1. INTRODUCTION

1.1. Report Structure

The report is organized in the following structure; first relevant background information regarding measuring the health of a bridge, WSNs, LoRa and LoRawan, and the internet of things will be presented. Following this, the aims and objectives of this report will be outlined. Next, a review of the relevant published literature will be evaluated. The design specifications and methodology for developing protoype one and two will be provided. Results from testing both prototype implementations will be presented and a discussion regarding these results and performance will be provided. Device limitations will be analysed, suggestions for further improvements will be discussed followed by a conclusion. Proceeding the conclusion will be the references and appendices.

1.2. Project Background

1.2.1. Wireless Sensor Networks

Wireless Sensor Networks (WSNs) are simple, low-cost networks that primarily consist of nodes and a base station [8]. WSN nodes usually comprise of some sensing or measuring capability acting as the physical layer, and relay this information via uplink to a base station for processing and then to a network server acting as the network layer. From here, the API from a network cloud service can be used to create GUI's and other applications for researchers and consumers which acts as the application layer.

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 [9] and the use of Bluetooth for communication between end-devices measuring temperature, luminance, carbon dioxide and humidity for energy-saving establishments [10]. 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 satellite technology are alternate approaches that offer extremely high data rates and range, however these technologies are not practical to implement in most situations due to exceedingly high costs.

1.2.2. Structural Health Monitoring

Structural Health Monitoring (SHM) is a vital practice for ensuring the safety and longevity of civil and industrial structures [11]. SHM involves continuously tracking change in structures which can be attributed to material aging, environmental influences or unforeseen incidents such as traffic accidents or natural disasters. These changes can be tracked using WSNs equipped with appropriate sensor modules, and integrating data transmission capabilities. A survey investigating the implementation of IoT technology for structural health monitoring (SHM) determined that WSN technology has revolutionized the health monitoring in various fields including civil engineering [12]. WSN systems can be deployed to measures a vast array of SHM indicators including temperature, velocity, acceleration, frequency and displacement. WSN can be deployed on a structure such as a bridge operating as Internet of Things (IoT) nodes. This deployment highlights the advantage of using WSNs for SHM since the collected data can be uploaded to the cloud for processing and distribution. Within the context of bridge monitoring, the integration of WSN with IoT for SHM can serve various application requirements for real-time data uplink such as monitoring acceleration and frequency characteristics. This data can be plotted on a continuous time spectrum and compared to observational data such as pedestrian load to verify the validity of simulated truss analysis models and finite elements (FE) simulation.

1.2.3. Internet of Things

The Internet of Things (IoT) is an 'interconnected network of things' [13], where 'things' in this context is defined as an end-device with WSN type capability. The IoT architecture comprises of six-layers, the coding layer, perception layer, network layer, middle-ware layer, application layer and business layer [13]. Thus to create this IoT architecture for research purposes the first five layers need to be implemented. LoRa end-devices act as the physical layer encompassing the coding and perception layer. The coding layer involves associating unique ID specifiers to each end device [13] and the perception layer is involved with on-board sensing and data acquisition. The network layer is a relay of this perceptual information to a gateway, and the middle-ware layer is the IoT cloud platform that facilitates these connections and receives information from the network layer. The application layer involves pulling the API or information from the network layer and developing apps or graphical user interfaces (GUIs) to display the data.

The Things Network (TNN) is an open-source LoRaWAN network server used to construct IoT cloud applications with end-to-end encryption and secure communication [14]. TNN exists on the middle-ware layer and can be used to deploy an IoT architecture using LoRa end-devices in the coding and perception layer, and utilize the LoRaWAN communication protocol in the network layer. TNN offers a console and API to develop applications that serve as the architecture's application layer. Figure 1.1 displays an example of an IoT architecture using WSN nodes, a LoRaWAN gateway, cloud storage and user devices.

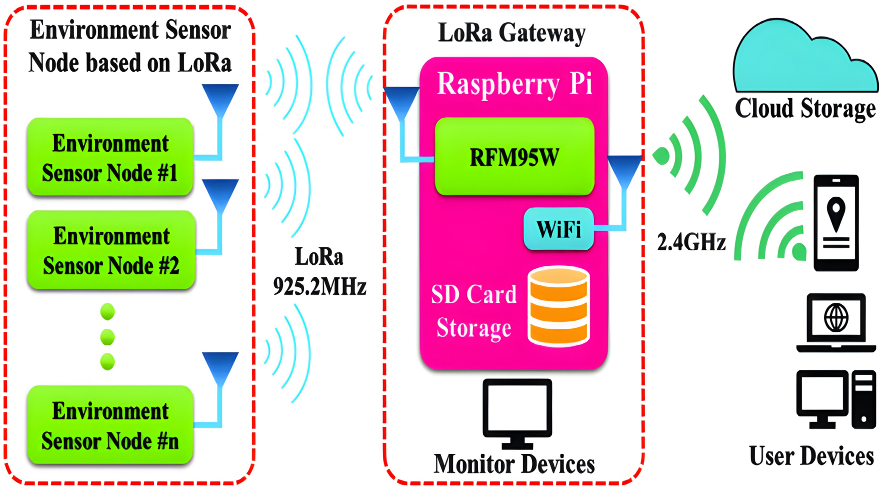

Fig. 1.1. The LoRa network architecture for agriculture area. [1]

