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LoRa-Based Wireless Sensor Network Testbed for Precision Agriculture Application

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***Abstract*—Over the past few years, Wireless Sensor Network (WSN) has seen many improvements, and there are various applications of WSNs in various domains. Most communication technologies have a trade-off between distance and power consumption, i.e., to reach a longer distance, high power is consumed. LoRa overcomes this problem by consuming less power and transmitting small data packets for a long distance. The objective of this research work is to use LoRa technology in Precision Agriculture applications to help the stakeholders in better decision-making. A small experimental testbed is set up for precision agriculture applications. This testbed had sensors to monitor pH, soil moisture, soil temperature, and NPK parameters. An Automatic Weather Station (AWS) is set up to monitor ambient weather parameters- temperature, humidity, rainfall, wind speed and direction, barometric pressure, solar radiation, and leaf wetness. These sensor parameters were collected at the LoRa Gateway and forwarded to a network server hosting the The Things Network (TTN) LoRa stack. Transmission statistics are collected and analyzed for this application for remote monitoring of agricultural farms for quick and efficient decision-making.**

***Index Terms*—AWS, LoRa, LoRaWAN, Precision Agriculture, TTN, WSN**

I. Introduction

Agriculture is the backbone of a country like India. Knowledge about agriculture practices was handed down from generation to generation in a family. But with reduced affinity to take up agriculture as a profession this traditional knowledge is being lost. Further, depleting water resources, increasing food shortage, need to adopt a large-scale operation model have necessitated the use of technology in agriculture. According to United Nations Food and Agriculture Organization, the global food requirement in 2050 will be 70% more than that in 2005-07 [1]. Thus, it is necessary to adapt technology in agriculture to optimize the available resources and increase the yield. Precision Agriculture (PA) is basically driven by real-time data to manage the variations in the environment, measure various environmental parameters, and build a better decision support system using predictive analysis. The advent of the Internet of Things (IoT) has seen the evolution of applications like precision agriculture.

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IoT helps generate relevant data for agricultural stakeholders using various sensors to monitor the soil condition, ambient weather, and plant health. The stakeholders use the data for better decision-making to increase productivity and returns. However, deploying a communication network with more sensors in an agricultural field is challenging.

A. About LoRa

LoRa (Long-Range) is an RF modulation technology for Low Power Wide Area Networks (LPWANs) designed by Semtech Corporation and has the ability to communicate up to 5 km in urban areas and up to 15 km or more in areas that have a clear line of sight. LoRa's ultra-low power requirement is another key characteristic that enables devices to operate for extended periods of time. LoRa is best suitable for deep indoor coverage, which includes multi-floor buildings, and it follows star topology for network design [2]. In the LoRa communication network, the messages are forwarded via a Gateway. The number of messages supported in a network depends on the number of gateways available in the network. The cost of deploying the LoRa-based network is very cheap and the operational cost is also very minimal.

LoRa uses a proprietary spread-spectrum modulation technique derived from Chirp Spread Spectrum (CSS). The lifetime of LoRa devices is improved using the concept of orthogonal spreading factors which make adaptive optimization of each node's power level and data rates. The spreading factor (SF) is decided based on the distance between the end device and the gateway i.e., low SF is required when the distance is less. RF transmission achieves a longer distance using code sequence multiplication. This also helps in lowering the signal-to-noise ratio (SNR) during transmission. There are different SFs available for uplink and downlink transmission. Uplink at transferred at 125 KHz channel with four different SFs (SF7 to SF10). The transmission bit rate is high is lower SF and the time on air is relatively less when compared to higher SFs. Downlink messages are broadcasted over 500 KHz channel with 6 different SFs (SF7 to SF12). Since LoRa operates in broadcast mode there are chances of collision when two packets using the same spreading factor arrive at the same time. But if one of the packets is stronger by 6 dB then it will pass through.

