A LoRa-Based Monitoring System for Agriculture

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***Abstract*—In this paper, we present a LoRa-based monitoring system implementing LoRa with simple MAC (medium access control) architecture as a lightweight alternative to more complex LoRaWAN systems for agricultural applications. Our developed system consists of several low-cost and low-power remote sensor nodes with LoRa transceivers in a star topology with a custom-built .NET data-logging and control application acting as the central node. Despite using LoRa without LoRaWAN, we were able to demonstrate the reliable collection of remote sensor data and control of remote nodes through field trials of the novel system conducted on a working cattle farm.**

***Index Terms*—LoRa, Internet of Things (IoT), smart agriculture, Low Power Wide Area Network (LPWAN), Wireless Sensor Network (WSN)**

I. Introduction

Agriculture is critical to support the world's increasing population. A United Nations report estimates that by 2030 the world's population could grow to around 8.5 billion, and reach 9.7 billion by 2050 [1]. This increasing population motivates existing farming practices to be modernised to increase efficiencies and improve production. With advances in technology and the need for increased efficiencies, farms are moving towards implementing smart and automated systems and adopting the IoT (Internet of Things) platform. IoT advances traditional farming with field and system monitoring through remote sensors and actuator control. Having live data on soil and crop health, machinery condition, animal behaviour, temperature, and environmental conditions allows for efficient and effective decision-making, enhancing quality, productivity, and resource optimisation in agriculture [2].

LoRa (from 'Long Range') is a wireless communications technology that is increasingly being used in agriculture. Its robustness, long distance, and low cost make it a superior choice for communications between farm sensors and actuators than other commonly used IoT communications technologies [3]. LoRa is a Low Power Wide Area Network (LPWAN) wireless communication technology [2], [4]. Due to the limitations or absence of cellular and broadband connections, rural and agricultural environments often become fully reliant on adopted wireless networks for IoT communications [5]. LoRa is a popular choice for this application, with its ability to form wireless sensor networks (WSNs) using inexpensive and low-power LoRa transceivers, microcontrollers, and sensors that can be installed in remote locations and powered from standalone power systems harnessing solar or wind energy.

The benefits of implementing smart and automated systems to enhance existing farming practices has been well-researched, showing consequent increases in efficiencies and production [2]. LoRa agricultural applications include monitoring weather, soil moisture, water storage and irrigation, security, and machinery and crop health [3].

Fig. 1. Solar-powered remote node mounted to fence post.

A. Problem Statement

There has been considerable research on the application of IoT to farm automation. However, this literature is often confined to studies of particular application types or characteristics and often use LoRaWAN implementations that are complex and cloud-based. Such implementations are often excessive for smaller agricultural producers with complexity and unneeded features potentially reducing deployment. There are fewer publications discussing the benefits of a simpler approach, of a more native LoRa implementation. This research aims to present an implementation of LoRa with simple MAC architecture as a lightweight alternative to LoRaWAN, exploring the real-world suitability through deployment in a working farm environment.

The remainder of this paper is structured as follows: Section 2 provides an overview of LoRa and reviews related research, Section 3 describes our methodology, Section 4 presents our findings and discussion, and Section 5 summarises this work and presents areas for future research.

II. Background

A. LoRa and LoRaWAN

LoRa is a low-power, long-range, but low-data-rate wireless communications technology promoted as an infrastructure solution for IoT devices to wirelessly communicate between nodes and gateway devices [6]. LoRa is a spread spectrum modulation technique using Chirp Spread Spectrum (CSS) [7]. CSS is very resistant to channel noise and frequency selective fading [8]–[9]. LoRa transceivers use the Industrial Scientific and Medical (ISM) bands and does not require licensing [4]. LoRa can reach distances up to 15 kilometres in rural areas, with a maximum data rate of 62.5 kilobits per second [10].

It is important to understand the difference between LoRa and LoRaWAN. Both terms appear commonly when discussing the wireless communication technology and are often misleadingly used interchangeably. Relating to the Open Systems Interconnection (OSI) model (as illustrated in Fig. 2), LoRa is the lower physical layer which defines the modulation scheme used to create the communications link [8]. LoRaWAN is a networking protocol that sits above LoRa. LoRa is proprietary and owned by Semtech, whereas LoRaWAN is open and maintained by the LoRa Alliance [7]. LoRaWAN, as the higher layer protocol, has weaknesses such as network scalability and complexity due to the number of devices and services required to form a typical implementation. LoRaWAN networks are usually constructed as a star or star-of-stars network with a LoRaWAN gateway device centred at each star network. LoRaWAN gateways mediate the communications to end devices and link the network to the internet [4]. LoRaWAN systems can be purchased off-the-shelf with implementations comprised of end devices, gateways, network and application servers, and dashboards or data portals [8]. Although more complex, LoRaWAN provides many additional features such as integration with cloud services and external systems.

