

University of Southern Queensland
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Condition Monitoring using a Low Power Wide Area Network based on LoRaWAN

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Abstract

The Internet of Things (IoT) offers opportunity for the reliable collection of data. Low power wide area networks (LPWANs) offer the establishment of IoT networks and devices with low power budgets. Some LPWANs like LoRaWAN also offer long distances connections, suitable to remote and widespread operating environments (Karimi & Atkinson 2013).

This project investigates the rollout of a LoRaWAN network and the development of a compatible data collection device to enable condition monitoring of critical track circuit devices in Aurizon's Network.

Aurizon requires a solution to remotely gather the available diagnostic information from these devices. When track circuits fail, they prevent the safe running of trains, can delay road vehicles at level crossings and cost considerable amounts in lost revenue while they are repaired. Aurizon relies on a large number of EBI Track 200 track circuit devices known to fail during their operational lifetime. Prior research has shown that majority of nuisance failures can be predicted and prevented through condition monitoring of these devices (Rose 2009). Due to the geographically diverse roll-out of these track circuits, traditional computer-based serial communications are not possible.

The first concept of the project was to source, purchase and modify a device capable of talking to the EBI Track 200 and broadcasting the data via LoRaWAN. Initial market research was undertaken to determine if an existing solution was available on the market that could be used to connect to an EBI Track 200 device and LoRaWAN. When no device could be found a Systems Engineering approach was undertaken to develop a device capable of reporting back condition information of EBI Track 200 devices over LoRaWAN.

A proof of concept device was built using an Arduino Uno which can connect to the EBI Track 200 device via an RS-485 serial connection to collect condition data. The data is then collected, encrypted and broadcast wirelessly over a private LoRaWAN, after which it is passed over a conventional network to a virtual machine, which authenticates and unencrypts the data. The data is then forwarded to an InfluxDB database for the data to be stored and displayed.

This project has achieved the collection and storage of condition data for critical track circuit devices utilising a proof of concept data logging device. The solution addresses the limitations of traditional serial communications. The collection of this data will allow for the implementation of proactive maintenance activities to reduce nuisance failures and improve the availability of train paths.

Further work is required to improve end device features, such as the inclusion for battery backed transmission, which will allow for powered status messages to be transmitted under blackout conditions. In addition, extra development on the private LoRaWAN network connected to Aurizon's internal data network, including performing field testing on active receivers will be required before site installation can occur.

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J. Ball

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Table of Contents

1. Introduction	1
2. Aims and Objectives.....	4
2.1. Project Aims and Objectives	4
2.2. Assumptions and Constraints	4
3. Literature Review	5
3.1. Related Condition monitoring works	5
3.2. The Internet of Things	6
3.3. LoRaWAN.....	8
3.3.1. Network Architecture	8
3.3.2. Battery Life.....	9
3.3.3. Device classification.....	9
3.3.4. Cyber Security	10
3.3.5. Australian specification	11
3.3.6. Adaptive Data Rate.....	11
3.4. Bombardier EBI Track 200 Digital Track Circuits	12
3.4.1. History	12
3.4.2. Description of operation	13
3.4.3. Condition Monitoring	14
3.5. Applicable standards and regulation.....	15
4. Methodology.....	17
5. Requirements	19
6. Design.....	21
6.1. Hardware	21
6.1.1. Microcontroller	21
6.1.2. Connecting the EBI Track 200	23
6.1.3. TTL to RS485 Protocol converter	23
6.1.4. Power	24
6.1.5. LoRa Shield	24
6.1.6. Enclosure	25

6.1.7.	Schematics	25
6.2.	Software.....	26
6.2.1.	Software Libraries	26
6.2.2.	Addressing EBI Track 200	26
6.2.3.	LoRaWAN settings.....	27
6.2.4.	Flow Charts	28
6.3.	Safety in Design Review	28
7.	Implementation.....	29
7.1.	Implementation Plan.....	29
7.2.	Procurement of materials and equipment	29
7.3.	Development of Software.....	30
7.3.1.	RS485 Module.....	30
7.4.	Construction	31
7.4.1.	Connecting the Arduino Uno.....	31
7.4.2.	Preparing the Serial Cable	31
7.4.3.	Connecting the system.....	31
7.4.4.	Device Setup for Uploading program.....	32
7.4.5.	Configure Gateway.....	32
7.4.6.	Set up Virtual Machines and Cloud Services	32
7.5.	Implementation Output.....	32
7.5.1.	Risk Assessment.....	32
7.5.2.	Manufactured Items	33
7.5.3.	Software.....	34
7.5.4.	Updated Design Artefacts.....	34
8.	Verification and Validation	35
8.1.	Verification.....	35
8.2.	Validation	35
9.	Acceptance and Handover	37
10.	Conclusion and Further Works.....	38
11.	References	39

12. Appendices	41
12.1. Appendix A – Project Specification	41
12.2. Appendix B – Resource Plan.....	42
12.3. Appendix C – Project Plan	44
12.4. Appendix D – Ethics and Consequences	45
12.5. Appendix E - Safety in Design	47
12.6. Appendix F – Gateway Requirements.....	53
12.7. Appendix G – Gateway Comparison Table.....	56
12.8. Appendix H – End Devices (Node) requirements	57
12.9. Appendix I – RAMS Analysis.....	60
12.10. Appendix J – Fault Finding steps for RS485.....	61
12.11. Appendix K – Gateway Code	63
12.12. Appendix L – End Device Code.....	67

List of Tables

Table 1 - Assumptions and constraints.....	4
Table 2 - EBI Track 200 Monitored functions	15
Table 3 - Arduino microcontroller comparisons	22
Table 4 - RS-485 pinout table.....	23
Table 5 - Device LoRaWAN settings.....	27
Table 6 - Gateway LoRaWAN settings.....	27
Table 7 - Resource Plan.....	42
Table 8 - Safety in Design	47

List of Figures

Figure 1 - System proposal.....	2
Figure 2 - LoRaWAN OSI model.....	8
Figure 3 - Example LoRaWAN network topology - reproduced from('A technical overview of LoRa and LoRaWAN' 2015).....	9
Figure 4 - AU915-928 channel frequencies - reproduced from (Alliance 2018)	11
Figure 5 - LoRaWAN protocol Spreading Factors (SF) versus data rate and time-on-air – reproduced from (Ducrot & Hersent 2016).....	12
Figure 6 - EBI Track 200 transmitter output signal – reproduced from (Rose 2009))	13
Figure 7 - EBI Track 200 basic track circuit (1435mm gauge) – reproduced from (Rose 2009).....	13

Figure 8 - The Engineer "V" Lifecycle.....	18
Figure 9 - Expanded System proposal.....	20
Figure 10 - System Overview	21
Figure 11 - Arduino Uno (Arduino 2019)	22
Figure 12 - (<i>MAX485 Module RS- 485 Module TTL to RS- 485 Converter Module for Arduino</i>).....	23
Figure 13 – MAX485 Module Schematic (YourDuino 2019).....	24
Figure 14 - LoRa Shield for Arduino (Dragino 2019).....	24
Figure 15 - IP55 enclosure with transparent polycarbonate cover (B&R Enclosures 2014).....	25
Figure 16 - EBI 200 data logging device schematic.....	25
Figure 17 – State-based operation chart of datalogging device software	28
Figure 18 - Arduino connected to RS-485 during testing.....	31
Figure 19 - Arduino connected to two EBI Track 200 Receivers	33
Figure 20 - Received Packet in LoRa App Server.....	33
Figure 21 - InfluxDB Dashboard.....	34
Figure 22 - Updated System Overview	34
Figure 23 - Project Plan.....	44

Glossary of Terms

ABP	Activation by personalisation
ACMA	Australian Communications Media Authority
Arduino	Refers to microcontrollers, IDE and software libraries
CQCN	Central Queensland Coal Network
DB	Decibels
DR	Data rate
EMC	Electromagnetic compatibility
IC	Integrated Circuit
IDE	Integrated development environment
IDE	Integrated development environment
IoT	Internet of things
LIPD	Low interference potential devices
Loc	Signalling equipment location case
LoRaWAN	Wireless communications protocol stands for Long Range Wide Area Network
LPWAN	Low Power Wide Area Network
OTAA	Over the air activation
RAMS	Reliability, Availability, Maintainability, Safety
RS-232	A form of serial data communications protocol
RS-485	A form of serial data communications protocol. Also known as EIA-485
SCADA	Supervisory control and data acquisition
SER	Signalling equipment room
SF	Spreading factor
SID	Safety in Design

1. Introduction

This project investigates the rollout of a LoRaWAN network and the development of a compatible data collection device to enable condition monitoring of critical track circuit devices in Aurizon's Network.

Aurizon owns and operates one of the world's largest coal rail networks, linking approximately 50 mines with three major ports in Queensland. In order to meet customer demand for train services the network must be available for the ongoing safe movement of trains. Several key assets in the Central Queensland Coal Network (CQCN) have been identified as critical to the availability of the network. One key asset forms part of Aurizon's Signalling system. The Bombardier EBI Track 200 Audio Frequency Track Circuits that have been widely installed across the Goonyella System. The costs incurred to Aurizon by failed track circuits is massive, especially when lost potential revenue is included.

Due to the geographically diverse roll-out of these track circuits, traditional computer-based serial communications are not possible. Research into LoRaWAN and its uses found a potential benefit in replacing traditional computer serial communications.

The underlying motivations for this project are to enable the collection of asset condition data to minimise causes of high-impact disruptions in order to:

- Increase Network availability to run revenue services through network pathing optimisation and improved long-term planning
- Improve Network's reliability by reducing unplanned delays through proactive maintenance interventions
- Decrease transit times between mine and port by reducing speed restrictions imposed on the Network
- Improve execution efficiency of asset renewal and maintenance through better forecasting of work

As part of developing the requirements an analysis was performed in Appendix D to ensure the project conforms with the ethical requirements of Aurizon and engineering best practice. Also discussed are consequences of the project.