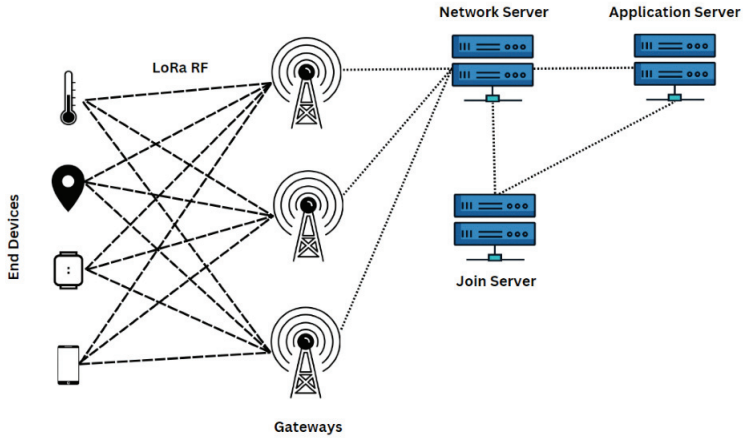

Fig. 1. A typical LoRAWAN Network Deployment Scenario

B. About LoRaWAN

LoRa is the physical layer (PHY), a wireless modulation technique used for long-range communication. LoRaWAN is an open networking protocol that delivers secure bi-directional communication, mobility, and localization services standardized and maintained by LoRa Alliance. The following are the major network elements available in LoRaWAN communication:

- LoRa-based End Devices
- LoRaWAN Gateway
- Network Server
- Application Server
- Join Server

LoRa-based End Device is a sensor or an actuator that is wirelessly connected to the LoRaWAN network through LoRa RF modules. LoRaWAN gateways receive LoRa packets and forward them to Network Server. There is no association between end devices and gateways, this reduces packet error rate. The gateway is also responsible to check the integrity of the uplink message by checking the CRC of the message. The uplink messages with correct integrity are forwarded to the network server. While forwarding the uplink message, the gateway adds some metadata, such as RSSI. RSSI value is used to determine the range of the gateway. The network server can receive multiple copies of the same message. The network server shall select the message based on RSSI value, and also, the downlink message will be sent to the gateway, which sent the message with the best RSSI value. Fig. 2 shows a typical LoRaWAN Deployment Scenario.

The network server is the one responsible for managing the network, adapting to the dynamic changing environment, and also establishing a secure communication channel for transferring messages. The application server is used to manage, interpret and store the collected data from the end devices. It also sends application-layer downlink messages to the application running on end devices. The other interesting salient feature of LoRaWAN is adaptability. An end device can be added to the network anytime – this is referred to as an on-air-activation process. The join server handles join requests and responds with the join accept frame.

C. Security in LoRaWAN

LoRaWAN network provides two aspects of security, one is device authentication and message confidentiality. Only authenticated devices are allowed to join the network. And each message is encrypted using AES with 128 bits key. The other security features are no eavesdropping, no replay attack and traffic flow cannot be altered.

II. Literature Review

The need to use IoT technologies in precision agriculture is inevitable now. There are different wireless standards and protocols to be used in precision agriculture. For precision agriculture applications, the amount of data generated is high, but the size of the data is very less. In most of the existing protocols and standards, the power consumption is directly proportional to the distance [3]. Because of this, most of the solutions are not suitable for precision agriculture applications. However, NB-IoT technologies such LoRa is really helpful in transmitting small data over a long distance with less power consumption.

Alessandra Dutra Coelho *et al*. [4] projected a network-server-based communication network using LoRaWAN for Precision Agriculture. The project acquires data from various sensors and sends the collected data to a Network Server using LoRaWAN technology. A Smart Mushroom House framework was developed using LoRaWAN by Nik Hisham Nik Ibrahim *et al*. [5]. The framework used three sensors such as temperature, humidity, and CO2 sensors, for measuring the change in the environment. The data collected from these sensors were disseminated to the gateway using LoRaWAN. Further, the data collected is analyzed and the control devices are activated based on the data analysis. This experiment also shows the average power consumption of LoRa devices is very minimal. The framework has helped in the good growth of mushrooms in terms of thickness and weight.