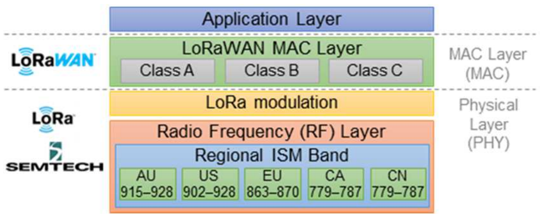


Fig. 2. LoRa and LoRaWAN protocol layers are illustrated as a technology stack [8].

B. LoRa Transceiver

Instead of having to manage the complexities of LoRaWAN, a simpler yet just as effective system can be developed using LoRa transceivers without LoRaWAN. The LoRa transceiver modules transmit and receive bytes of data in the form of messages. The implementation of the modules is that elementary; the message can contain any kind of data the application needs.

Many LoRa transceiver modules are available and are typically interfaced with microcontrollers over UART (Universal Asynchronous Receiver-Transmitter) serial communications. Manufactured by Ebyte Technology, we use the E220-900T22D modules in this research. Ebyte claims a range of up to 5 kilometres and a transmit power of up to 22 dBm. The transceivers operate within the 850.125–930.125 MHz frequency range. The message size is configurable up to 200 bytes and has a data rate of up to 62.5 kbps. The E220-900T22D transceiver uses Semtech's LLCC68 LoRa transceiver chip to perform wireless modulation [10].

C. Multiple Access Protocols

Multiple Access Protocols facilitate multiple nodes or users sharing a common communication medium. The protocols operate within the MAC layer of the OSI model [7]–[8]. Contention-based (random), and reservation-based (scheduled) approaches are mainly used for regulating access on wireless networks [11]. In reservation-based approaches, such as Time Division Multiple Access (TDMA), complete prior knowledge of the entire network is required so that a schedule can be decided. The nodes require strict synchronisation to obey this schedule. Implementation often requires significant and complex overhead; however, this approach does achieve a reduction in collisions by avoiding transmission between interfering nodes [11]. On the other hand, a contention-based approach is much simpler as there is no requirement of complete prior network topology knowledge nor global synchronisation. ALOHA is a popular contention-based protocol that transmits regardless of the medium state, dealing with collisions by retransmitting messages where an acknowledgement was not received [11]. Conversely, there are other contention-based protocols, such as Carrier-Sense Multiple Access (CSMA), that will wait until the medium is silent before transmitting [12].

D. Related Work

With the rapid adoption of the IoT platform in recent years there has been significant research into LoRa as a wireless communications technology used in long-range and challenging applications that were previously unfeasible with prior technologies like cellular or WiFi. LoRa is used in transport and smart city infrastructure [13], Internet of Medical Things (MIoT) [14], wildlife monitoring [15], and even in life-saving applications like natural disaster detection [16]–[17] and search and rescue [18] systems. However, agricultural environments seem to be where LoRa has found a significant niche, with increasing research exploring the implementation of LoRa enabling communications in farm IoT systems.

Published work on LoRa in agriculture almost always implements LoRaWAN as the network protocol. [3] presents a performance evaluation of LoRaWAN for agricultural systems using simulations to model real-world behaviour for hundreds of nodes; finding that a single-gateway LoRaWAN network can support up to 1,000 nodes with a minimum transmission interval of one hour and is suitable for agricultural sensors. [6] explores an aerial-based data collection system developed using LoRaWAN with unmanned aerial vehicles (UAVs) for livestock monitoring in rural farms. The UAVs achieved robust performance in collecting sensor data accessible through cloud infrastructure.

Using LoRa without LoRaWAN is less common; however, some research has been performed. [12] presents a prototype LoRa-based system for detonation of low explosives in underground mining. Using a relay network topology, [12] was able to develop a message-passing system in which control data is transmitted from an Initiator to a Detonator node through many Relay nodes. In addition to presenting an attractive alternative to more typical detonation signalling using infrared or copper cable, [12] describe their system as making a potentially dangerous industrial process safer than it currently is. Furthering this work, [9] explores the LoRa signal propagation in a similar application presenting measurements and analyses from an underground block cave gold mine. [9] found that LoRa propagates very well underground even without line of sight and has great potential for this very challenging application. Above ground, [19] characterises the propagation of LoRa in forest, urban, and suburban environments; concluding that signal stability greatly depends on the environment and is more stable in lower-density areas. The use of LoRa without LoRaWAN in agricultural systems is a largely neglected area and is the topic of this research.