1.2.4. LoRa and LoRaWAN

Low Power Wide Area Network (LPWAN) is a communication technology that offers wide coverage, similar to satellite networks, while maintaining lower data rates akin to ZigBee. The technology is distinguished by its ultra-low power consumption and cost-effective deployment and maintenance [15].

LoRa and LoRaWAN, forms of LPWAN technology, were developed to overcome the scalabilty issues associated with traditional WSN configurations that relied on short-range communication protocols such as Zigbee and Bluetooth [8]. These configurations often used a mesh network layout, which introduced challenges in network management and power consumption with increasing network size [15].

LoRaWAN's unique 'star of stars' configuration addresses these challenges by enabling scalable network expansion with reduced complexity. LoRa itself is a Chirp Spread Spectrum (CSS) modulation technique developed by Cycleo, offering a Medium Access Control (MAC) protocol and operating on license-free, region-dependent Industrial, Scientific and Medical (ISM) frequency bands [15].

1.3. Aims and Objectives

The primary goal of this research is to establish an IoT-driven Structural Health Monitoring (SHM) system for Griffith University's footbridge. This project aims to develop, deploy, and test two iterative prototypes designed to monitor the bridge's health by assessing key indicators such as vibration frequency and acceleration. These prototypes incorporate the first five layers of the IoT architecture: coding, perception, network, middleware, and application layers.

The development process for these two prototypes is progressive, with each prototype incorporating increasing complexity in components and software to ensure the efficient operation of the final system.

1.3.1. Prototype 1: Testing IoT Layers 1-3 and Software

The first prototype primarily tests the software and the first three layers of the IoT architecture. This stage uses two Arduino MKRWAN1300 devices, one functioning as a LoRa node (layers one and two) and the other as a pseudo LoRaWAN gateway (layer 3). An ADXL335 3-axis accelerometer collects vibration data from the beam along the z-axis. This data is processed at the node, with the maximum frequency peak and acceleration values identified and transmitted via LoRa to the gateway. A Python script logs the received data, which is then visualized using a plotting script.

Objectives for Prototype 1 include:

1. Validation of the MKRWAN devices' functionality and their compatibility with the LoRaWAN protocol.
2. Integration of an accelerometer into the node and development of a software module to accurately sample and digitize raw acceleration values.
3. Creation of a software algorithm to conduct FFT analysis on these discrete values, and identification and logging of the peak frequency.
4. Development of software capable of accurately logging and plotting the raw acceleration data from the node.
5. Successful transmission and reception of maximum acceleration and peak frequency data between the node and the gateway with a focus on data accuracy and minimal packet loss.
6. Design and implementation of software for logging and visual display of the maximum acceleration and peak frequency data received from the gateway.
7. Determination of the maximum effective range for LoRa packet transmission between the node and the gateway and identification of factors potentially affecting the range.

1.3.2. Prototype 2: Implementing IoT Layers 4-5 and Hardware Deployment

The second prototype further develops the system by introducing the middleware and application layers. It replaces the breadboard with a custom PCB and encloses the setup within a 3D printed enclosure for durability and protection. The MKRWAN device operates as the LoRa node, while a RAK7268 WisGate Edge Lite 2 serves as the LoRaWAN gateway. The node samples the bridge's acceleration and transmits the average maximum acceleration and frequency to the gateway. The gateway then forwards the data to the TNN cloud (middleware layer). The Arduino IoT Cloud dashboard's advanced graph feature is utilized to visualize and analyze the received data (application layer).

Objectives for Prototype 2 include:

1. Design, fabrication, and testing of a custom PCB to replace the breadboard used in Prototype 1.
2. Design and fabrication of a durable enclosure that can be securely mounted on the Griffith University footbridge without interrupting its usage.
3. Establishment of a reliable LoRaWAN connection between the node and the gateway, with consistent data transmission to the TNN cloud.
4. Integration of Arduino IoT Cloud variables for data logging and visualization using the dashboard's advanced graphs feature.
5. Execution of field testing on the bridge to validate complete system integration, including software functionality and signal strength.

Overall, the project aims to advance the understanding and application of IoT in structural health monitoring systems, potentially contributing to improved maintenance and safety practices.