Practical Precision Agriculture with LoRa based Wireless Sensor Networks

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Keywords: LoRa, Wireless Sensor Network, Precision Agriculture, Orchard, Vineyard.

Abstract: Precision agriculture is enabled by using real-time data to manage environmental variations, measure performance to improve upon previous seasons, and perform predictive analysis to make better growing decisions, resulting in higher production yields with lower production costs. Although beneficial, collecting and analyzing the environmental data is an expensive and complicated endeavor. Numerous existing wireless sensor network (*WSN*) solutions rely on protocols such as 802.15.4 b (LR-WPANs) and 802.11x (WLAN) but provide limited transmission range, complex communication stacks and data management, and high power consumption. Additionally, many existing services introduce challenges with data ownership and residency. These factors present a high barrier to entry for growers. The resources required to implement and maintain sensor networks are too high to justify the investment. This work presents an approach that uses inexpensive and effective hardware that is easily setup and maintained. Costs to implement the network are reduced through the use of open-source hardware. Transmission ranges and power consumption are improved by using long range (LoRa) radio transceivers. By addressing these limitations, growers will be better enabled to adopt new technologies, ultimately improving sustainability, viability, quality and profit margins in agriculture.

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1 INTRODUCTION

Precision agriculture is an approach to farming that uses information to ensure crops can grow in optimal conditions. Environmental variations can result from climatic conditions, soil composition, cropping practices, weeds, or diseases. Monitoring key point indicators allow growers to track their crop's status, which can help them to determine if crops are suffering from water stress, nitrogen stress, or if diseases are developing. Environmental variations result in loss of crops and inconsistent growth. When conditions vary, adjustments can be made to regular farming activities to control or stimulate growth in plants. The collected data is also useful for measuring performance and improving upon previous seasons. Using precision agriculture reduces production costs by mitigating waste. Ultimately, precise growers can produce higher quality products with fewer resources and increased profit margins.

Sensor networks have been extensively investigated for use in agricultural settings (Ojha et al., 2015; Jawad et al., 2017) to collect real-time environmental data. Early investigators experienced challenges with complexity of deployment, network connectivity and battery life (Beckwith et al., 2004). While systems can be deployed with a wire-based system that provides power and facilitates data transfer over a stable wired connection, they are inconvenient because large amounts of wire are needed to connect the sensor nodes. The wire must also be concealed in a manner that does not limit accessibility and is protected from machinery and environmental degradation. Damaged wires will disable some or all of the sensor network and will require user intervention to troubleshoot and restore functionality.

Wireless sensor networks were introduced to improve practicality. The wireless components are powered by batteries and connected through a wireless medium. Figure 1 depicts a typical wireless network deployed in an agricultural setting. The sensor nodes (blue pins) are deployed strategically across a field within range of the central gateway (orange pin) and depending on the choice of transceiver, modulation technique and allowable transmission power, nodes may communicate directly with the gateway or require intermediate nodes to act as cluster-heads and

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Gresl, J., Fazackerley, S. and Lawrence, R.
Practical Precision Agriculture with LoRa based Wireless Sensor Networks.
DOI: 10.5220/0010394401310140
In *Proceedings of the 10th International Conference on Sensor Networks (SENSORNETS 2021)*, pages 131-140
ISBN: 978-989-758-489-3
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Figure 1: A potential node deployment in a grape vineyard.

facilitate routing to the gateway (Heinzelman et al., 2002; Fazackerley et al., 2009). The gateway is connected to the Internet to allow remote users to monitor the different growing parameters that can be used to improve decision making in an agricultural setting. A database stores the sensor data and is accessible through the network for configuration and sensor data analysis (Ojha et al., 2015).

Although wireless sensor networks are more practical than wired networks, they also come with their own set of challenges and limitations. The hardware required to setup a network to cover large rural areas is expensive. There is also a significant amount of effort required to setup or modify the network. WiFi or Bluetooth protocols can be used for the data transfer, but are complicated protocols that provide limited transmission range with high power consumption. While mesh networks can be constructed to increase transmission range, it increases the complexity of the solution, leading to higher power consumption and increased network traffic. Both WiFi and Bluetooth protocols have high overhead that are unnecessary for applications in agriculture.