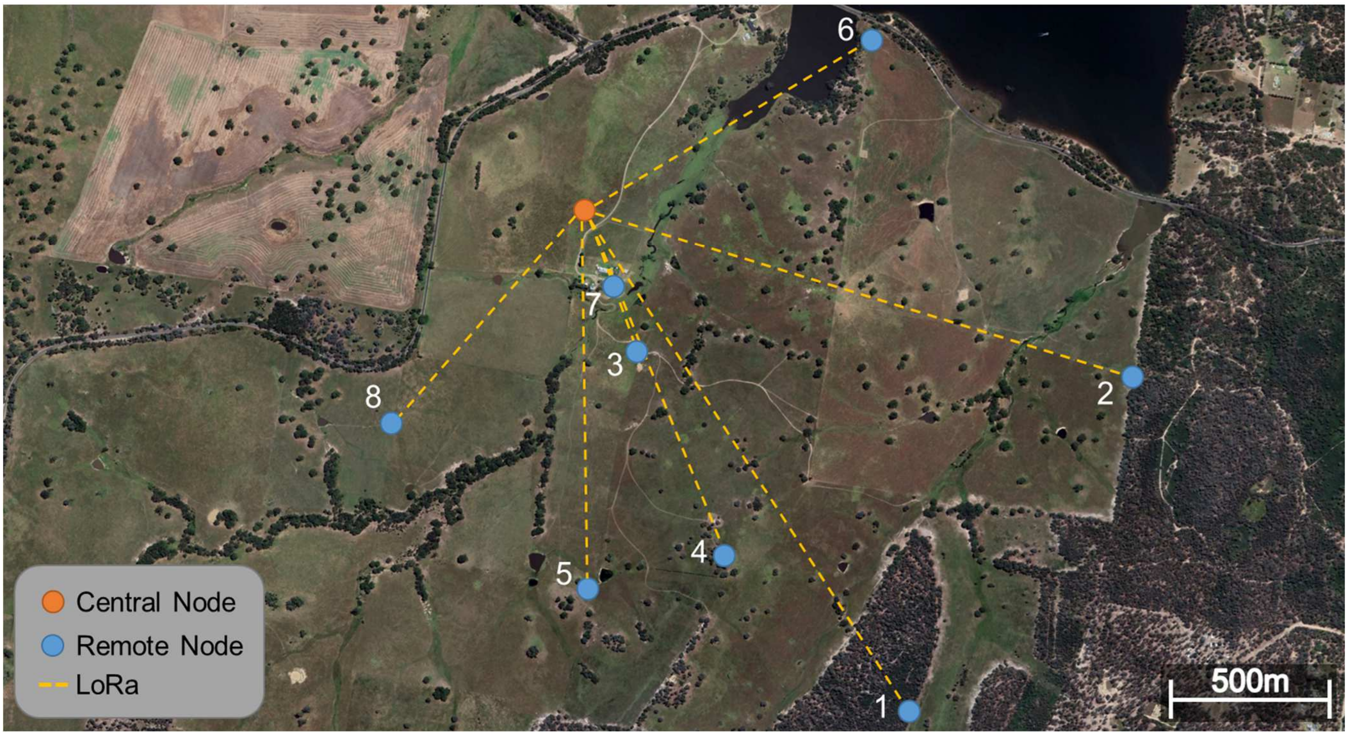


Fig. 3. Map of node deployments.

III. Research Methodology

A. System Design Overview

We deployed our system on a working cattle farm in Gippsland, in regional Victoria. The system consists of 8 remote nodes configured in a star network topology around a central node acting as the base node of the network, as illustrated in Fig. 3.

The remote nodes periodically transmit messages to the central node and provide temperature and humidity sensor data. Network performance and quality metrics were also recorded. The remote nodes were located within the test area aiming to provide a diverse range of installation environments that are representative of farm and agricultural deployments. The field research was initially conducted over a period of 5 weeks to enable analysis of performance across a range of weather and environmental conditions. The system was then left in operation for an additional 3 months collecting data from the remote nodes totalling a period of 124 days.