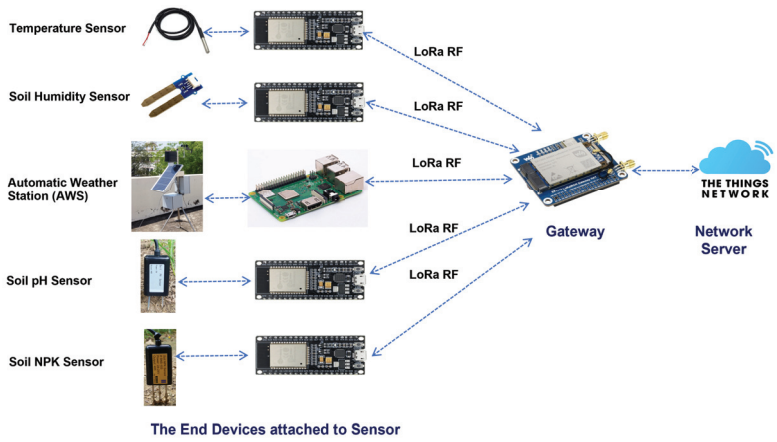

Fig. 2. A 5-Node Experimental Setup connected to a single Gateway

An experimental study was conducted in an academic institution to study about LoRa coverage and transmission [6]. The study has given more insights into LoRa network deployment and scalability. The nodes and the gateway should have a clear line of sight with no obstacles for better coverage. The number of gateways in the network setup is also determined by all nodes' Spread Factor (SF) rather than the coverage distance. The path loss exponent should also be considered to determine the number of gateways/nodes. In terms of scalability, for city-scale deployment, more gateways are required to cover a distance of 500m, and this increases installation and operational costs. Performance metrics is very essential to determine the efficacy of the network. The performance metrics such as Received Signal Strength Indicator (RSSI), Packet Error Rate (PER), Signal-to-Noise Ratio (SNR), Packet Reception Rate (PRR), Data Extraction Rate (DER), etc., shall be used to determine the performance of the network [7].

LoRaWAN-based low-power sensor network was designed for precision agriculture applications like greenhouse sensing and actuating [8]. The design used relatively cheap components, including sensors. The data collected from the reference sensor and low-cost sensors are transferred to the LoRaWAN Gateway and TTN. A dashboard was designed with Web Technologies to visualize the collected data. A low-cost IoT-based monitoring system was proposed for precision agriculture. The proposed design uses LoRAWAN for communicating with two end devices. One of the end nodes is accessible to WiFi, and the collected data are disseminated to a cloud-based server for storage. The test result concludes a critical observation that the probability of success in reaching a higher distance depends on the small packet length [9].

A LoRa-based sensor network was designed for agricultural monitoring. The network was constructed using open-source hardware, which reduces the network implementation cost. Also, the network was capable of sending a low volume of data to long distances with less power consumption. The network has a single-channel LoRa receiver mounted on a Raspberry Pi board which acts as a gateway. LoRa eXchange (LoRaX) protocol was used as a communication protocol between sensor nodes and gateway. The sensor nodes in the network use a novel collision handling protocol to avoid any data collisions. The proposed architecture was very easy to deploy and maintainable [10]. One of the most used wireless telecommunication networks is Cellular Networks. Cellular Network has become popular due to its wider coverage. A cellular communication-based low-cost wireless sensing system was designed for precision agriculture [11]. The end nodes in the network use 868 MHz radio frequency to send sensor data to a coordinator node. The coordinator node, in turn, forwards the data to the cloud server by using a 4G communication network. The coordinator node consumes more power as it is performing more energy-demanding operations.

Dushyant Kumar Singh *et al*. proposed a state-of-art solution for local weather monitoring in [12]. The design in this work considered using soil and weather conditions for intelligent irrigation-based systems. The importance of soil health and ambient weather condition is very essential for the better growth of crops. And that helps in planning and optimizing various resources. The parameter consideration is very crucial in urban and precision agriculture. LoRa connectivity is integrated with the commonly used Programmable Logic Controllers (PLCs) for smart farming applications [13]. To automate various activities and to control different machines, PLCs are been used in agriculture applications. The controlling is actuated using the commands triggered via a LoRaWAN communication network. The experimental results conclude that LoRa is an effective technology for smart agriculture applications. Although the usage of LoRa in precision agriculture is promising, there are some challenges that need to be considered while applying LoRa technology. Some of the significant challenges with LoRa are co-existence with other radio technologies, allocation of channels, and mitigation of interference, there are chances that LoRa frames can be demodulated using low SNR and cross-technology transmission. The development of new hardware is required to support the deployment of LoRa networks [14].

Fig. 3. Automatic Weather Station

III. Experimental Setup

As already mentioned, the LoRaWAN-based communication network shall have three basic network elements. The following components are used in this experimental study:

- End Device – ESP32 + Sensors + LoRa RF
- Gateway – SX1302 LoRaWAN Gateway HAT
- Network Server – The Things Network Stack

An End Device is a combination of ESP32 Microcontroller [15] along with Sensors and LoRa-Ra-01 RF Transceiver module. For the experimental study, sensors such as probe based Temperature Sensor, Grove Soil Moisture Sensor, Soil pH Sensor, and Soil NPK Sensor are used. The end device is programmed using MCCI-Catena – Arduino LMIC (LoRaWAN-MAC-in-C) library, which is basically used to send and receive uplink and downlink messages.