For agriculture sensing networks, barriers to entry are high costs, complexity, and power consumption. High costs discourage growers from wanting to invest in the technology without a clearly identified return. Deployments need to be accessible to users and straight forward to implement and expand. Finally, devices must be power efficient reducing the need for continual service.

In this work we propose a sensor network data exchange and control protocol targeted for agricultural applications. The system is based on LoRa (Semtech, 2020) physical layer transceivers which are commonly available in low cost formats. The contributions of this paper are:

- A self-determining distributed time slot transmission algorithm and novel collision protocol
- An architecture for node management and control
- A localized data management strategy
- A deployment of a prototype system, directly applicable to real-world agricultural challenges.

The paper outline is as follows. Section 2 presents an overview of previous approaches and discusses the LoRa protocol. The proposed architecture, communication and control and time slot algorithm are presented in Section 3. Discussion of the practical deployment is in Section 4. The paper closes with future work and conclusions.

2 BACKGROUND

The Okanagan Valley is one of Canada's principal fruit growing regions. The semi-arid region is an agriculturally intense area stretching 200 km north from the US border and is approximately 20 km wide. The region presents exceptional growing conditions with hot summers and relatively mild winters. Extensive information on soil conditions is available with areas of high productivity stretching along a series of long, deep narrow lakes which help to regulate growing conditions for different tree-fruit and grape varieties. In terms of agriculture in British Columbia, the majority of the province's tree fruits are produced in this region, including extensive high-value cherry production for the Asian market as well as grapes for wine production. The Okanagan Valley is one of the largest fruit and wine producing areas in Canada.

Figure 2: Scab infected apples showing the development of lesions on the foliage and fruits[1].

Due to the geography of the Okanagan valley, growing regions are small with many compact growing operations. The margin on fruit crops is low due to increasing operational costs and climate variability.

[1]Shuhrataxmedov, CC BY-SA 3.0 https://creativecommons.org/licenses/by-sa/3.0 via Wikimedia Commons

Figure 3: Grapes infected with powdery mildew[2].

Interest has focused on how precision agriculture can improve crop quality and increase profit margins.

In the fruit growing industry, growers are often faced with making decisions based on limited information for the well-being of their crop. Interest has grown in the area of disease modelling to better predict and manage the crop. With a more in-depth understanding of crop growing conditions, predictions can be made to help manage disease outbreaks with minimal cost leading to higher overall crop quality. Two key crops where sensor-based precision agriculture can significantly impact growing decisions leading to improved yield and profit margins are apples and grapes. Apple scab (Figure 2) is a common and ongoing disease caused by the Ventruia inaequalis fungus in the wetter interior growing regions. In the Okanagan Valley it is especially common in years with above average rainfall (AgriService BC, 2018).

With wine grapes, similar challenges exist with the development and management of the fungus Uncinula necator. It causes grape powdery mildew which attacks grape plants and limited related species. For popular wine grape varieties in the interior of British Columbia, it is the most common and widespread disease of grapevines (British Columbia Ministry of Agriculture, 2015).

While both diseases significantly impact local fruit crops, disease modelling and forecasting for improved management can be done with temperature and leaf wetness sensors (Garofalo and Cooley, 2020). In many cases, modelling is completed with a limited number of data input points. With early model tests in the Okanagan valley, accuracy was reduced due to model variability based on local conditions (British Columbia Ministry of Agriculture, 2015); more temporal and spatial data is needed for accurate modelling. While commercial systems are available, they are cost prohibitive to many growers as they require not only hardware costs but ongoing fees for data access. This presents additional barriers for growers as they do not have direct control over their data. While larger data sets over a wide area help to improve modelling and prediction allowing growers to better visualize and predict risks during a growing season, current solutions present barriers to adoption due to cost and complexity of implementations.