The central node is located on a private telecommunications pole used for supplying wireless broadband to the property, with power and network connectivity available. A small form factor industrial PC is located at the pole and interfaces with a LoRa transceiver module over serial communications. We developed a custom .NET application written in C# that executes on the PC to provide logic and control as the central node. The PC can be accessed remotely through the local area network (LAN) from the farmhouse, and externally over the internet through a virtual private network (VPN). The .NET application logs all messages to a local MySQL database and additionally to comma-separated values (CSV) text files for future analysis. By implementing a local database solution we are able to efficiently query the database to extract summarised system and performance data. Storing the data locally on the central node also ensures that our system is not dependent on a reliable internet connection. Where internet connectivity is available, the central node periodically updates a remote application programming interface (API) of a dynamically updating web page that we have developed for remotely monitoring the system. This web page, consisting of a map overlay with system data is shown in Fig. 4 and is available online at https://stevencumming.io/lora. Data is updated through the API every few minutes. This web page presents one method of visualising data from our system; though, with our chosen system design other methods can be easily developed and implemented.

Fig. 4. Dynamically updating web page with live system data.

The remote nodes were located within the test area in a combination of line-of-sight (LOS) and non-line-of-sight (NLOS) installations to explore the effect this has on performance. The remote nodes use a microcontroller to interface with external sensors and the LoRa transceiver. Being solar-powered and a small form factor, the nodes can be located on fence posts, gates, troughs, or even storage tanks as shown in Fig. 5.

Fig. 5. Remote node with water level sensor deployed on a water storage tank.

B. Communication Protocol

The multiple access protocol we developed is based on pure ALOHA. The remote nodes periodically transmit messages to the central node. The central node responds in acknowledgement, and the cycle continues indefinitely. Transmitting nodes begin message transmission whenever they are ready to send, regardless of the channel state. Sensor data is communicated by the remote node inside the message payload. Configuration data is also sent by the central node permitting dynamic updates to the system parameters. We chose a message length of 64 bytes to provide sufficient space for sensor and control data and still allow for efficient processing. With a short transmit interval, thousands of messages were communicated over the LoRa network for each day of field research. To measure the performance of the prototype system we have designed the protocol to monitor the number of successful and unsuccessful message attempts. This is achieved by indexing each message by the node address (of the remote node, as sender), and a sequence number. For each successful message transmission and subsequent acknowledgement from the central node, the sequence number is incremented. We refer to this successful two-way handshake as a completed transaction.

The period (transmit interval) is timed by the remote node. If an acknowledgement is not received from the central node within the defined period (often, we used 90 seconds) after transmission, indicating a collision has occurred, the remote node retransmits the message with the same sequence number — though with an incremented attempts counter to keep track of the number of retry attempts that were required for a completed transaction. Messages are validated to check that the recipient is correct (as a shared channel) and that the message is complete and valid using a checksum.

As the remote nodes share a common medium, the LoRa channel, we implemented a medium access control technique within the protocol. While the nodes are coarsely timed around the interval, with no accurate internal time-keeping mechanism the medium access is essentially random. This made the ALOHA protocol a suitable choice to model. We use a rudimentary contention resolution algorithm, forcing the remote nodes to wait for a random delay (between 5 and 15 seconds) before re-transmitting any unsuccessful message attempt. This behaviour can be toggled from the central node dynamically in the configuration data transmitted, permitting investigation of the impact on performance when used.

C. Form Factor and Hardware Design

As illustrated in Fig. 6, the remote nodes consist of only a few components: solar panel, battery, solar charge controller, antenna, NodeMCU microcontroller, and LoRa transceiver module. Additionally, sensor modules can be added to interface with the NodeMCU. Using the ESP8266 Arduino Core [20] architecture permits interfacing with many of the 'Arduino Compatible' sensors available in the market, often with supplied code examples and compatible libraries making implementation in the application trivial. In our application, we used DHT22 temperature and humidity sensors to monitor the ambient environmental conditions at the node locations. Additionally, one of the remote nodes was configured with an ultrasonic water level sensor to measure the water volume of a storage tank (Fig. 5).

