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\section{Introduction}

\section{Bridge Health Monitoring}

\section{Wireless Sensor Networks and LoRa}

Wireless Sensor Networks (WSNs) are simple, low-cost networks that primarily consist of nodes and a base station \cite{WSN-WaterQual}. WSN nodes usually comprise of some sensing or measuring capability and relay this information via uplink to a base station for processing and then to a network server. Innovating many field of industry and research, these distributed networks of nodes have been valuable in many contexts. For example, the use of ZigBee communication technology for air pollution monitoring \cite{ZigBeeAirPolution} and the use of Bluetooth for communication between end-devices measuring temperature, luminance, carbon dioxide and humidity for energy-saving establishments \cite{BTenergySaving}. Although these WSNs have worked in the past, the future of this technology lies in developing systems that have high scalability and range, something that ZigBee and Bluetooth inherently lack. Cellular and satelite .... space study ... somewhere

Long Range (LoRa) technology was introduced

\section{The Internet of Things and LoRaWAN}

The configuration of WSNs have typically been a deployment of Wireless Personal Area Network (WPAN) or Low Power Wide Area Network (LPWAN) standards, where nodes are setup in a mesh layout using a short-range communication protocol such as ZigBee and Bluetooth \cite{WSN-WaterQual}. The main implication with these protocols is that the mesh implementation inherently bottlenecks scalability due to exponentially increasing network requirements and power consumption \cite{IOTandLORAWAN-SmartFarm}. Long Range Wide Area Network (LoRaWAN) is a solution to implementing an LPWAN system with minimal complexity and scalability whilst also being low power. LoRa by definition is a chirp spread spectrum (CSS) modulation technique developed by Cycleo offering a Medium Access Control (MAC) layer protocol and operates on the `licence-free region-dependent industrial, scientific, and medical (ISM) frequncy bands' \cite{IOTandLORAWAN-SmartFarm}. In Australia the operational ISM band for LoRa is between 915 and 928 MHz. LoRaWAN is the ideal technology for agritulcutral and regional purposes due to its long range, low power and long lifetime.

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\section{Review of the Published Literature}

This literature review analyses the works already conducted in the field of WSNs and LoRaWAN communication protocol in terms of signal strength, IoT cloud architecture and security. The relation of this report in regards to the existing literature will be discussed.

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Gehani et al. in 2021 \cite{LoRa-Agro-Informatics} implements a LoRaWAN IoT architecture for measuring Agro-Informatics regarding the detection and classification of pathogens affecting the roots of plants. The signal strength of the LoRa packet was measured in terms of received signal strength indication (RSSI) and signal-to-noise ratio (SNR) in various depths between 0 cm to 60 cm. The experimental setup consisted of a simple transmission and receiving Adafruit Feather M0 microcontrollers using an RFM95W based LoRa radio transceiver operating on the US915 MHz frequency. A rechargeable 3.7 lithium polymer 500 mAh battery was used for the power supply and a ceramic antenna was used for the buried microcontroller. The transmitting node was initially placed inside a bucket containing dry soil, and the receiving node placed 3 m away logged the RSSI and SNR for ten LoRa packets. A diagram of the experimental setup is shown in figure \ref{lora-bucket}.

\begin{figure}[h]

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\caption{Experimental Setup for LoRa Node in Soil \cite{LoRa-Agro-Informatics}}

\includegraphics[scale=0.5]{Sections/Literature-Review/Lora-bucket.pdf}

\label{lora-bucket}

\end{figure}

The results conclude that the LoRa transmitter was capable of transmitting packets when buried within 60 cm with the recommendation that depth does not exceed 50 cm. The depth of the transmitter node proved to be inversely proportional to the RSSI value which did not drop below the minimum signal power required for demodulation. The results of the depth transmission in this study are helpful in deducing appropriate enclosure thickness for the purposes of this report.

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Wixted et al. in 2016 \cite{LoRa-WSN} evaluates the indoor and outdoor performance of the LoRaWAN physical layer and network layer across the central business district (CBD) of Glasgow city, Scotland. The LoRaWAN testing involved the implementation of Multitech mDot devices which comprised of a LoRa wireless chip and ARM processor. These nodes interfaced with a Raspberry Pi via USB which was used to record the current location. A cabled gateway and two gateways using mobile connections were placed at the top of three buildings. The LoRa nodes were configured via the Stream Technologies IoT platform, acting as the application layer, and the nodes transmitted packets in which successful or failed acknowledgements (ACK)s were logged. Data was collected by walking through the city streets and the data from the network server was logged in a database.

The reliability experimental setup involved nodes repeatedly sending messages over a long period of time and iterating over multiple spreading factor (SF)s. In this scenario the node was placed 1.9 km from one gateway an 2.1 km from a second gateway.