2.1 Sensor Networks

In the design of low-power wireless sensor networks, energy consumption is a key factor. Transmission of data costs more in terms of energy than local storage and processing (Pottie and Kaiser, 2000). Sensors typically have been a small 8-bit processor with limited local memory, a series of sensors and a transceiver for communications (Akyildiz et al., 2002). Processors are often chosen based on cost, memory and energy efficiency. Energy efficiency is a key consideration as it impacts the usable life of a sensor in the field before having to be serviced or replaced. A device or sensor node is required to last for an extended period of time without service. Previous research has led to the development of numerous sensor platforms such as the MicaZ and TelosB nodes. These have been replaced by a number of low-cost, open source platforms such as the Feather M0[3] that include numerous transceiver options. These new platforms offer significantly increased processing speeds and memory capacity, due to the introduction of low-cost and high-speed 32-bit ARM based cores. This creates a further opportunity for local processing and increased energy efficiency.

Sensor networks have been an ongoing area of research that has been accelerated by the Internet of Things. Sensor networks have been extensively investigated in areas such as industrial and factory automation, environmental monitoring, agriculture and military applications (Akyildiz et al., 2002; Culler et al., 2004; Romer and Mattern, 2004). Sensor networks have been further enabled by being able to connect to cloud data storage, visualization, and analysis platforms to leverage the volume of data that is collected. It is an emerging paradigm that is fusing existing data collection systems with smart systems, frameworks and other devices to offer potential growth in economics and industry (Kumar et al., 2019).

With the explosive growth of IoT devices in areas such as healthcare, smart homes, traffic management, industry 4.0, security and surveillance and agriculture (Kumar et al., 2019), it is important to understand that each of these domains present different challenges and opportunities for the IoT.

[2]Maccheek, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=971184

[3]https://www.adafruit.com/category/830

Precision agriculture for high value crops presents unique challenges that are different from other IoT application domains. While many IoT applications focus on extremely large numbers of data generation devices that are potentially in motion while connected to the internet, many agricultural applications focus on data collection from a low number of static devices.

Agricultural industries benefit from using wireless sensor networks, but growers are hesitant to invest in the technology if it is not practical for their application. An ideal agricultural product is one similar to smart home technologies with light bulbs. Growers should be able to purchase a central gateway that sensor nodes can communicate with. New sensor nodes should easily synchronize with the central gateway and be configurable through it. The gateway should also support the option to be connected to the Internet to provide remote configuration and data analysis. Above all, growers should rarely need to replace sensor nodes or their batteries.

For wireless sensor networks to be sustainable in agriculture, they must be affordable, require little user intervention, stay powered for long periods of time, stay protected from the elements of nature, be easy to implement and modify, and transmit at long ranges while handling radio interference. This is a long list of requirements, but they can all be achieved inexpensively with the emergence of open-source hardware, open-source software, and 3D printing technology. In general, improving transmission distances and reducing power requirements will make wireless sensor networks more practical and affordable for the grower.

Previous works have considered using protocols such as 802.15.4 b (LR-WPANs, including Bluetooth and Zigbee) and 802.11x (WLAN) but provided limited transmission range, complex communication stacks and data management, and high power consumption (Vieira et al., 2003; Buratti et al., 2009; Fazackerley and Lawrence, 2010). For applications that have focused on using these technologies in agricultural applications, challenges exist with the power and limited transmission distance. This means that for areas of more that 25-50 meters, devices are required to use multi-hop route or mesh networking. This introduces additional complexities in terms of device synchronization, energy consumption and lifetime (Cagnetti. et al., 2020).

Recently, interest has grown in the area of Low Power Wide Area Networks (*LPWAN*) as a way to address power and link distance challenges presented by previous technologies (Lavric and Petrariu, 2018). Numerous vendors are active in this space and are focusing on improving the performance of wireless sensors (Georgiou and Raza, 2017). These devices provide coverage areas where gaps exist in the current short-range wireless space and address many of the requirements (Raza et al., 2017). One of the most promising technologies in this space is LoRa which allows for flexible, long range communications at a low price point and power budget. LoRa is a layer 1 protocol that allows higher levels and network architecture to be built upon it. The LoRa Alliance has defined a cloud-based medium access control (MAC) layer protocol called LoRaWAN (Sornin, 2017) allowing for the development of large scale systems. Numerous applications have been proposed utilizing LoRa and LoRaWAN technologies.

