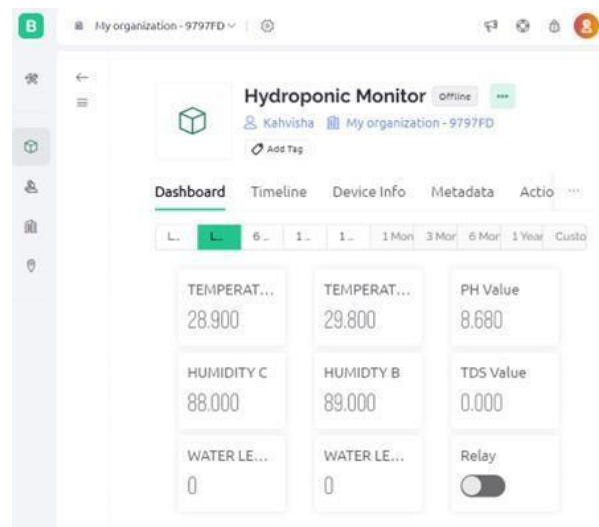


Figure 11: Blynk App interface

Users may always view the most recent information on the hydroponic system due to the frequent updates. Based on previous experiment the optimal system update on interval of 10s to make sure no packet data loss during transmission especially on long distance transmission utilizing LoRa modle. Users can monitor data with the Blynk app, from anywhere as long as there is internet access but it also gives them control over the Lora Wi-Fi node's relay.

Conclusion and Future Work

In conclusion, the project's goal of developing multi-node wireless communication for the efficient management of an Internet of Things hydroponic system has been accomplished. In order to accomplish it, ESP32-based nodes with a variety of sensors and LoRa communication technologies have to be integrated. Analysis of data transmission in various scenarios, including both Line of Sight (LoS) and Non-Line of Sight (NLoS), yielded important information about signal strength and packet loss.

Based on the study and research done, the automated hydroponic system design that has been suggested exposes a number of important conclusions. First off, three to five nodes are the ideal amount for effectively transmitting data to the master node without experiencing any packet loss. Next, if the transmitter's time delay is adjusted to 10 seconds, all data will be received without any packet loss. Thirdly, there is a 50-meter maximum effective distance restriction for Wi-Fi Direct data transfer (Node-to-Node). Technology can no longer reliably sustain communication beyond this distance. Similarly, the maximum effective distance for LoRa- enabled data transmission is determined to be 100 metres for this type of module. The system's network architecture gains a specialized wireless communication component with the integration of LoRa Sx1278. The LoRa Gateway and sensor nodes can communicate wirelessly over long distances due to these modules.

In order to guarantee strong and dependable communication within the given boundaries, these distance restrictions must be considered while fine-tuning and optimizing the suggested design.

Therefore, the distance can be placed further than 150m by adding an acknowledgement code at both transmitter and receiver to notify the data has been received, in case if the data loss in transmission the receiver will acknowledge the transmitter to resend the data back.

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