The proposed system is shown in Figure 1 in its most basic form whereby live trackside asset information can be accessed through digital reports. Once the data is collected further works will be required to set up intelligent analysis of the data. This in turn will identify potential impending fault modes, allowing for preventative maintenance to be organized. This project recognizes these further use cases, however focuses on the collection, transmission and storage of the data in preparation for these use cases.

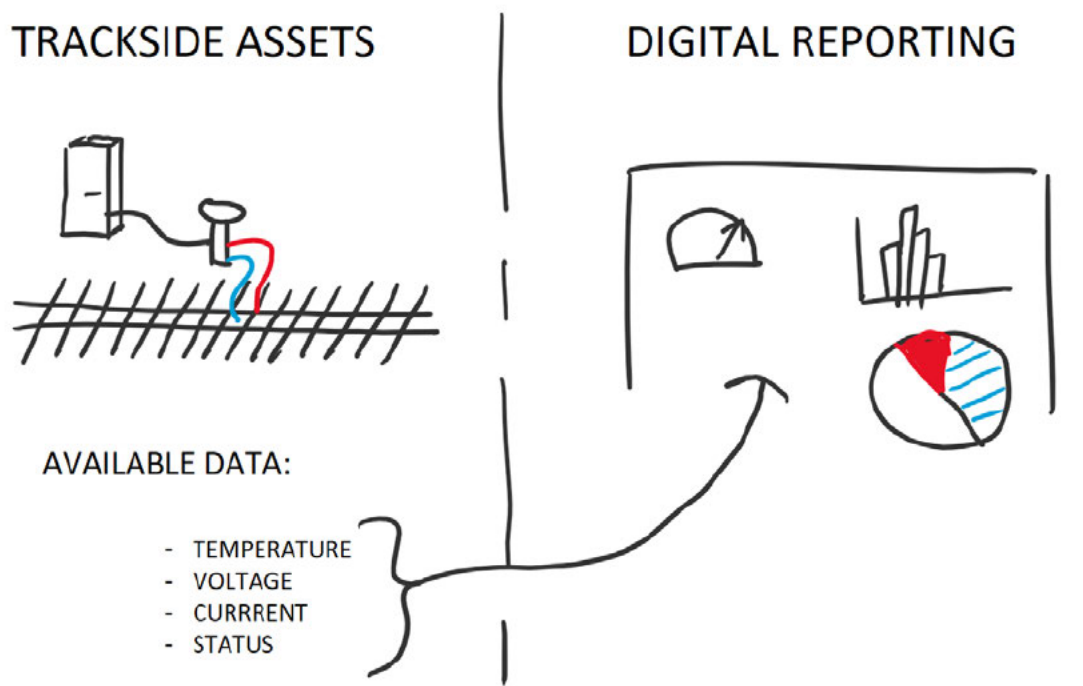


Figure 1 - System proposal

The EBI Track 200 Track Circuits devices have a serial output which can send key diagnostic information from each device. These diagnostic systems can predict failures, which if used correctly can be used to organize preventative maintenance, resulting in achieving each of the described objectives above. Due to the long-distance relationship between power and communications facilities in the CQCN it has not been viable for large scale investments in traditional SCADA equipment to enable this condition data to be collected. Therefore, an alternative has been sought.

In recent years Low Power Wide Area Networks (LPWAN) utilizing the Internet of Things (IoT) have emerged as a viable alternative to traditional SCADA systems. Aurizon is already investigating LPWAN technologies with a recent trial of NB-IOT to take actual readings of both ambient air temperature and rail temperature at key locations. From preliminary reports this trial has been more expensive than first anticipated, however there are alternative technologies available. One alternative, LoRaWAN, has been identified by Aurizon as a potentially more suitable technology for their LPWAN needs.

This project aimed to find a suitable device available on the market that could collect the condition data output from the EBI Track 200 Receiver Track Circuits and send it via LoRaWAN back to Aurizon central data servers. This in turn would enable the collected data to be used in preventative maintenance planning. The result of which would be an increase in network availability and reliability. A decrease in speed restrictions over failed tracks and improved asset maintenance work forecasting.

The project took place in 2019, during this time no suitable device was found available on the market. This resulted in a change of scope for the project, where a proof of concept device would be developed that could meet the functions of the original objectives.

A device was developed that could retrieve the condition monitoring data from an EBI Track 200 Receiver over RS-485 serial and broadcast this data via LoRaWAN. The data was able to be successfully received over LoRaWAN forwarded over a traditional network to be authenticated, unencrypted and stored in an Influx DB database. This database was set up with a dashboard which displayed live condition data.

A notable limitation to this success was the LoRaWAN network was not able to send this data back over the Aurizon intranet due to security concerns. In order to connect these two networks together a suitable LoRaWAN gateway would be required. Testing of the range of the LoRaWAN connection was also unable to be completed without this suitable gateway.

2. Aims and Objectives

2.1. Project Aims and Objectives

The aim of this project was to identify and procure a device that could collect the condition data output from the EBI Track 200 Receivers Track Circuit devices and send this data back to central Aurizon data servers over the LoRaWAN protocol. At the time this project was undertaken no such suitable device could be found as a result a proof of concept device was developed to meet the original requirements.

For this project to be successful it must meet certain requirements which have been developed through discussion with key stakeholders at Aurizon.

1. Devices will not interfere with the safe operation of the EBI Track 200 Track Circuits
2. Collected data must be the available values that are applicable to failure prediction and first line maintenance
3. All data broadcast over LoRaWAN must be encrypted
4. Collected data must be accessible by Maintenance and Engineering personnel.
5. Total Device cost to be under \$50

2.2. Assumptions and Constraints

The following assumptions and constraints limited the project. A review was undertaken when no suitable device could be found to determine if the assumptions and constraints were still valid or if new assumptions or constraint would be required.

Table 1 - Assumptions and constraints

ID	Description	Review status
1	Device to utilize RS232 or RS485 to communicate with the EBI Track 200 Receiver	Valid
2	Device to be battery powered with a 5-year lifetime assuming 4 broadcasts per hour	No longer valid
3	Does not require battery powered solution, can utilize the EBI Track 200 power	New
4	Assume broadcasts every 1 minute	New
5	Device cost to be less than \$50	No longer valid
6	Maximum distance between device and LoRaWAN gateway 10km	Valid
7	Gateway will be powered over ethernet	Valid

3. Literature Review

3.1. Related Condition monitoring works

For the purposes of this project, Condition Monitoring is defined as “Seeking signs of impending failure or performance deterioration in an asset, generally by measuring one or more suitable parameters and initiating a pre-determined response.”(Stroud & Elphick 2005). This definition is supported by previous investigations and reports into condition monitoring.

Condition Monitoring in the railway industry is only a relatively new concept. This is largely due to two separate issues. The first issue is geographical in nature. The physical distance between assets in a rail environment is an engineering hurdle that is still being addressed daily. Systems that need to communicate together are often kilometres away from each other, which requires either expensive cabling and associated trenching activities for direct physical connections or some form of wireless connection. Due to the safety critical nature of equipment that is being connected between sites, messages that are sent need to be guaranteed to be received in time to make safety critical decisions.

The second issue was having no devices readily available to connect to existing infrastructure. Without drive from asset managers there was very little industry development of equipment that could be connected to existing assets. However, during the late 1990’s there was a shift. Manufacturers of wayside systems came to realise through discussion with rail networks, that there was an increasing desire to have condition monitoring, readily available for their assets. This led to an increase in market availability in add on devices that could be connected easily to existing assets, reducing the need for networks to develop devices in house. In turn manufacturers were also starting to include diagnostic ports on their equipment that would provide detailed asset information when connected, either locally or remotely.

While the railway industry is the primary focus there are Condition monitoring projects from alternative industries that are just as applicable. (Murphy 1998) discusses the need to move to a condition based, “reactive” maintenance routine for the Proserpine co-operative sugar milling association. Also discussed are the benefits of predictable machine breakdowns, the reduction in downtime, reduced spare parts and efficient planning of maintenance activities

They go on to evaluate different condition-based monitoring techniques as well as the sensors and actuators that are required to perform these kinds of monitoring. A key takeaway from this project is the requirement to collect data that can be used to perform in depth analysis. While this analysis will be the key driver in realising savings and improving maintenance schedules the collection of good useable data is required before this can even begin.

A recent example of a condition monitoring projects in railway applications is discussed by (Karaduman et al. 2018), “Condition Monitoring Platform in Railways Based on Iot” – where photos of pantographs are taken

and analysed to determine condition. The photos are bypassed over an IoT network. While the IoT network is not described the legitimacy of using an IoT solution for wireless communication is confirmed.

3.2. The Internet of Things

The internet of things is described by (Suresh et al. 2014) as “an interconnection of computers, electrical equipment and previously unconnected items in daily lives. This could be anything from a small atom to a large ship.” The end purpose of the Internet of Things is to increase machine to machine decision making, resulting in less human interaction. This is supported by (Karimi & Atkinson 2013) which describes a future in which the Internet of Things is billions of smart devices connected to create a network of intelligence. This intelligence may be derived from human decisions after reviewing the presented data, from machine made decisions or a combination of the two. The main take away of this accepted thinking of the Internet of Things is the reliance on real data to make informed decisions. Hence this project is primarily targeted towards the reliable collection of data.

There are many challenges that come with connecting new devices to IoT networks. These challenges are described by (Kais et al. 2019). Some applications have specific requirements such as long range, low data rate, low energy consumption and cost effectiveness. Depending on the intended application these different requirements can adversely affect the technology that is used to connect devices. Well established radio technologies such as Bluetooth may for example not be suitable for use in a long range or low power application.