2.2 LoRa and LoRaWAN

The LoRa, (**Lo**ng **Ra**nge) protocol is a RF modulation technology developed by Cycleo in 2009, which was later acquired by Semtech in 2012. The technology uses a proprietary chirp spread spectrum modulation technique which enables data communication over long ranges (>15 km line of sight), while using little power, making it a flexible solution for rural use cases in smart agriculture (Ojha et al., 2015). LoRa operates in the unlicensed ISM bands worldwide. Although there are multiple license-free bands, most long range protocols operate in the sub-gigahertz license-free bands, the most prominent of which are a large contiguous band from 902-928 MHz and narrower bands at 864-870 MHz, and 433 MHz depending on the region of the world a device is operating in.

With LoRa, key parameters need to be agreed upon that control the channel bandwidth (*BW*), the spreading factor (*SF*) and the coding rate (*CR*). The spreading factor controls the duration of the chirp with larger SF's being able to transmit further but with a slower data rate for a given bandwidth. LoRa also includes the option of forward error correction as coding rate that will encode 4-bit data with redundancies into 5, 6, 7 or 8-bits. For LoRa devices to communicate, two devices must be operating in the same band, and share the same channel bandwidth, spreading factor and coding rate. Unlike other wireless technologies, LoRa data transmission rates are in the order of kilobits per second.

As the data rate is low, this makes LoRa most suitable for implementations that do not require large amounts of data transferred over short periods of time. LoRa is ideally suited for low volume, and periodic transmission of sensor data.

LoRaWAN is a MAC layer protocol utilizing LoRa, that focuses on medium access and network congestion. While LoRa allows physical point-to-point communications, LoRaWAN offers a complete network topology, focused at scalability towards hundreds of thousands of devices connecting to the Internet. With LoRaWAN, the topology requires a gateway that encapsulates network dataframes as well as providing cloud-based network services for storage and analysis (Ertürk et al., 2019). LoRaWAN as a communication protocol has been used for agricultural applications (Davcev et al., 2018; Kokten et al., 2020). While a suitable technology, numerous limitations exist as LoRaWAN gateways and end nodes are costly compared to LoRa. Additionally, with LoRaWAN a cloud-based network service is required as data residency is no longer on site. LoRaWAN is targeted for large scale networks and is prohibitive for cost sensitive applications.

In contrast, LoRA allows developers to utilize low-cost, open-source solutions knowingly sacrificing high scalability. Specifically for cost sensitive, agricultural applications this is suitable as an installation may only require hundreds of nodes. Unlike with LoRaWAN, developers can implement low-cost, local data storage and visualization tools, allowing a grower to maintain control of data privacy and ownership. Finally, as many agricultural locations lack internet connectivity, LoRa devices can be run decoupled from the internet, offering maximum flexibility.

3 SENSOR ARCHITECTURE USING LoRa

A sensor network architecture for agricultural monitoring captures low speed and a low volume of data, which offers flexibility in the design of the architecture. LoRa is an ideal candidate to satisfy power and link budgets and forms the communication backbone of the proposed architecture. For small scale agricultural deployments, LoRa eliminates the need for complex and energy intensive routing and synchronization protocols, allowing for sensor nodes to communicate directly with the data collection point.

For the development of apple and grape disease models, parameters such as air temperature, leaf-wetness, and humidity are measured. These are relatively slow moving parameters with respect to time. This allows nodes to sample at a low interval on the order of minutes between readings. Additionally, as data is used in a predictive fashion for forecasting, the real-time delivery requirements for data can be relaxed. This allows latency tolerant delivery where a node is not required to deliver data immediately upon sampling. Another key consideration is the size of the data being transmitted. With LoRa and the time on air constraints, focus must be given to minimize the amount of data being transmitted against the needs of the application.