The results of the LoRaWAN performance indicate that in several trouble spots, such as a 100 m pedestrian underpass, the GPS failed to operate but LoRaWAN was able to continue communication. Additionally, the multi-gateway setup meant that many locations were detected by more than just one gateway.

Figure \ref{LoRaWAN-performance-testing} displays the experimental results with markers indicating ---

The results of the reliability testing indicate that the

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Fox et al. in 2019 \cite{IoT-Regional-Service} presents the design architecture for a LoRaWAN based IoT system for wind turbine monitoring in a local region in Ireland. The IoT architecture in this study comprised of three main components, an end device, gateway and IBM IoT cloud platform.The end device was an Arduino Pro Mini as an end-device powered by two double A batteries. A Multiconnect Conduit IP67 was chosen as the gateway, using a 3dBi dipole antenna. Notably the gateway was configured to network server mode such that the gateway also acts as a network server. The IBM cloud platform was deployed to connect the LoRaWAN network to the cloud. This was accomplished using an MQTT broker as the back-end messaging protocol. The chosen IBM cloud services include an IoT platform for monitoring end devices and gateways in real-time, a cloudant for concurrent read and write processes in the form a NoSQL database, and a cloud db2 warehouse implemented with SQL database service. A Node Red Cloud Foundry application instance was created to interconnect the LoRa gateway to the IBM cloud.

A meteorological mast was placed nearby an existing wind turbine to collect wind speed and direction data. The data collected by this mast was processed using the Node Red program flow, providing real-time visualisation, alerts and event monitoring. The application layer deployment also allows for data filtering, data pre-processing and data comparison between multiple end devices. Figure \ref{red-node-app-flow} displays the Red Node Cloud Foundry application flow within the IBM cloud. The device message format clearly displays valuable meta data such as timestamp, device EUI, RSSI, SNR, SF, frequency and the message payload. The payload is extracted, processed and displayed in an interface by assigning relative values to their respective interface nodes.

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\caption{Red Node Cloud Foundry Application Flow \cite{IoT-Regional-Service}}

\includegraphics[scale=0.6]{Sections/Literature-Review/red-node-application-flow.pdf}

\label{red-node-app-flow}

\end{figure}

This paper demonstrates the successful development of a LoRaWAN IoT system with the primary focus on the deployment of the IoT cloud architecture. The IoT architecture is specifically designed to gather and analyse data related to a 6kW wind turbine. Due to the nature of LoRaWAN deployments, the integrated system is capable of being adapted to service other applications needed in the region. The LoRaWAN deployment was subjected to some challenges, notably LoRa's limited transmission capacity, specifically sending large packets of data quickly for applications requiring quick response times in mind. Issues such as battery life also plague the serviceability of the end device, however this is entirely subject to required onboard computation since LoRaWAN end devices are typically considered low-power. The study contributes to the existing body of LoRaWAN research with an emphasis on the integration with a cloud platform to form a fully implemented system service. Future endeavours of the study highlight the need to broaden the system's application base and enhance end device optimization for both the current system and future applications.

Wildan et al. in 2020 \cite{LoRa-Smart-Home} focuses on the design and implementation of a GUI for smart home systems based on LoRa technology. The aim of this study was to bridge the gap between human users and smart home devices by creating an interface that leverages LoRa's long-distance and low-power capabilities. The objective was to offer remote control functionality for various household electronic devices. The study explores the limitations and potentials of LoRa technology in the efficiency and safety of a smart home. The conclusion of the study was that LoRa-based smart home systems through web-based interfaces effectively allows monitoring and control of home conditions and electronic devices. The main limitation was the delay in data transmission, but the system performance was robust, evidenced by a high satisfaction rating among 50 users. The data transmission delay was on average 3.86 seconds including packet air time and time needed for the web browser to parse data to the interface. Even with a high user satisfaction, the data transmission delay is further evidence that LoRaWAN systems are inherently limited for implementations that require real-time responses.

Maziero et al. in 2019 \cite{Monitoring-Electric-Parameters} developed a monitoring system to track electrical quantities using LoRaWAN technology. The goal of this study was deploy a real-time monitoring system for the Federal University of Santa Maria campus. The data analysis panel was created using Grafana software, offering the flexibility to monitor both electrical quantities and the communication network. A panel was made for monitoring electrical quantities such as voltages, currents, power and consumed energy, whilst another was used to track connectivity metrics such as power factors, delivery rate, RSSI and SNR. The study concluded that the monitoring system built using LoRaWAN technology and the application layer monitoring software was able to effectively acquire and visualise electrical quantities in real time. From the 10 deployed smart meters, most meters were found to have a packet delivery rate of 95\%.

The reviewed research evaluates the performance of a Smart Gateway network architecture using two key metrics: Throughput and Packet Loss. The research focuses on LoRa communication, a popular protocol used in long-range, low-power applications, typically employed in IoT devices.