IoT deployments have been investigated for many railway applications. There have been reviews for

“Railway as a Thing” (Oransa & Abdel-Azim 2015) investigate the control systems in charge of the safe operation and movement of railway traffic as a potential “thing” to be connected. It proposes the use of 3G to connect devices to the network. This allows for long range nature of the devices but accepts that power is normally readily available at locations where the “things” are that are connected to the control system.

“A universal sensor data platform modelled for real-time asset condition surveillance and big data analytics for railway systems” (Lee & Tso 2016) developed a sensor to be attached to a train and report to the on board train network which would send live data back to central servers through the on board train management system. This sensor relied on power to be available from the train and for the existing train communication network to report back. Since the device was to be connected to the train it made allowance for operating conditions such as high vibration environment, electromagnetic compatibility and offline memory storage.

“Internet of Things for Smart Railway: Feasibility and Applications” (Ohyun et al. 2018) proposes the use of LTE as it is a similar technology to existing GSM-R. They discuss in detail the geographical problems related to having such a large network that requires covering. They recommend battery power to mains power for node devices with a 3-year minimum battery life. It is noted that LTE is particularly power hungry compared to Bluetooth but it’s longer operational reach is more appealing in this case. Further investigation is undertaken to understand the power consumption of the LTE devices in the aim of calculating power consumption and

reducing it where possible. Gateways requirements are discussed and concluded that mains power will be required for a gateway with a long range transmit/receive profile so that they may connect reliably to multiple devices. A performance comparison is undertaken to compare LTE to LoRa. Their findings show that LTE and LoRa have a similar range, however LTE is more suited to indoor obstacle penetration, whereas LoRa is more suited to external (outdoor) uses. They find that both LTE and LoRa have low data transmission error rates (packets that aren't received). They find that LoRa consumes 1/3 less power than LTE and detail ways to reduce this power consumption further by managing the transmit power, which can be derived from the data rate and by modifying the duty cycle (idle/transmitting states). NB-IOT is also briefly discussed to use slightly more power than LoRa with a reduction in data latency. Ohyun describes it as a good middle ground choice between LTE and LoRa.

As briefly discussed already, due to the large spreading of equipment throughout the rail network a suitable IoT network technology must be compatible with Long Range connections. From the literature review above it was also determined that the devices (nodes) should also be battery powered, so heavy consideration should be given to a low power requirement. To extend battery lives of new devices new so called "low power wide area networks" (LPWAN) have been developed with the intention of decreasing the power consumption of devices. This is achieved by limiting the uplink time, downlink time and adjusting the message sizes and network speeds.

Described by (Karimi & Atkinson 2013) the most critical factors in a LPWAN is:

- Network architecture
- Communication range
- Battery lifetime or low power
- Robustness to interference
- Network capacity (maximum number of nodes in a network)
- Network Security
- One-way vs two-way communication

Currently technologies that are classed as an LPWAN that are available on the market are:

- NB-IOT
- Bluetooth
- Zigbee
- Sigfox
- LoRaWAN

Aurizon is already investigating the use of NB-IOT. Due to the overall cost of the NB-IOT system it was deemed necessary to investigate alternative LPWAN solutions to give an indication of costs. This project is

intended to thoroughly investigate the suitability of LoRaWAN. This was to include an end-to-end solution as well as an estimation of system costs, including components, labour, service life and decommissioning.

3.3. LoRaWAN

LoRaWAN is a form of Low-Power, Wide-Area Network. It was specifically created with the intention of optimizing battery lifetime, capacity, range and cost ('A technical overview of LoRa and LoRaWAN' 2015). It also features encryption for all messages. Referencing the OSI model shown in Figure 2:

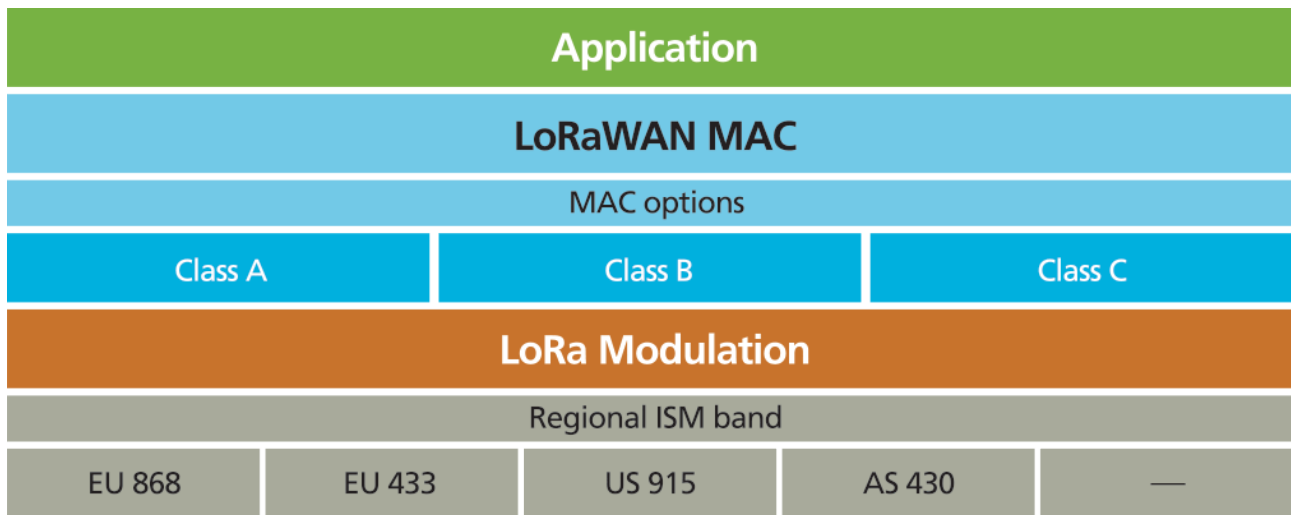


Figure 2 - LoRaWAN OSI model

LoRa is the physical layer or the wireless modulation utilized to create the long-range communication link. While LoRaWAN can be mapped to the Datalink and Network Layer (*LoRaWAN Overview*). Unlike older wireless systems that use frequency shifting modulation as the physical layer LoRa is based on chirp spread spectrum modulation which can achieve similar low power properties while also increasing the communication range. Chirp Spread spectrum is very resilient to interference.

3.3.1. Network Architecture

LoRaWAN networks are connected in a star topology. While it may be possible to set up the LoRaWAN in a mesh network topology the implications of doing so would see reduced battery life as nodes will need to have additional transmit and receive windows to pass information from other nodes back to nearby gateways. Due to how critical battery life of nodes is and the long-range nature of node to gateway connections, mesh networks should not be necessary to drastically reduce costs of setting up a network. Therefore, setting up LoRaWAN in a mesh network topology will not be investigated as part of this project.

The messages sent by LoRaWAN network nodes can be received by multiple gateways, each gateway will pass the message back to a network server. This network server will need to manage redundant messages schedule acknowledgements as well as complete security checks. Due to nodes not relying on a single gateway they can be mobile, in the sense that they don't need to handover between gateways. This feature allows for asset tracking applications. There has already been discussion regarding this feature at Aurizon, a successful

rollout of multiple gateways will allow for increased use cases. However, tracking mobile assets is out of scope of this project.

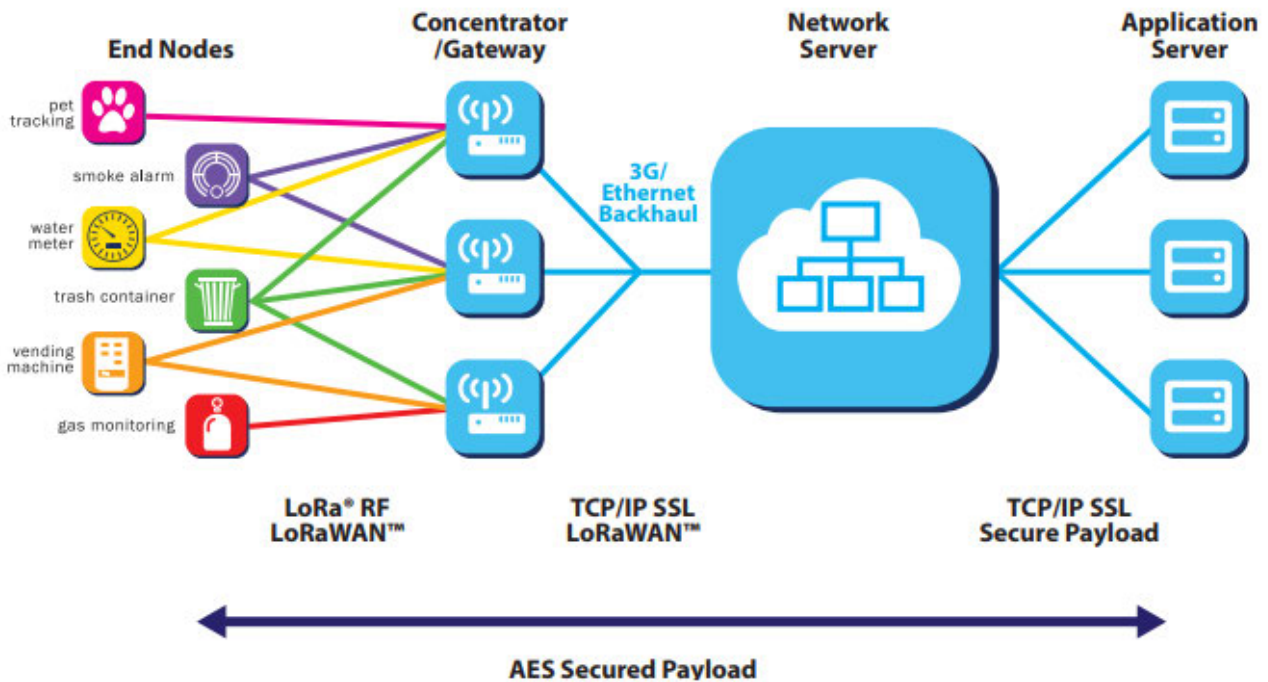


Figure 3 - Example LoRaWAN network topology - reproduced from('A technical overview of LoRa and LoRaWAN' 2015)

The major benefits that LoRa can give to Aurizon are its long-range capabilities and its obstacle penetration.