The following protocol defines interactions and exchange of data between nodes and a gateway using the LoRa physical layer and is called the LoRa eXchange protocol (*LoRa-X*). With LoRa-X, two key parameters are:

- *Sample Frequency* which defines the expected sample frequency or rate needed for a given sensor in a device's sensor suite.
- *Transfer Frequency* which defines how often a node will attempt to transmit data to the sink.

These parameters are used to determine expected node behaviour with the gateway.

The following sections discuss the node and gateway software architecture and behaviours, as well as node-gateway interactions and transmission time slot determination.

3.1 Node Architecture

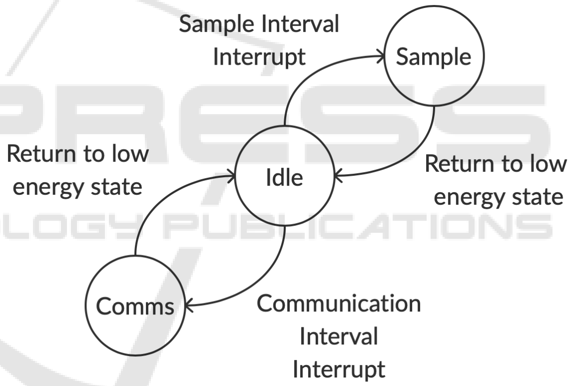

Figure 4: The three phase LoRa eXchange protocol system.

Nodes operate in one of three stages during their lifetime (Figure 4).

1. *Idle* - During the idle phase, devices operate in a predetermined low energy phase.
2. *Sample* - During the sample phase, devices complete the required sampling and local processing of data as required by the sensor suite which can include storing data in a local persistence layer. The transceiver is left in a low energy state during this phase and the mechanics of sampling is specified by the the application. Any data or messages required to be sent to the sink are constructed and transferred to the transmission queue which will be serviced during the communication phase.
3. *Communication* - During the communication phase, the node will switch to a transmission

phase. During this phase, the node will attempt to transmit all data messages in the transmission queue.

In provisioning the system, consideration must be given to the the amount of data that is being transmitted along with the SF, channel bandwidth and coding rate for the LoRa transceiver. In some regions devices are limited to a strict time on air or channel idle times when operating in the ISM band. The overarching goal is to have the device on the air as little as possible and minimize the amount of data being transmitted.

3.1.1 Transmission Queue

Each node maintains a queue to manage the transmission of data to the sink. When data is generated during the sampling phase, each sample set is added to the queue in order. Data sets will be transmitted based on the order of sampling. When the node enters into the communication phase, it will attempt to transmit the queued messages to the sink. Each sample is transmitted to the gateway utilizing a reliable datagram. If the gateway acknowledges receipt of a sample, it is removed from the queue and the node will attempt to transmit the next element in the queue.

If the node does not receive a response within a given timeout period, a re-transmission will be attempted. The sensor node will attempt to transmit the sample in the front of the queue until it receives acknowledgment or until it has attempted an amount of transmissions equal to the current size of the queue (number of elements currently held). If the gateway is not available at a given time slot, the samples will remain in the queue and are transmitted during the next scheduled transmission. Configuration of the sample and transfer frequencies need to consider the size of the data being transmitted in addition to the number of devices in the network (the number of available time slots) to ensures proper queue management, such that it does not fill up quickly.

3.2 Gateway Architecture

The gateway is constructed from a single channel LoRa transceiver coupled with a Raspberry Pi single board computer. This reduces costs significantly while supporting the ability to customize packets. As a result of the long transmission distance of the LoRa physical layer, the system utilizes a single gateway. The majority of target installations are smaller in size than the transmission distance for LoRa eliminating the need for complex routing and device-to-device synchronization.

The gateway is continuously powered and provides access services for the nodes and users. It provides a local database that maintains information about the gateway transceiver, sensor node configurations, geo-location information for nodes and the data generated by each node. It also controls synchronization of sampling and communication parameters between nodes and the gateway. Additionally, it maintains a local web server allowing users to interact with the gateway and nodes, and provides an MQTT hook so sensor data can be published to an external broker.