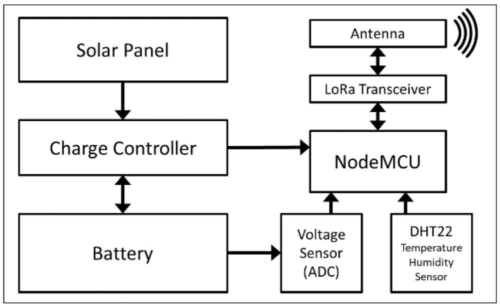
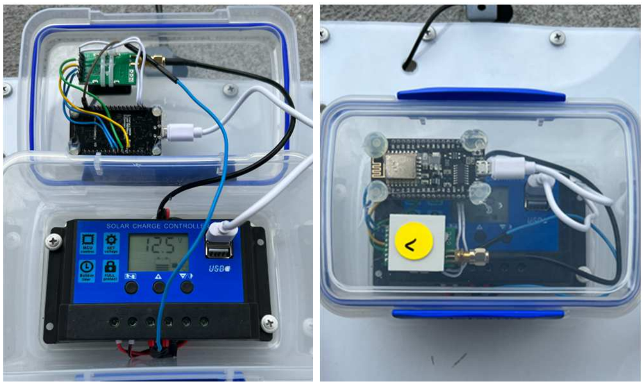


Fig. 6. Block diagram of remote node components.

The 10 W solar panel charges a 12 V 9 Ah deep cycle battery through a solar charge controller. The inexpensive solar charge controller performs energy management independent of the NodeMCU simplifying the application. With a built-in DC-DC converter, 5 V is supplied to the NodeMCU over USB. The solar charge controller also features low voltage disconnect functionality, in which the USB output is turned off in order to protect the battery from over-discharge. Depending on the node location and available sunlight, additional solar panels can easily be added to provide sufficient energy to power the system overnight.

The LoRa transceiver is connected to the NodeMCU providing power and communications. Sensors can be interfaced with the NodeMCU through the I/O (Input / Output) pins. The DHT22 uses a single digital input pin for its communication bus. To monitor the battery level we used a voltage divider circuit (two resistors in series) to lower the 10–14 V battery level to a proportional 0.6–1.0 V (15:1) level safe for the NodeMCU analog to digital converter (ADC). Fig. 7 shows the electronics mounted within a plastic container on the underside of the solar panel.

The small form factor of the remote nodes allows for versatility in mounting and installation. The electronic components can easily be fitted on the underside of the solar panel with only the battery located externally. Switching to a lower profile energy storage, for example, lithium batteries could further reduce the footprint even allowing for the system to fit enclosed within the solar panel frame. We gave preference to mounting to the top of gate strainers and fence posts (as shown in Fig. 8) as this provided a sturdy platform, protection from livestock, and befits the farm monitoring application. The battery is located underneath the solar panel providing sufficient protection from weather exposure.



(a) Underside of the solar panel showing the components.

(b) Components are secured within a sealed container.

Fig. 7. Remote Node.

Fig. 8. Remote node mounted on gate strainer post.

The low material cost of the remote nodes also makes them suitable for harsher applications where the nodes could even be used sacrificially. In areas prone to natural disasters, such as bushfires or flooding events, they could serve as an early detection system at scale with sensors to detect indicators (such as smoke, fire, or water) and eventually succumbing with ceased communications [16]–[17].

The central node consists of a LoRa transceiver module communicating over serial to a small form factor PC. In our system, a small industrial PC is mounted within a steel electrical enclosure on a private telecommunications pole. There is Ethernet network connectivity with internet access and 12 V power available to supply the PC. The LoRa transceivers were powered with 5 V from the PC USB port. Mounted approximately 3 metres above ground there is sufficient protection from livestock. The antennas were mounted at the top of the pole (approximately 5 metres above ground) and provided 360-degree unobstructed coverage.

D. *Coexistence*

To compare the performance impact of a saturated LoRa network with a single-remote node network, we fitted one of the deployed remote nodes with an additional LoRa transceiver, antenna, and NodeMCU to essentially act as an additional independent node. Only the solar power components are shared. It is configured to communicate on another channel, separate from the primary network.

The primary LoRa network operates on channel 74, which is 924.125 MHz. Offset by 4 channels (4 MHz), the single-remote node test network operates on channel 70, 920.125 MHz. The central node is similarly equipped with an additional transceiver and executes two instances of the .NET application each using their own LoRa transceiver connected over serial. The test network serves as a baseline to quantify the impact of channel contention and the subsequent reliability of the system. Being physically collocated helps to eliminate environmental variations so we can directly compare the network performance.

E. *Performance Analysis*

To characterise the performance of the network several metrics have been implemented and are captured in our communications protocol. The protocol similarities between our technique, pure ALOHA, and IEEE 802.3 Ethernet allow us to measure network performance using established metrics.