3.3.2. Battery Life

Due to the nature of an LPWAN battery lifetime becomes a significant factor in choosing a device. While there is power readily available at the sites that have been chosen for this project the time and cost of updating asset information in databases and engineering drawings dwarfs the intended time and cost objectives of this project. For this reason, the device will need to rely on an internal power source, whether that just be a long-life battery or coupling a battery with an energy harvesting device to extend the lifetime of the device. One of the great benefits of LoRaWAN nodes are their asynchronous communications. They spend most of their lives in sleep mode and can wake up on triggered events or on a schedule to reduce power consumption.

3.3.3. Device classification

End-Devices utilising LoRaWAN are classified into three different categories. Class A, Class B and Class C. These different classifications allow for increasing usage at the expense of battery life. A brief description of the differences is given below.

Class A devices are used for bi-directional communications where an uplink transmission is followed by two short downlink receive windows. The transmission slot is scheduled by the end-device when required and random time variation is applied (see ALOHA-type of protocol). Due to these transmit and receive windows being scheduled by the end-device and only small windows available this class device consumed the lowest

power. These communication limitations also limit the uses of the device to applications that can wait until the next transmission to receive a message from the server.

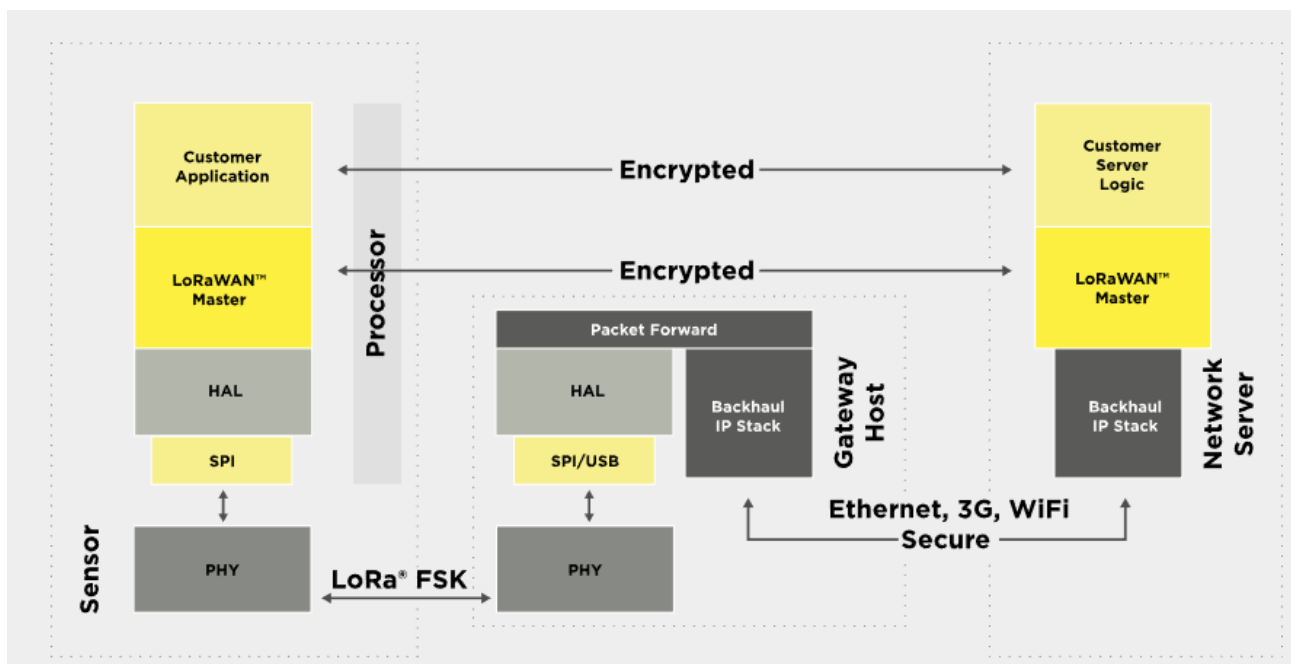
Class B devices are used for bi-directional communications where the end-device has extra scheduled receive windows on top of the aforementioned Class A send and receive windows. In order for the end device to open the receive window at the scheduled time there is a synchronisation required between the gateway. While this allows the server to know when the end-device is listening it does increase the power consumption of the device.

Class C devices are used for bi-directional communications similar to Class B with the exception of having the maximum receive slots available, this gives the end-devices an almost continuous open window to receive messages, they are only closed when the end-device is transmitting. In turn with Class B operations, Class C have an even high-power consumption due to the nature of the receive windows being almost always available.

Reviewing the classifications above the end-devices for this project will need to be Class A type end-devices.

3.3.4. Cyber Security

LoRaWAN utilizes two layers of security. The first is in the network layer, it is known as the network session key (NwkSKey). It is used to ensure the nodes connecting to the network have been authenticated. The second layer of security is in the application layer, it is known as the application session key (AppSKey). This layer of authentication ensures that the network operator does not have access to the end user’s application data. These layers of security are achieved using AES 128 encryption coupled with key exchanging which utilizes an IEEE EU164 identifier.



Both NwkSKey and AppSKey can be obtained on first boot up in a method known as Over the Air Activation (OTAA). This method of activation relies on devices sending a join request to the available LoRa Network, at

which point it will receive a device address and an authorization token. The device will then derive session keys from a root AppKey which needs to be pre-provisioned in the device (Ducrot & Hersent 2016).

Similarly, Both NwkSKey and AppSKey can be pre-loaded onto devices in a method known as Activation by Personalization (ABP). Server-side management will be required to manage the ongoing provisioning of devices with the correct keys.

Due to Aurizon being an owner/operator there are internal ringfencing policies in the company that prevent the sharing of information. The node authentication coupled with the prevention of allowing the network operator from accessing end data will allow for these networks to be utilised by all facets of the company without potentially breaking these ringfencing requirements.

3.3.5. Australian specification

The Australian specification for LoRaWAN sets the channel frequencies as: AU915-928, AS923

Version 1.1 of the Australian regional parameters (Alliance 2018) are summarised below:

- Upstream – 64 channels numbered 0 to 63 utilizing LoRa 125 kHz BW varying from DR0 to DR5, using coding rate 4/5, starting at 915.2 MHz and incrementing linearly by 200 kHz to 927.8 MHz
- Upstream – 8 channels numbered 64 to 71 utilizing LoRa 500 kHz BW at DR6 starting at 915.9 MHz and incrementing linearly by 1.6 MHz to 927.1 MHz
- Downstream – 8 channels numbered 0 to 7 utilizing LoRa 500 kHz BW at DR8 to DR13) starting at 923.3 MHz and incrementing linearly by 600 kHz to 927.5 MHz

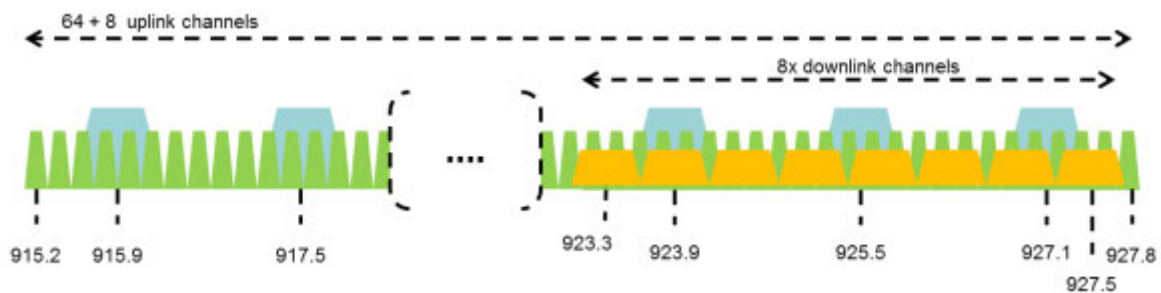


Figure 4 - AU915-928 channel frequencies - reproduced from (Alliance 2018)

- AU ISM band end-devices may use a maximum Equivalent Isotropically Radiated Power (EIRP) of 1 watt
- The payload depends on the selected Data Rate. The maximum payload permissible is 250.

3.3.6. Adaptive Data Rate

The LoRa communication standard uses different data rates ranging from 300 bit per second (bps) to 5kbps for a 125kHz bandwidth. In order to maximize the battery life of each device and the overall capacity of the system an Adaptive Data Rate scheme is utilised for each connected device. LoRaWAN will actively optimise the communication data rate to minimize the airtime and power consumption of devices. The following table

details the data rate as a function of the distance and spreading factor (SF). It can be expected therefore that the further end devices are away from a gateway the more power they will need to expend due to the associated increased time on air.

Spreading factor (at 125 kHz)	Bitrate	Range (indicative value, depending on propagation conditions)	Time on Air (ms) For 10 Bytes app payload
SF7	5470 bps	2 km	56 ms
SF8	3125 bps	4 km	100 ms
SF9	1760 bps	6 km	200 ms
SF10	980 bps	8 km	370 ms
SF11	440 bps	11 km	740 ms
SF12	290 bps	14 km	1400 ms

(with coding rate 4/5 ; bandwidth 125Khz ; Packet Error Rate (PER): 1%)

Figure 5 - LoRaWAN protocol Spreading Factors (SF) versus data rate and time-on-air – reproduced from (Ducrot & Hersent 2016)

3.4. Bombardier EBI Track 200 Digital Track Circuits

For this project to be deemed successful the network needs to reliable and accurately send the data from the track circuit technology. Aurizon has requested that the device that be connected be the Bombardier EBI Track 200 Digital Track Circuit devices which are currently installed on the Goonyella System.