3.2.1 LoRa-X Interaction Models

When a new node is initially powered in the network, it will send its unique serial number to the gateway until it receives a response. The serial number is based on the unique 128-bit serial number assigned to the microprocessor at manufacturing. With LoRa-X, as devices only need to be uniquely identified within the local cluster, this address is only used to uniquely identify the node during initialization. For regular communications, the sensor node will utilize a logical ID assigned by the gateway for local communications. The size of the logical ID can be adjusted depending on the number of logical devices in the network. The logical ID is used for addressing to reduce the number of bytes required during transmissions.

When the gateway receives the serial number from the sensor node, it will query its local database to determine if the node has already been synchronized and assigned a logical ID. If the unique 128-bit serial number does not exist in the system, the gateway will generate and assign a logical ID. If the node is already registered with the gateway, the current configuration information and logical ID will be queried. The gateway will return to the node the assigned logical ID, the current gateway date and time, and the desired sample frequency and transmission interval frequency. Once a node has been assigned a logical ID and received its sample frequency information, it is considered to be synchronized.

The gateway maintains a local web service that allows a user to connect to the gateway and add additional node configuration information, descriptions, and coordinates. A user can change configuration information regarding sampling and transmitting frequencies. Changing either of sampling or transfer frequency will update the sync status to *Required*, and will flag the gateway to initiate a re-synchronization with the sensor node during the target node's next time slot. This allows for the parameters of the network devices to be modified without having to restart the network.

During normal operations, a node will transmit data to the gateway during its calculated time slot. When data is received from a node, the gateway

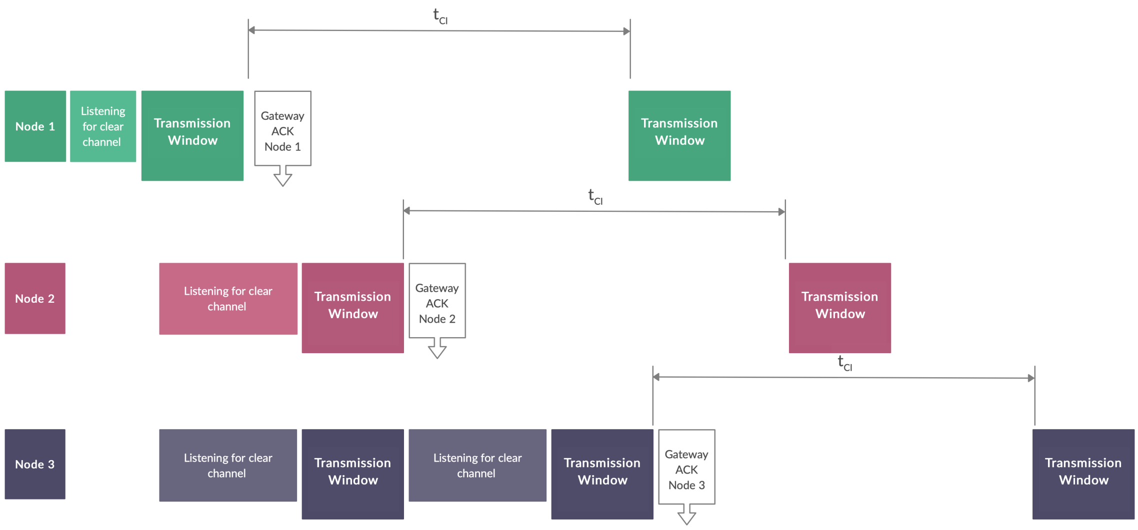

Figure 5: Autonomous greedy time slot determination.

parses sensor sample data, inserting the payload into the gateway database. The gateway acknowledges the successful receipt of data from a node.

3.3 Autonomous Greedy Time Slot Determination

The goal is to allow the network to converge to a state where nodes are not transmitting at the same time interval to reduce the energy expenditure. Unlike other LoRaWAN techniques that use pure Aloha (Haxhibeqiri et al., 2018), slotted-Aloha (Polonelli et al., 2019) or autonomous slot assignment (Zorbas et al., 2020), sensor nodes utilize a transmission frequency interval and channel inactivity to determine an available unstructured time slot. The goal of the time slot algorithm is for a node to determine an available time window and attempt to utilize the same interval for future communications.