When the remote node receives a reply acknowledging the current transaction, and thus completing it, the sequence number is incremented. As such, the Packet Loss Ratio (PLR) can be calculated:

$$PLR = \frac{attempts - completed\ transactions}{attempts} \quad (1)$$

Per node, we can determine the average attempts required to complete a transaction (that is, attempts over completed transactions).

Additional metrics are recorded by the central node and logged for analysis: RSSI (Received Signal Strength Indicator) values are captured from the LoRa transceivers for both the transmitted and received messages and are measured in dBm, checksum error counters for message frames that fail validation, and the transmission interval is logged as this can be changed dynamically for each node.

Fig. 9. Central node installed on private telecommunications pole.

TABLE 1. KEY PERFORMANCE METRICS OF SYSTEM

Remote Node		Total Transactions	Total Attempts	Average Attempts	PLR	RSSI (dBm)	Success Rate (attempts = 1)	Success Rate (attempts ≤ 5)	Success Rate (attempts > 5)
1	1.80 km NLOS	22,852	39,531	1.73	42.19%	-105	82.52%	95.81%	4.19%
2	1.76 km NLOS	71,161	108,549	1.53	34.44%	-103	74.68%	97.87%	2.13%
3	0.45 km LOS	100,868	106,080	1.05	4.91%	-67	95.56%	99.99%	0.01%
4	1.11 km NLOS	65,310	108,019	1.65	39.54%	-102	76.81%	96.46%	3.54%
5	1.14 km LOS	72,714	107,494	1.48	32.36%	-86	78.37%	97.81%	2.19%
6	1.02 km LOS	99,944	106,105	1.06	5.81%	-69	94.35%	>99.99%	0.00%
7	0.23 km LOS	30,945	32,952	1.06	6.09%	-66	94.49%	99.98%	0.02%
8	0.86 km LOS	99,244	115,921	1.17	14.39%	-74	89.48%	99.63%	0.37%

IV. FINDINGS AND DISCUSSION

A. *Performance Overview*

Over the 124 days of field research, the system generated 1,287,689 messages that were recorded for analysis across the eight deployed nodes on the primary (shared channel) system. The remote nodes transmitted 724,651 messages, of which 563,038 were successfully received and replied to by the central node as completed transactions. This resulted in an overall PLR of 22.30%. Several considerations are attributing to this PLR, though overall, the results of the system are quite promising. It is necessary to analyse the variances that were tested to explore which of those factors impact the overall PLR. Table 1 highlights some of the key performance metrics.

While an overall PLR of 22.30% may not be representative of a highly reliable system it would be misleading to consider this in isolation. For a wireless sensor network and target application of IoT in agriculture, it is often not necessary to have a low PLR or guaranteed delivery for every message attempt. For sensors that have relatively slow-changing values, such as those typically found in agricultural applications, it may be sufficient to capture this within several message attempts with a fast enough interval. For example, we can examine the temperature data collected over the initial 33-day period for Node 6 within a single transmit attempt and interval of 90 seconds. 25,047 temperature data points were collected; of which 9,879 (39%) had no change to the previous reading, and another 9,817 (39%) had a change of only 0.1℃. 98.7% (24,723) of the temperature readings had changed less than 0.5℃ from the previous reading. Where the transmission took up to 5 attempts (where the duration between logged temperatures would be up to five times the interval, and in this example 7.5 minutes) there were similarly 98.48% of sequential readings differing by <0.5℃ and 99.89% within 1.0℃. For an agricultural application, this resolution and variation are typically well within acceptable limits, and we can establish that the integrity of the data is not adversely affected where a message may take several attempts to be received.

We can examine the number of attempts against the transactions completed for each of the remote nodes, as Fig. 10 illustrates. Node 1 while yielding the worst PLR of 42.19% with over 39,531 attempts, still completed at least one transaction within 5 attempts 95.81% of the time. Conversely, and most reliably, Node 6 was able to complete at least one transaction within 5 attempts for almost all (>99.99%) of the 99,944 recorded transactions. Similarly, Nodes 3, 7, and 8 each achieved a completed transaction within 5 attempts >99% of the time.