3.4.1. History

A brief history of the Bombardier Audio Frequency track circuits technology is given in the Technical Paper by John Rose “Recent development in audio-frequency track circuit techniques”. The EBI Track 200 track circuits are an upgraded version of the previously branded TI21 audio frequency track circuit technology. The analogue devices have been in service globally since 1980 and continue to be used throughout the world today. As these devices have aged, they are reaching life expiry and require replacement. Targeted to be able to be used as a direct replacement for the aging analogue technology devices, the EBI Track 200 devices bring an upgrade to a digital system that has improved the frequency stability, extended the range of applications and of note to this project a high-quality in-built condition monitoring system.

3.4.2. Description of operation

As already discussed, the EBI Track 200 audio frequency track circuit technologies are used to provide detection of traffic over sections of railway lines. This is achieved by way of utilising frequency selective keying (FSK) which is a modulation technique, that can provide strong harmonic interference immunity and long signal transmissions. To that end these track circuit can achieve lengths of 1100m in electrified systems. Each track circuit operates on an FSK principle where each audio frequency carrier is modulated between a pair of frequencies 34Hz apart at a shift rate of 4.8Hz.

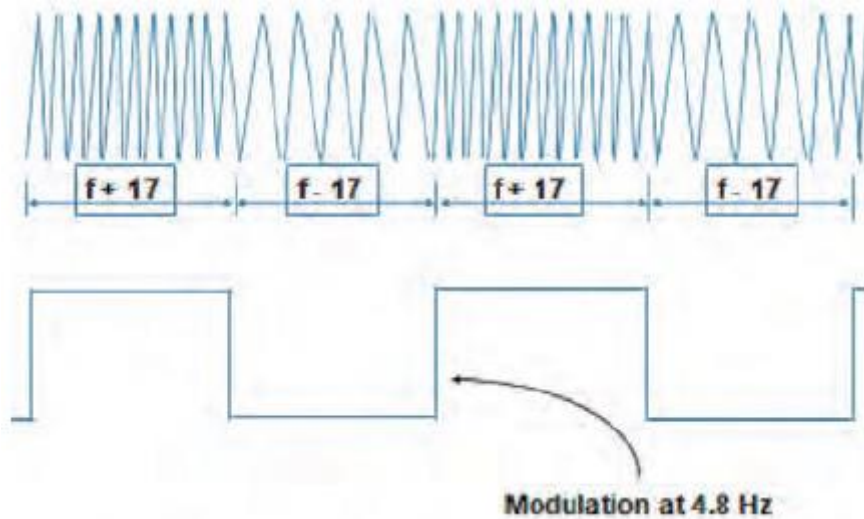


Figure 6 - EBI Track 200 transmitter output signal – reproduced from (Rose 2009))

To achieve separation of track circuits on joint-less tracks, a pair of series resonant tuning units are used to electrically separate the two different track sections.

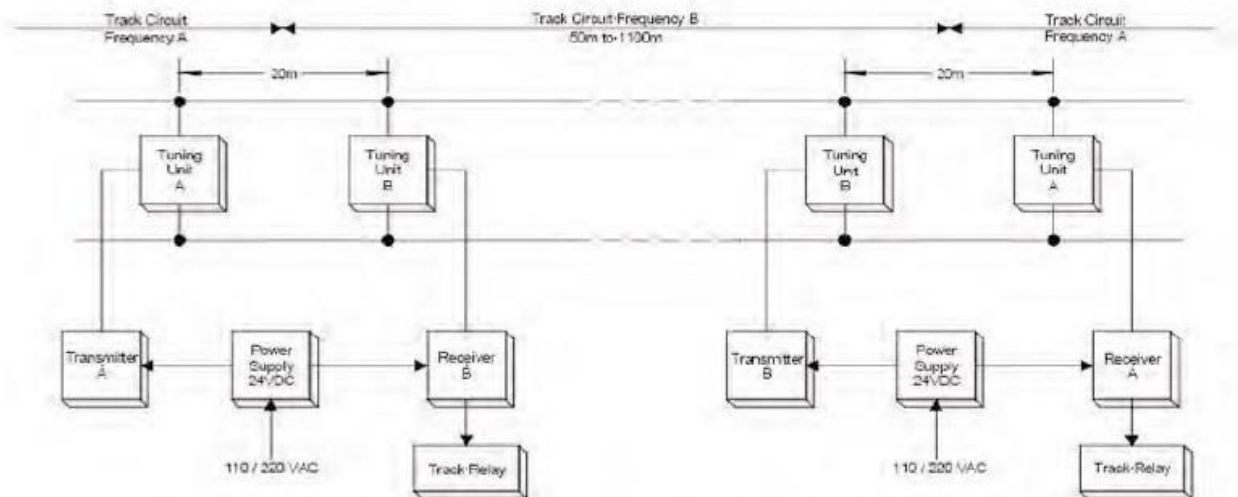


Figure 2: EBI Track 200 basic track circuit (1435mm gauge)

Figure 7 - EBI Track 200 basic track circuit (1435mm gauge) – reproduced from (Rose 2009)

3.4.3. Condition Monitoring

Rose (2009) describes how the operation of audio frequency track circuits are affected by trackside environment. He notes that the following four factors can have a detrimental effect on reliability:

1. Ballast Impedance
2. Track to Sleeper insulation integrity
3. Integrity of track connections
4. Track contamination

The first three directly affect the amplitude of received signal. This amplitude is normally referred to as the 'clear track current'. Track circuits with stable clear track currents (do not vary by more than a few percent) are seen to have good quality ballast conditions, (high impedance), good quality sleeper insulation, and good quality track connections. Unstable conditions indicate that one or all three factors are taking place and corrective maintenance will be required to prevent nuisance, right-side failures. These kinds of failures lead to a reduction in the availability and reliability of the network by causing train delays, speed restrictions and trigger reactive maintenance activities. These in turn result in a loss of revenue for both Aurizon and Mines.

Track contamination affects the ability of the train wheels to shunt the track circuit. This leads to an increase in shunted track current at the receiver. If this is left too long without being addressed the track circuit can show as clear when it is occupied. This wrong side failure condition can lead to extremely dangerous situations including track collisions, derailments and level crossings failing to activate.

EBI Track 200 devices provide clear track current, shunted current and threw train detection threshold as serial data via a standard nine-way D-type connector. It also has a configuration key which captures event sequences that are likely to be valuable in understanding behaviour of the device. This method only allows for post-incident examination and analysis of fault data. Real time data can also be read off the condition monitoring digital displays mounted on the front face of each transmitter and receiver module.

Monitoring is an important tool in improving availability as technical staff can readily monitor actual track circuit conditions and detect problems such as ballast degradation or loosening connections before complete failure occurs. Importantly the monitoring process of the EBI Track 200 Receivers is completely isolated from their safety critical train detection functions. This will maintain their Safety Integrity Level once a data logging device is connected.

There are 71 individual items that can be tracked by the EBI Track equipment. However not all of these are available from an EBI Track 200 receiver, fewer again are available from the Serial port. Of the remaining number of items, the following list describes the items that are most likely to vary over time and are all provided through a single command. These items include the critical 'clear track current' and 'shunted track current' which are both dependent on the "IAVE" and the "ITHR".

Table 2 - EBI Track 200 Monitored functions

Monitored function code	Description of monitored function
TEMP	Unit internal temperature
VPSU	External power supply voltage
SERN	Receiver Serial Number
MODS	Receiver Modification state
FREQ	Frequency Code
RLST	Output relay drive status
ITHR	Auto-set current threshold
VOUT	Output relay drive voltage
IOUT	Output relay drive current
ILSB	Lower side band input current
IUSB	Upper side band input current
IAVE	Average Input Current
LERC	Last Error Code

3.5. Applicable standards and regulation

Relevant rail specific legislation has been included below even though critical consideration for this project has been given to ensure that the operation of trains is not affected by any stage of the project.

All rail transport operators must abide by the following legislation and standards.

- Rail Safety National Law (Queensland) Act 2017
- Rail Safety National Law (Queensland) Regulation 2017
- Transport Infrastructure Act (1994)
- Transport Infrastructure (Dangerous Goods by Rail) Regulation 2018
- Transport (Rail Safety) Act – 2010
- AS 4292.1:2006 – Railway Safety Management

All new Aurizon electrical installations must abide by

- Electrical Safety Act – 2002
- Electrical Safety Regulation - 2013
- Code of Practice for Safe Electrical Work – 1997
- AS/NZS 3000:2007 – Wiring Rules

All new Aurizon telecommunications installations must abide by

AS/NZS 2772.1 (Int):1998 Radiofrequency fields

All new Aurizon installations must abide by:

- OH&S Act – 2004
- OH&S Regulations – 2007

In Addition to the above this project deals with radio frequency technology. Currently the Australian Communications Media Authority (ACMA) is Australia's communications and media regulator. ACMA is responsible for regulating electromagnetic compatibility (EMC), radio frequency radiation and managing access to radio frequency spectrum bands. LoRaWAN devices are classed under the Radiocommunications (Low Interference Potential Devices) Class Licence 2000 (the LIPD Class Licences). LIPD Class Licences. By ensuring compliance with the LoRaWAN standard for Australia requirements of the LIPD Class Licence will also be met (*LoRaWAN Australia*).