For a node to determine its time slot, it first listens for channel activity. If the channel becomes free, a node will attempt to transmit messages currently being held in the queue. If the message transmission is successful, the node will receive an addressed acknowledgement from the gateway. The next time slot for transmission is calculated as:

$$time\_slot_{t+1} = t_{window\_end} + t_{CI} \quad (1)$$

where $time\_slot_{t+1}$ is the start time of the next available window for the local device, t_{window_end} is the end time of the last successful transmission window and t_{CI} is the requested interval between communication events. The assumption is that $t_{CI} \gg t_{window}$. Each node uses the local real time clock to determine the end of the last transmission that was acknowledged successfully and calculates the start of the next window by adding the required communications interval time.

Neither Aloha, where nodes attempt to transmit when they have data and use an exponential back-off (windowless), or slotted Aloha, which uses discrete time-slots for transmission, use the status of the last transmission windows as a basis for determining the next likely available transmission window. With the proposed protocol, as each node listens before transmission, no two nodes will have the same window end time for any transmission. In the event that two or more devices attempt to transmit at the same time, the gateway will only acknowledge one device, forcing the other to re-enter the transmission cycle.

Consider Figure 5 which demonstrates the timeline for three nodes autonomously determining the next available time slot. For node 1, as the channel is clear, it is able to transmit and receiving an ACK without contention, thus determining the next time slot during which it should attempt communications.

For nodes 2 and 3, they both determine that the channel is busy and wait for the channel to go idle. In the example, both devices detect a clear channel and attempt to start their transmission window. While the transmission window represents a probabilistic time period where there are no other devices transmitting, each individual packet transmission is handled in a pure-Aloha fashion to resolve single over-the-air collisions. In this example, node 2 is acknowledged forcing node 3 to wait an additional time period before attempting to re-transmit again.

To reduce the chances of collision, nodes use a randomized back-off factor during the initial startup to reduce the probability of multiple devices attempting startup at the same time interval. While the chance exists that a large number of devices will transmit at the same time during startup, the practical implementation of this is low due to randomized offset, and clock imprecision and drift in each node.

4 PROTOTYPE IMPLEMENTATION

An experimental network deployment was developed to validate the LoRa eXchange protocol connecting a series of nodes to a gateway (Figure 6). The central gateway is a Raspberry Pi 3 B+, with a 1.4 GHz processor, 1 GB of SDRAM memory, WiFi and microSD memory card support. The gateway uses the same RF95 LoRa radio transceiver as the sensor nodes attached to a Dragino LoRa Pi hat.

Nodes are based on the Feather M0 + LoRa open-source platform which uses a Microchip SAMD21 ARM based processor running at 48 MHz and an RF95 LoRa transceiver. Each node contains a thermistor for temperature sampling as well as the ability to report its own battery voltage level. Devices also contained a digital BME280 sensor[4] which measures relative humidity, temperature and barometric pressure. Control of transceivers was done with the open-source RadioHead packet radio library[5] that allows for direct control of the LoRa transceiver as well as providing reliable and addressable communications between transceivers.

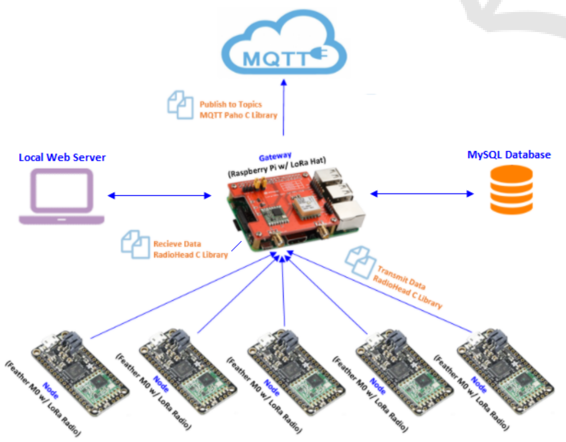

Figure 6: The LoRaX gateway and node architecture.