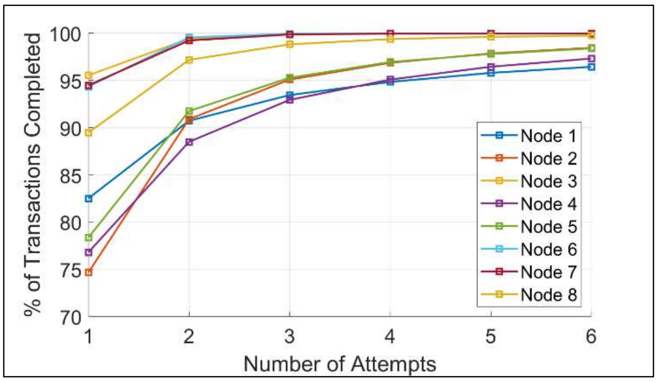


Fig. 10. Percentage of transactions completed by attempts.

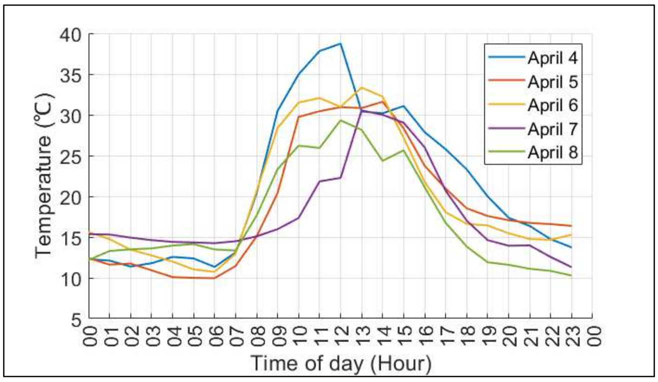


Fig. 11. Node 4 daily temperatures over sample period.

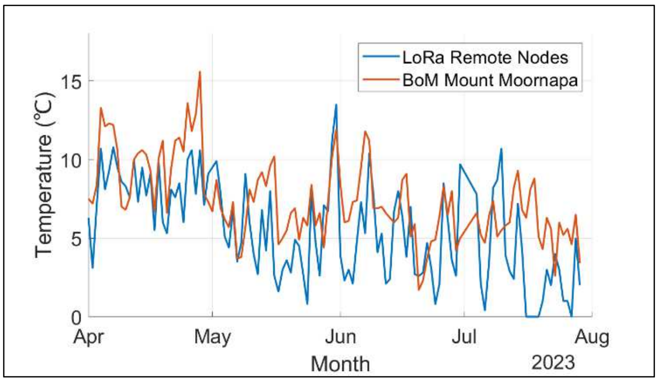


Fig. 12. Daily minimum temperatures recorded from both our system and weather station data oberserved at Mount Moornapa sourced from the Bureau of Meteorology [21].

Reinforcing the system application in farm automation, we can observe the real-world sensor data. Temperature data for Node 4 is shown in Fig. 11, where we can observe the average hourly temperature changes throughout the day over a sample of the test period. Fig. 12 shows the daily minimum temperatures recorded and averaged across each of the remote nodes and temperatures recorded by the Bureau of Meteorology weather station at Mount Moornapa [21] (located 40 km away and approximately 350 m higher altitude). Using this data, we can verify our recorded temperatures where the data closely matches. We can also observe the daily minimum temperatures trend cooler on the approach to the winter months. While dependent on the actual application of the sensor data, it is evident that our system is able to successfully produce and record real-world data.

B. Environment

The remote nodes were deployed in varying environments to be representative of agricultural deployments and as such have produced interesting and varied findings. The average RSSI values of the remote nodes (as outlined in Table 1) range between -105 and -66 dBm. LoRa typically has a lower limit of -130 dBm [7], as such the remote nodes all communicated satisfactorily within range. As the receiving and transmitting RSSI values for each node are expectedly similar, we can average those and relate them to the environmental conditions. Fig. 13 compares the averaged RSSI values observed for each node against their distance from the central node.

Line of sight was a major factor affecting signal quality. Nodes 3, 5, 6, 7, and 8 were each located with a direct line of sight to the central node. With a collective average RSSI of -72 dBm, the nodes were communicating with strong signal strengths. For comparison, when developing the system in the testing stages the nodes were communicating within 20 cm with an RSSI of approximately -60 dBm. Node 8, as shown in Fig. 14, has a line of sight of 856 m to the central node and a strong signal with an average RSSI of -74 dBm.

Conversely, non-line-of-sight deployments are expected to have a worse RSSI [7] which has been reflected in our system results. Nodes 1, 2, and 4 operated without line-of-sight to the central node and were communicating through hills and terrain. With an average RSSI of -103 dBm the remote nodes were still above the minimum acceptable signal strength. Nodes 1 and 2, being the furthest nodes did however have a significantly higher retry attempt average, and subsequently higher PLRs of 42.19% and 34.44%, respectively. Also with a comparatively high PLR, Node 4 at 39.54% was 1,110 metres from the central node and similarly did not have line-of-sight.