4. Methodology

This section will detail the engineering approach used to deliver the project. The following engineering approach is based on a Systems Engineering lifecycle and methodology. This approach was used to conform with Aurizon engineering requirements. Systems Engineering is defined by the Systems Engineering Society Australia as:

Systems Engineering is an interdisciplinary approach that provides the means to enable the realisation of successful complex systems (SESA 2011). It focuses on

- Defining & scoping customer needs and required functionality early in the development cycle.
- The development of an agreed system specification.
- The application of architectural and design skills to decompose the system specification into a structured hierarchy of progressively smaller but cohesive sub-systems and well-defined interfaces.
- Continuous change, release and configuration management of the system, its sub-systems and interfaces.
- Structured validation, verification and integration of the subsystems whilst continuously considering the complete system problem.

The Systems Engineering approach used by this project will comprise of five processes.

1. Requirements
 - a. In this section the requirements for the project will be developed, focusing on stakeholder needs and motivations
2. Design
 - a. In this section an engineering solution will be formed to meet the requirements. The solution will be based on the results of the literature review and be completely documented ahead of implementation
3. Implementation
 - a. In this section the design will be implemented. Any deviations from the design will be documented.
4. Verification and Validation
 - a. Running in conjunction with the Implementation phase the Verification and Validation will be performed to confirm that the implementation meets the design and that the design and any variations made during implementation meet the original requirements.
5. Acceptance and Handover
 - a. Once the verification and validation show that the implementation has satisfactorily met the requirements and meets the intent of the design handover of the final product can occur. For this project, this is defined as return of hardware, handover of the final solution accompanied by the final version of this report.

These processes are typically represented over a system lifecycle represented as the V-model shown below

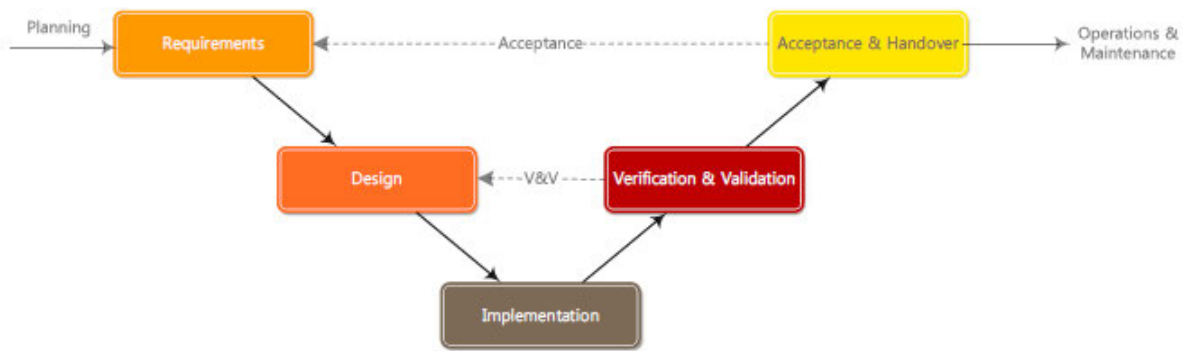


Figure 8 - The Engineer "V" Lifecycle

In the previous section of this report we have undertaken an in-depth literature review and covered the background technologies relevant to the project. In the coming sections the development of a concept device is discussed in detail. The decision to develop a device capable of connecting via RS485 to LoRaWAN comes from a limitation found when undertaking a market review of available devices.

At the formation of the project from first concept of making a remote asset data source available the intention was to source, purchase and modify a device capable of talking to the EBI Track 200 and broadcasting the data via LoRaWAN. Upon detailing the requirements of the device (Appendix H) and performing an 'ideal' RAMS analysis (Appendix I) initial market investigation found devices that had limited capability to connect in a suitable way. For example, a device was found that could connect to RS485 and the hardware layer LoRa protocol, this was deemed inappropriate for the function of this project as it left serious cyber security flaws open for data breaches that would not comply with the requirements of the IT department within Aurizon. Further investigation included browsing catalogues and contacting manufactures about the availability of such device. It was found that no such device was readily available however there were offers from manufacturers to develop and manufacture a suitable device. Due to the budgetary limitations of this project, this option could not be investigated further. It was decided through discussion with the Principal Engineer at Aurizon, supervising this project that those options could be investigated after the successful implementation of a concept device, it was then suggested that the scope of the project change to develop such a concept device.

In altering the scope of the project, the wider stakeholders were approached again and the original requirements of the end device, formed through discussion and development of the RAMS analysis were updated. The intention of this update was to enable broader development options while designing and implementing the first version of the concept device. The following section details the updated requirements specification for the concept device implementation.

5. Requirements

This system is provided to meet stakeholder needs. Aurizon is the key stakeholder client who have a legitimate interest in the system throughout its lifecycle. Aurizon requires a solution to remotely gather the available diagnostic information from these devices. When track circuits fail, they prevent the safe running of trains, can delay road vehicles at level crossings and cost considerable amounts in lost revenue while they are repaired. Due to the geographically diverse roll-out of these track circuits, traditional computer-based serial communications are not possible. Key staff within Aurizon were identified and consulted to ensure that their needs/requirements were understood.

The outcome of these consultations revealed that Aurizon requires a solution to remotely gather the available diagnostic information from these devices. It was further identified that their underlying motivations for this project are to minimise causes of high-impact disruptions in order to:

- Increase Network availability to run revenue services through network pathing optimisation and improved long-term planning
- Improve Network's reliability by reducing unplanned delays through proactive maintenance interventions
- Decrease transit times between mine and port by reducing speed restrictions imposed on the Network
- Improve execution efficiency of asset renewal and maintenance through better forecasting of work

Through discussion with the client the requirements for the project were developed and refined to meet these objectives. Attached in Appendix F, H & I are the originally developed and agreed requirements for the project. Through consultation these were modified during the project as both, no suitable devices were found on the market at the time of the project, and funding for a gateway was removed. As such the updated requirements are listed below.

1. Develop a proof of concept condition monitoring device data logger;
2. Collect EBI Track 200 condition monitoring output data with the device;
3. Broadcast the data over a LoRaWAN connection.

With the input of the literature review undertaken in section 3 these stakeholder requirements have been expanded to include more detail. This has been summarized below as the design requirements.

1. Develop a proof of concept data logging device
 - a. Utilize RS485 to interrogate multiple Receivers from one device
 - b. Power can be sourced from EBI Track 200 Unit, locally available power or batteries
 - c. Build using development board
2. Collect Data
 - a. Collect new diagnostic data from each receiver at maximum intervals of 5 minutes
3. Broadcast Data

- a. Send Data over LoRaWAN as soon as it is ready.
- b. Low Power Sleep until device needs to start again

In addition to these design requirements the system proposal shown in Figure 1 has been expanded to visualise the expansion of the requirements. This can be seen below in Figure 9.

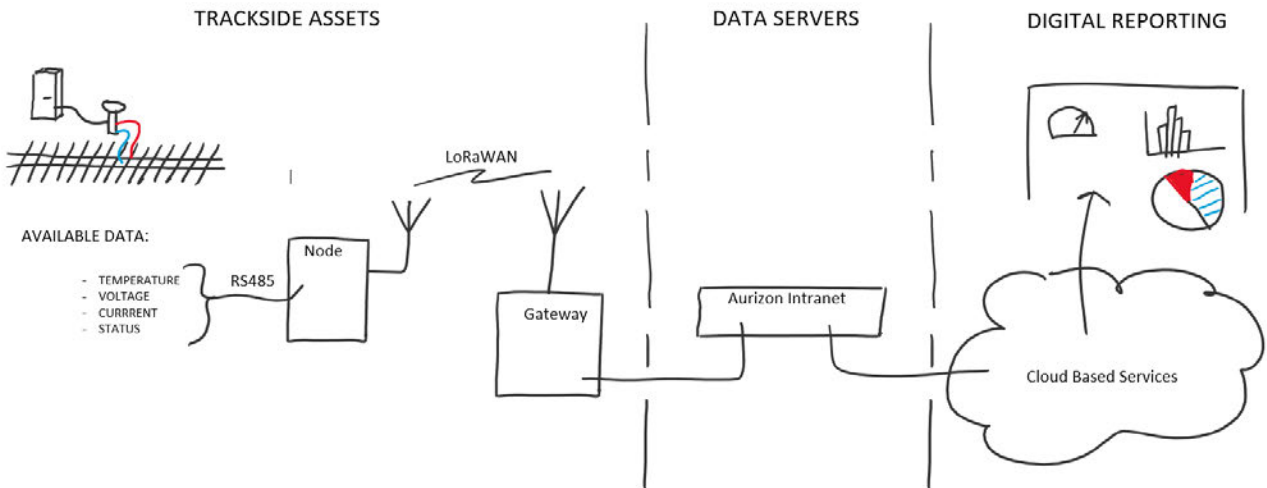


Figure 9 - Expanded System proposal

As part of developing the requirements an analysis was performed in Appendix D to ensure the project conforms with the ethical requirements of Aurizon and engineering best practice. Also discussed are consequences of the project.

6. Design

The Design portion of this project translated the requirements into a set of definitive information and artefacts sufficient to allow the physical implementation and construction of the system. Key activities in the Design phase were:

- Identifying design inputs standards and technical specifications
- Using design methods and techniques
- Performing a Safety in Design (SID) Review
- Producing design outputs

An overview of how the LoRaWAN is proposed to be implemented is shown Figure 10 below. The data logging device consisting of the Arduino Uno will be installed locally with the EBI Track 200 Receivers, typically in the corresponding Track Loc. The Corresponding gateway will be installed in a nearby SER, which contains an ethernet link back to Aurizon's Central Data servers. The LoRa protocol will facilitate the transfer of information from the Loc to SER and the available network will pass the encrypted information back to the central data servers.