Local to the Raspberry Pi, a MySQL database is used to store information about the central gateway,

[4]https://www.bosch-sensortec.com/products/environmental-sensors/humidity-sensors-bme280/

[5]https://www.airspayce.com/mikem/arduino/RadioHead/

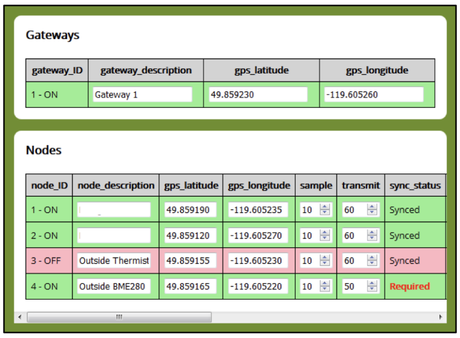

Figure 7: The LoRaX gateway and node configuration.

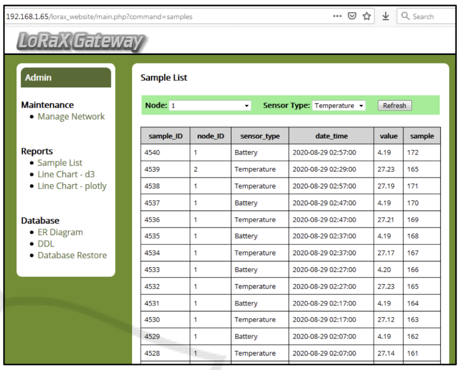

Figure 8: The LoRaX gateway dashboard showing list of samples with filter options.

sensor nodes, and sensor samples, which are visible through a web portal (Figure 7). The Gateway has attributes for a description and GPS coordinates. A gateway can be named and pinned on a satellite network map within the user interface.

A description and GPS coordinates are also captured for each node as well as information used by the gateway while synchronizing with sensor nodes. The device serial number is used to identify sensor nodes before synchronization. Timestamp attributes are included to track a sensor node's most recent transmission and synchronization with the gateway. Lastly, there is data storing the number of minutes a sensor node should wait before sampling and transmitting samples. The gateway contains an MQTT hook allowing it to publish sensor data to an external MQTT broker for use by other applications.

A test deployment was installed to evaluate network performance. Node and gateway placement can be viewed on the network map using the Google Maps API and allows for the configuration of the connected components.

On power up, the sensor nodes synchronize with the gateway and start sampling based on the sampling and communication intervals provided by the gateway. Data that has been received at the local gateway can be viewed by logical node ID, and sensor

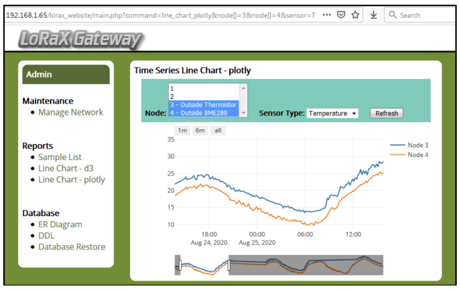

Figure 9: The LoRaX gateway for longitudinal visualization of temperature data.

type (Figure 8). The samples list can be filtered to only display sensor data for a specific node and sensor type. Longitudinal data analysis can also be viewed for multiple nodes by sensor type (Figure 9).

5 CONCLUSIONS AND FUTURE WORK

Wireless sensor networks can increase sustainability in agriculture by providing growers with usable data. Through the use of open-source software and hardware designs, coupled with LoRa transceivers, inexpensive and power efficient sensing solutions can be developed for agriculture allowing for long transmission distances and wide coverage from a single gateway installation.

The wireless sensor network developed in this project uses LoRa transceivers and an efficient channel management mechanism to reduce energy usage for data transmission with a novel collision handling protocol. The architecture is easily deployed and maintained.

Future work will investigate detailed performance characteristics for the LoRa eXchange protocol. Additionally, a large scale network will be deployed in an agricultural setting to demonstrate the benefits of precision agriculture and ease of use of the approach.

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