The end devices communicate with other external networks such as the Internet using Gateway or Concentrator. SX1302 LoRaWAN Gateway HAT mounted over Raspberry Pi is used. The Raspberry Pi runs an application called Packet Forwarder which is used to send/receive, uplink/downlink messages. The packet forwarder application requires a configuration file in JSON format containing all details such as Frequency, SF value, RX Power, etc., The IP traffic from Gateway is routed via Wired Ethernet connectivity. The Network Server is responsible for storing the data sent by the Gateway. The Things Network (TTN) Stack Community Edition was used [16]. The Things Stack architecture is based on microservices, and it allows for scaling, service distribution, and interoperability with other LoRaWAN networks.

A small experimental setup shown in Fig. 2 was constructed with 5 End Devices, a LoRaWAN Gateway, and a Network Server. One of the end devices, Raspberry Pi [17], was interfaced with the Automatic Weather Station (AWS). The AWS collects ambient weather information such as air temperature, relative humidity, wind speed, wind direction, solar radiation, barometric pressure, leaf wetness, and rainfall. The ambient weather information collected by the Raspberry Pi end device is shown in Fig. 5. These parameters help determine climatic change and make decisions on seasonal cropping. Also, the information shall be used to control other vital parameters for plant growth. The AWS was procured and installed. The data collected through AWS is interfaced with Raspberry Pi using a socket interface. The interfaced data is transmitted to the gateway using the LoRa Radio module. The AWS deployed is shown in Fig. 3. Each end device is uniquely identified by two EUIs (Extended Unique Identifier): Application EUI and Device EUI. Both EUIs are 64-bit identifiers. Apart from EUIs, each end device shall have an Application Key for secure transmission of data between the Gateway and the network server. As a first step, the EUIs must be registered in the network server; only then is the device join request accepted.

Once the end device is up, the device sends a Join Request to the Join Server. In this case, the Join Server is TTN. The request contains three fields JoinEUI, DevEUI, and Device Nonce. The Join Server authenticates the device and returns a Join Accept message to the end device. The Join Server shall send JoinNonce, NETID, and DevAddr as part of the Join Accept message. The end device shall derive a session key by using all these field values. The session key is used for secure communication with the Network Server and end-to-end secure communication with the Application Server as well. Fig. 4 shows a single-end device with a pH Sensor attached to

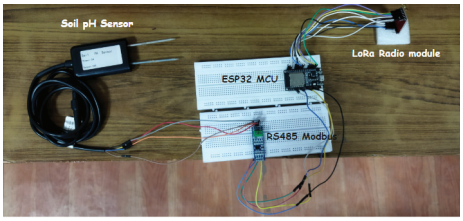

Fig. 4. A Single End Device with pH Sensor attached to ESP32 along with LoRa Radio Module

Fig. 5. Automatic Weather Station Interfaced with Raspberry Pi to collect Ambient Weather Parameters

the ESP32 microcontroller along with the LoRa Radio Module.

Time Synchronization in End Devices

The Gateway is attached to a back-haul network using a 4G Modem. The end devices must be synchronized with the Gateway so that data transmission can be scheduled. Each node reads data from the attached sensor and transmits the data to the Gateway at an interval of 60 seconds. Once the end device boots up, it sends its identifier to the Gateway for registration. This registration happens asynchronously. Once the registration is successful, the end device sends a time request frame to the network server via Gateway. The network server shall reply with a timestamp, and that will be used as a reference time in the end devices.

Data Analysis and End User Mobile Application

The data collected from various nodes is stored in TTN Cloud Storage. The data is made available to the stakeholders, such as farmers, agriculturists, pedologists, etc., through a Mobile Application. The mobile application interfaces with the TTN Cloud Storage to get the stored data. The stakeholders may be interested in very recent soil and ambient weather readings. The stakeholders can view Soil Parameters and AWS Parameters anytime and anywhere. For certain types of crops, it is necessary that some of the soil parameters, such as pH, humidity, temperature, etc., have to be maintained to some range. Failing so, the crops may die, or it may lead to less yield. To monitor the soil parameter values, a monitoring application was designed. The various soil parameter threshold levels can be configured using the monitoring application. The monitoring application also interfaces with the cloud data and sends a notification to the registered mobile number via SMS when any soil parameter goes out of the threshold range. Fig. 7 shows the screenshot of a mobile application displaying Soil and AWS Parameters.

IV. Results and Discussion

The 5-Node experimental setup is tested with European Frequency Band (EU868). The end devices are placed at different locations far away from Gateway. The Gateway is configured to use only a single channel for data transmission and reception. For downlink transmission, SF7 was used as a spreading factor with a 500 KHz channel, and for uplink transmission, SF8 with a 125 KHz channel was used.