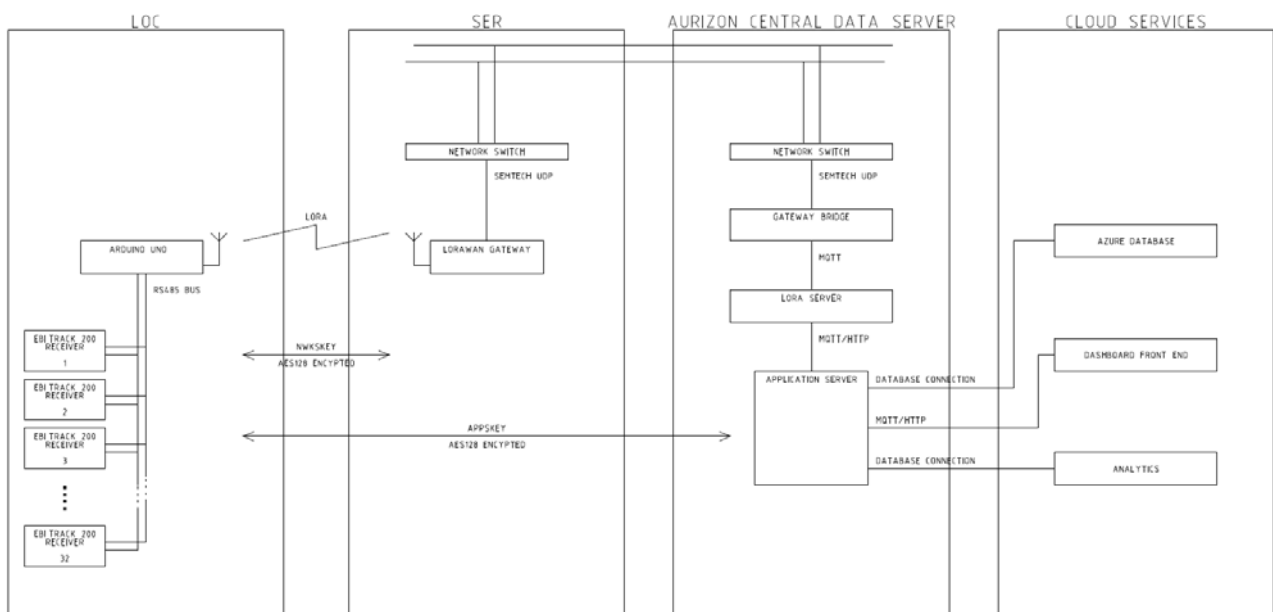


Figure 10 - System Overview

6.1. Hardware

Appendix B details the resource plan that was developed for the project. It lists the required materials and tools that were determined in Section 6 and 7.1.

6.1.1. Microcontroller

A Microcontroller had to be selected for the development of the concept stage device. For this project the Arduino range of microcontrollers were deemed appropriate. In the context of this project Arduino refers to both the physical microcontrollers, Integrated Development Environment (IDE) and the libraries of open

source software. The reason Arduino was deemed appropriate as opposed to other microcontroller options was due mainly to the availability of owned and unused boards. This coupled with Arduino’s open source hardware and software allows for relatively inexpensive and widely supported interfaces. Most Arduino boards utilise ATmega processors. Key considerations of the available boards were analysed in Table 3.

Table 3 - Arduino microcontroller comparisons

Board	Mega2560	Uno	Nano
Processor	ATmega2560	ATmega328P	ATmega328P
Operating Voltage	5V	5V	5V
CPU Speed	16MHz	16MHz	16MHz
Analog In/Out	16/0	6/0	8/0
Digital IO/PWM	54/15	14/6	14/6
EEPROM [kB]	4	1	1
SRAM [kB]	8	2	2
Flash [kB]	256	32	32
USB	Regular	Regular	Mini
UART	4	1	1

An Arduino Uno was selected as the microprocessor for the concept device.



Figure 11 - Arduino Uno (Arduino 2019)

6.1.2. Connecting the EBI Track 200

EBI Track 200 receivers requires a serial connection to communicate. This connection can either be through RS232 or RS485 protocols. Both protocols use a serial data format as follows 38400 baud, 1 start bit, 8 data bits, 1 stop bit, no parity, no handshaking and operate in half-duplex (Millar 2012). RS485 supports a multidrop network topology, meaning it can talk to multiple devices over one bus. Enabling the RS485 communications would simplify the physical devices needed to a single unit per location case. For the physical serial connection, the following pinout table is to be used. Note a standard DE-9 female connector is to be used.

Table 4 - RS-485 pinout table

Pin	Function in RS-485
1	Connect to Pin 9 (mode select)
2	Signal pair
3	<i>Do not connect</i>
4	Relay Common
5	0V
6	Signal pair
7	<i>Do not connect</i>
8	Relay Normally Open
9	5V supply

6.1.3. TTL to RS485 Protocol converter

To allow for the Arduino Uno serial interface to communicate over RS485 an RS485 module to suit Arduino was sourced. The module is based off a MAX485 IC and operates from a +5V power supply level and can achieve a maximum transmission rate of 2.5Mbps. The module comes complete with a 120Ω terminating resistor for the RS485 transmission. To allow for the correct conversion from the Arduino TTL to RS485 the RE and DE pins have been provided to set the device into Transmit/Receive states. These pins need to be set high to allow for successful transmit from the Arduino and low to allow for successful receive operations.

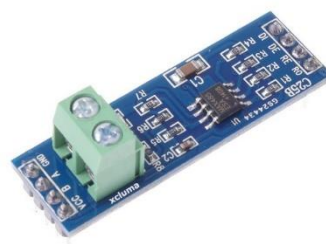


Figure 12 - (MAX485 Module RS- 485 Module TTL to RS- 485 Converter Module for Arduino)

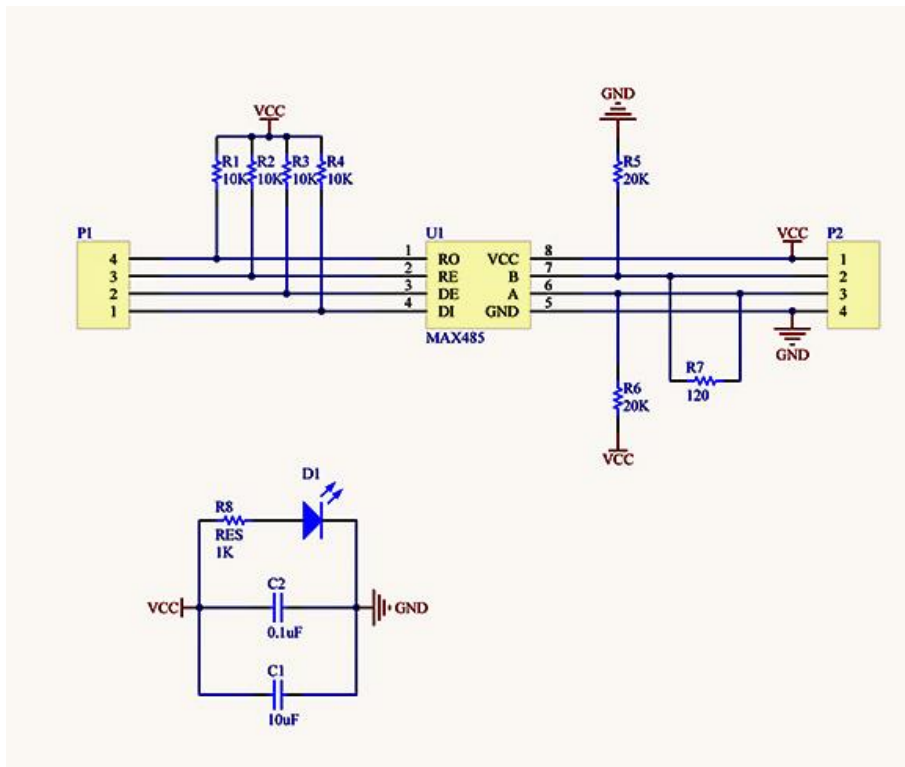


Figure 13 – MAX485 Module Schematic (YourDuino 2019)

6.1.4. Power

The Arduino and RS485 module both require power from a 5V source. This was achieved using the serial connection of the EBI Track 200 which is capable of supplying 100mA @5V. A major benefit to the power source chosen is no modifications are required of the installations of EBI Track 200's. However, this will mean that under blackout conditions no data will be logged or transmitted including status information about the power outage. A key recommendation would then be to include an alternative source of power to allow the device to transmit information while the EBI Track 200 device lost power.

6.1.5. LoRa Shield

A 915MHz Dragino LoRa Shield was used to enable the Arduino Uno to broadcast over LoRaWAN. This shield came with a compatible Antenna which was utilised rather than purchasing a new antenna the antenna connects to the board through an I-Pex connector.

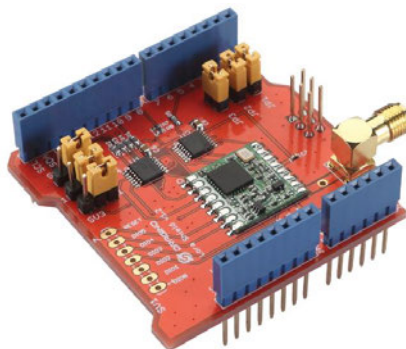


Figure 14 - LoRa Shield for Arduino (Dragino 2019)

The Dragino LoRa Shield has unused pins available. These are described by the documentation provided by Dragino, which serves as the datasheet for the device. The available spare pins will be used to enable the RS485 connection to the EBI track 200, these connections are shown in the Schematic in section 6.4.1.

6.1.6. Enclosure

As the device was only to be built on a development board no enclosure was procured. The “PJ151515T” enclosure below is recommended for this project as these specific enclosures are used consistently throughout Aurizon Signalling installations.