Throughput, the effective rate of data transfer, was tested by examining the number of packets successfully sent over a given time, with measurements taken across several clients, each sending 496-bit data. The study's findings suggest that the system throughput is inconsistent across various numbers of clients, with a decrease observed when 2 and 4 clients were active, but an increase noted with 3 and 5 clients. Overall, the average throughput across a 1-meter range communication was 489 bit/s. This is considerably lower compared to other similar systems studied, with the researchers attributing the diminished performance to the additional processing steps involved, like data entry into the database and providing web server services.

Packet Loss, the proportion of packets lost during transmission, was evaluated by comparing the amount of data received by the gateway versus the amount requested from the gateway. As with throughput, packet loss was also inconsistent across the varying numbers of clients, with a significant spike when the system operated with 2 clients. On average, the system recorded a packet loss of 26\% across a 1-meter communication range, a considerably higher value compared to other studied systems.

The study concludes that the developed system can successfully manage up to 5 clients, register, and request data automatically, and concurrently run LoRa communication alongside the user interface of the information system. Nevertheless, the system can only operate within the local gateway's range, and the average throughput and packet loss were recorded at 489 bit/s and 26%, respectively.

The researchers acknowledge the limitations of their system, particularly in terms of packet loss and throughput, compared to traditional LoRaWAN systems. They recommend further research to enhance the network architecture, potentially by adding communication mechanisms between gateways, or by incorporating a centralized network to manage multiple gateways, which could provide a larger network scale. They also recommend adding encryption and decryption formats for increased security, and testing the system using real sensors and assessing LoRa parameters in the process.

The primary themes in this study revolve around system performance (throughput and packet loss), limitations of the existing setup, and recommendations for future work to improve system capabilities and security.

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The studies reviewed in this paper all center around the exploration of LoRaWAN (Long Range Wide Area Network) technology, focusing on several key areas: the basic setup of LoRaWAN end devices, signal strength measurement (RSSI and SNR), IoT cloud implementation, and the limitations of LoRaWAN.

One application of LoRaWAN is in the field of Agro-Informatics, as demonstrated by Gehani et al. (2021) \cite{LoRa-Agro-Informatics}. Their research focused on utilizing LoRaWAN IoT architecture for the detection and classification of plant pathogens. The signal strength of the transmitted LoRa packets was evaluated through Received Signal Strength Indicator (RSSI) and Signal-to-Noise Ratio (SNR) at various depths from 0 cm to 60 cm. Their findings suggest that LoRa transmitters can function effectively when buried within a depth of 60 cm, provided the depth does not exceed 50 cm. This research serves as a valuable foundation for designing enclosure thickness in various applications. A diagram of the experimental setup is shown in figure \ref{lora-bucket}.

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\caption{Experimental Setup for LoRa Node in Soil \cite{LoRa-Agro-Informatics}}

\includegraphics[scale=0.5]{Sections/Literature-Review/Lora-bucket.pdf}

\label{lora-bucket}

\end{figure}

Fox et al. (2019) \cite{IoT-Regional-Service} expanded on the architecture of LoRaWAN-based IoT systems with a focus on wind turbine monitoring in Ireland. Their study comprised three main components: an end device, a gateway, and an IBM IoT cloud platform. This research demonstrated a comprehensive IoT cloud architecture deployment, covering real-time monitoring, concurrent read/write processes, and database service implementation. Despite the successful deployment, challenges such as LoRa's limited transmission capacity and end device battery life were highlighted, emphasizing the need for future optimization. Figure \ref{red-node-app-flow} displays the Red Node Cloud Foundry application flow within the IBM cloud. The device message format clearly displays valuable meta data such as timestamp, device EUI, RSSI, SNR, SF, frequency and the message payload. The payload is extracted, processed and displayed in an interface by assigning relative values to their respective interface nodes.

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\label{red-node-app-flow}

\end{figure}

In another exploration of LoRaWAN capabilities, Wildan et al. (2020) \cite{LoRa-Smart-Home} designed and implemented a GUI for smart home systems leveraging LoRa's long-range and low-power benefits. They addressed a key limitation in LoRaWAN – the delay in data transmission – noting that while the system performance was generally robust, delays average 3.86 seconds, potentially limiting real-time responses in certain applications.

Maziero et al. (2019) \cite{Monitoring-Electric-Parameters} deployed a real-time monitoring system for tracking electrical quantities at the Federal University of Santa Maria campus. Utilizing Grafana software, they created a panel for tracking both electrical and connectivity metrics, demonstrating the effectiveness of combining LoRaWAN technology and application layer monitoring software for real-time data acquisition and visualization.

In summary, these studies provide insights into the diverse applications of LoRaWAN, while also revealing some inherent limitations. Future research in this area should continue to explore ways to optimize this technology, particularly in terms of real-time data transmission and power management.