Terrain was an interesting factor, one that seems to have been largely inconsequential producing similar results to an open-field test at a similar distance. Node 1 was deployed in moderately dense bushland (Fig. 15). While an additional solar panel was necessary to compensate for the obstructed sunlight required to power the node, the RSSI was observed to be less than 2% higher than Node 2, which was in an open field and 40 m further from the central node. The PLR for Node 1 (42.19%) was notably higher than Node 2 (34.44%); though, in a practical sense, this only resulted in a 2.06% increase in transactions that required more than five attempts to complete. While the elevation profiles are similar for both nodes (Fig. 16), the bushland did not present significant deterioration to the node performance.

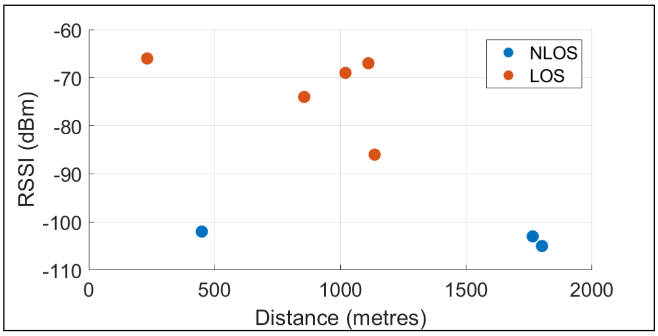


Fig. 13. RSSI over distance for LOS and NLOS.

Fig. 14. Node 8 facing Central Node, at 856 m.

Fig. 15. Node 1 deployed in bushland.

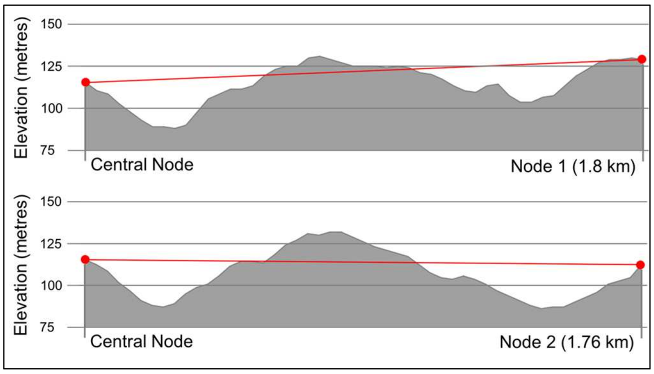


Fig. 16. Elevation profiles for Nodes 1 and 2 highlighting the lines of sight (red).

C. Scalability

The single-remote node test network resulted in 40,501 messages recorded, with 36,758 completed transactions over the initial 33-day test period. The overall PLR of 9.24% is considerably better than the 22.30% achieved by the primary (shared channel) system. However, it would not be feasible to separate single nodes on independent channels as a means of improving performance. There are limited channels available within the ISM bands, and it is impractical to have multiple transceiver modules, antennae, and interfaces installed at the central node. Instead, efforts should be made to improve channel utilisation with efficient MAC protocols allowing for higher density and better performance.

V. Conclusion and Further Work

In this paper, we have presented a LoRa-based monitoring system and have demonstrated that implementing LoRa with simple MAC architecture serves as a lightweight alternative to more complex LoRaWAN systems. We have shown that using LoRa without LoRaWAN can be just as effective at communicating sensor and actuator data from field devices. We have integrated antennae, transceivers, solar panels, and batteries as well as developed software for this agricultural monitoring system. Our work has shown that LoRa is cost-effective, useful, and reliable in agriculture. Through field research, we have demonstrated that LoRa potentially fills a gap where large and cloud-based systems are ill-suited.

As well as extending the system into other agricultural applications, future work will include the following: Understanding and characterising the impact of weather and seasonal changes over a longer term and the effects on signal quality and system robustness. Integration through the .NET application interfacing externally with other systems and databases, such as industrial automation systems. Exploration of other MAC protocols, including a full implementation of slotted ALOHA comparing against polling-based methods. Evaluating the suitability of additional sensor types using the NodeMCU I^2C communications bus to expand the I/O available. Exploring the use of more capable microcontrollers with additional processing and I/O capabilities such as the ESP32.

VI. References

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