Each end device is configured with a simple TDM algorithm to transmit sensor data at an interval of 60 seconds. The Gateway was able to receive all 5-Node's data without any collisions and packet drop. There was no mismatch in CRC, and the packet error rate is 0%. The experimental setup was tested for 24 Hours. During the testing window, each node was programmed to send a data packet every 60 seconds. 1440 data packets were transmitted by a sensor node. The Gateway received $5 \times 1440 = 7200$ data packets in total. The Gateway handled all data packets and forwarded them to the TTN cloud. Also, the Gateway sent an acknowledgment for each data packet. Table. I summarizes the statistics collected in Gateway. Fig. 6 shows the live data sent by an end device to the cloud server.

The mobile application sends a data query through APIs. The API is responsible for getting data from the cloud. The most recent data available in the cloud server was displayed in the mobile application.

TABLE I
GATEWAY: DATA TRANSMISSION - STATISTICS

Size of End Device Packet	20 Bytes
Packets Forwarded	7200
Packets Received	7200
CRC OK	100%
CRC FAIL	0%
NO CRC	0%
Datagram Size	205 Bytes
Acknowledged Rate	100%
TX Errors	0
TX Rejected (Collision Packet)	0
TX Rejected (Too Late)	0
TX Rejected (Too Early)	0

V. Conclusion and Future Work

Monitoring of soil parameters and ambient weather parameters is critical in precision agriculture. The monitoring shall help to make better and more efficient agricultural decisions. A small experimental setup was designed to collect data from various sensors, with a 5-node setup, the LoRa-based communication network was working without collisions, packet drop, CRC failures, and packet errors. This shows that LoRa technology best suits Urban and Precision agriculture applications.

The experiment shall be further enhanced to adapt some of the other features, such as the European Frequency Band (EU868) to be replaced with Frequency Band for India, add more data analysis components and present the results more visually using graphs/charts and, the 5-node setup can be scaled to add more nodes with some additional sensors.

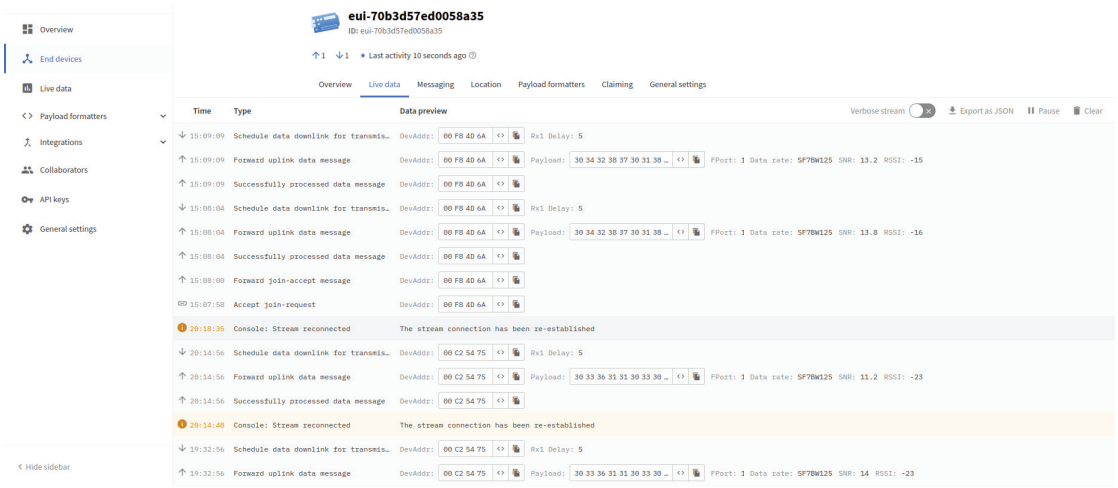

Fig. 6. Live Data of one of the End Devices in the Cloud Server

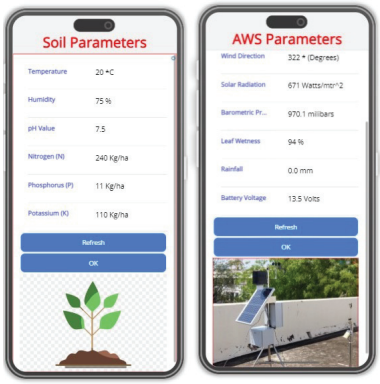

Fig. 7. Mobile Application displaying Soil and AWS Parameters

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