Figure 15 - IP55 enclosure with transparent polycarbonate cover (B&R Enclosures 2014)

6.1.7. Schematics

Using the design inputs and referring to each of the available datasheets for the components the following schematic was created to allow for simple Construction and Verification against the design.

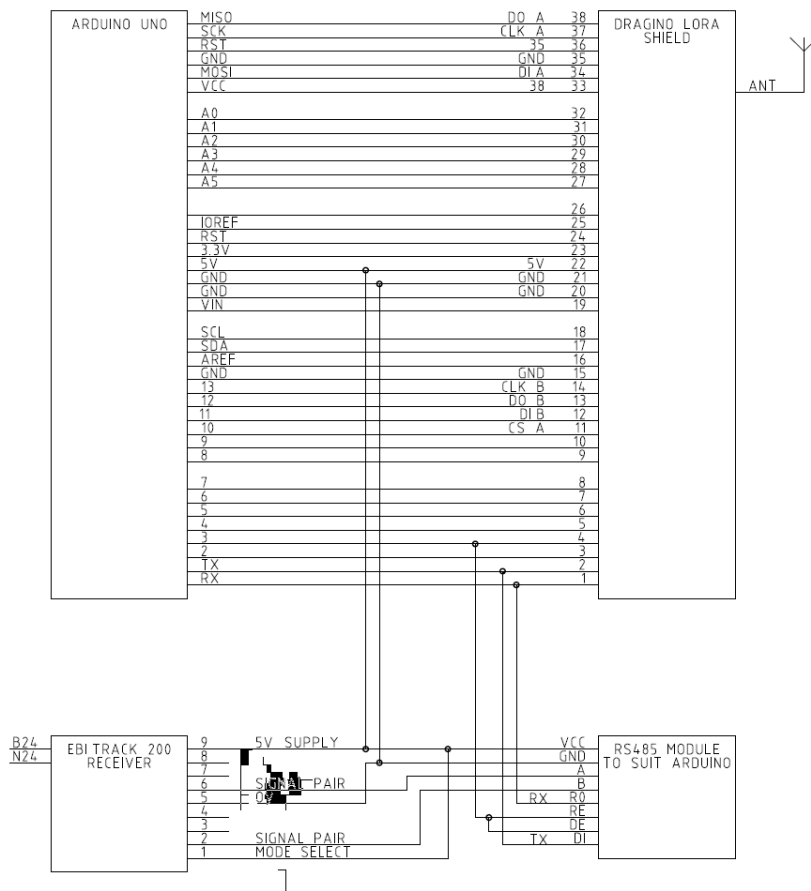


Figure 16 - EBI 200 data logging device schematic

6.2. Software

The decision to use an Arduino as the microprocessor, it follows to use the Arduino IDE to write, assemble and upload the code to the device. The Arduino IDE is a free, open source IDE available through the Arduino website.

6.2.1. Software Libraries

Prebuilt, free and open libraries are available in the Arduino IDE. These are useful for quickly providing extended functionality for specific hardware and data manipulation.

LoRaWAN implemented in C (LMIC) libraries were used to simplify the setup and control of the LoRaWAN libraries. The library creates easy access to modify the required LoRaWAN settings in Section 6.1.6. This is further explored in the Implementation of the software in Section 7.3.

In order to minimise the transmit time of messages, packet sizes were reduced through the implementation of the Cayenne Low Power Protocol (Cayenne LPP) library. This protocol condenses key bit information into a buffer to reduce the required bytes of send data, this in turn reduces the amount of transmission time to send a message. To use Cayenne LPP the received messages need to be decoded by Cayenne

6.2.2. Addressing EBI Track 200

To successfully talk to the EBI Track 200 receiver device over RS485 three methods of addressing can occur.

1. Address the EBI Track 200 Receiver by unit serial number.
2. Address the EBI Track 200 Receiver by the key serial number.
3. Address the EBI Track 200 Receiver with a “broadcast to all” command.

Only the first two options would be suitable for a multidrop network as these options allow for individual machine information to be extracted without corrupting the messages. By addressing by the unit serial numbers, a condition monitoring device will need the ability to be updated locally where the serial numbers are available through the condition monitoring interface or on the side of the unit casing. The downside to this solution is if maintenance teams need to replace the EBI track 200 units the condition monitoring device will need to be updated again with new unit serial numbers.

The best solution then would be to use the serial address of the key, which would rarely be replaced. In the event of a receiver device being replaced the key would not normally need to be replaced and would be inserted into the new receiver device. Once plugged into the new unit the condition monitoring node would continue to perform without needing to be updated with new address information.

Once the unit has been addressed a message needs to be sent with the broadcast to request diagnostic information. This can be in the form of a specific request, where one item is requested. A general request where a subset of items is requested or a request all command.

1. Request all information message

2. Request subset of information message
3. Request specific information message

The output of the messages is in the form of a unit serial number, Internal timestamp, command, parameter, information. For multiple outputs the “parameter, information” part of the message becomes a list of comma-separated values.

6.2.3. LoRaWAN settings

The following LoRaWAN settings are to be programmed into the device, these settings may need to be changed to match the available gateway for testing.

Table 5 - Device LoRaWAN settings

Device Class	Class A
Operating Frequencies (MHz)	923.2 923.4 923.6 923.8 924.0 924.2 924.4 924.6 924.8
Channel Selection	Channel 2
Data Rate (kbps)	5
Spreading Factor	7
Cycle Time	5 seconds

The following gateway settings should be used, which will allow the above device settings to connect the device.

Table 6 - Gateway LoRaWAN settings

Operating Frequency (Centre)	924.3MHz
Channel Selection	Channel 2

6.2.4. Flow Charts

The following state-based operation chart was developed to create a rough draft of the operation of the device. Its intention is not to explicitly state every operation of code, instead the general function of each step-in order to achieve the desired outputs.

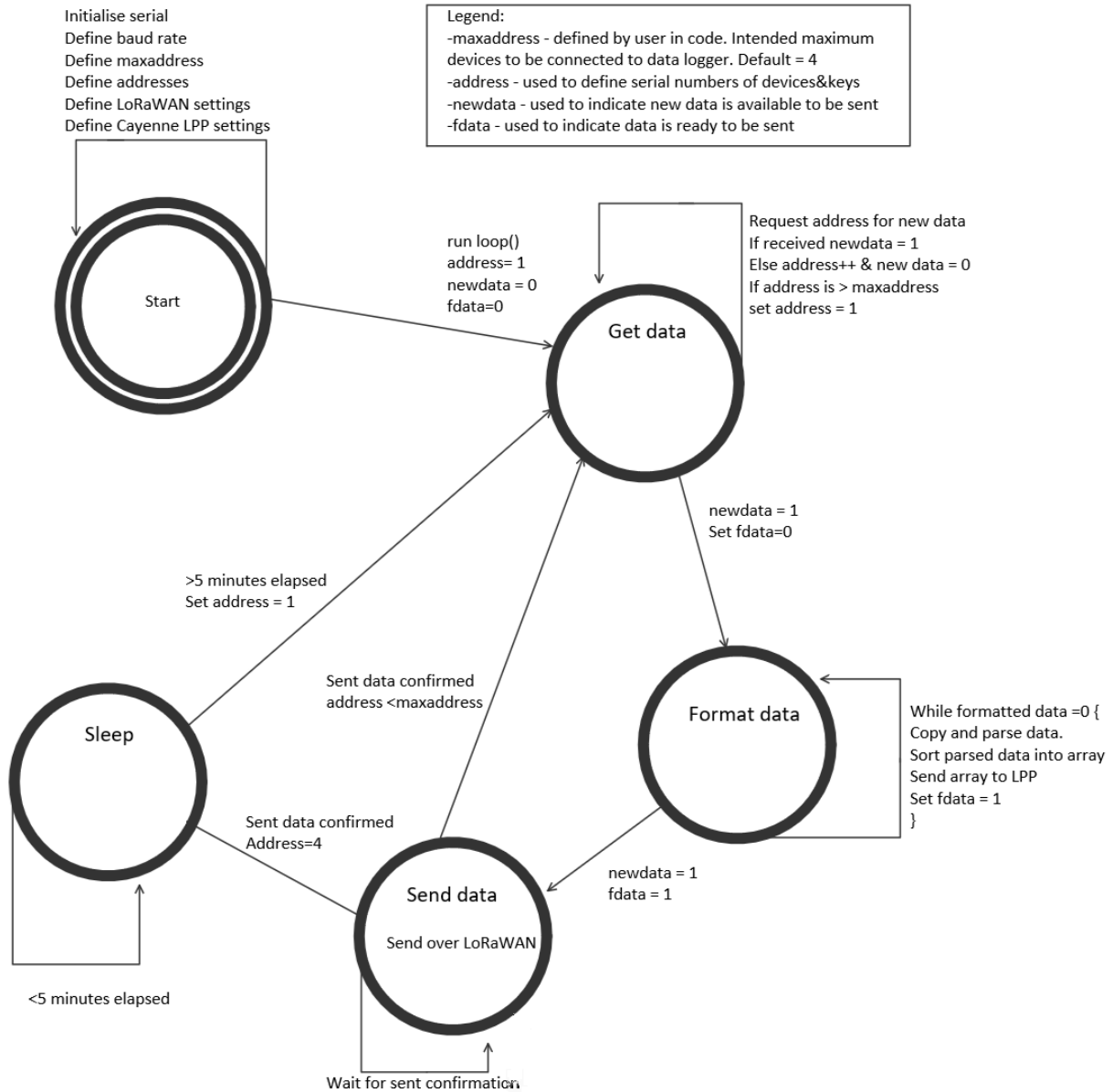


Figure 17 – State-based operation chart of datalogging device software

6.3. Safety in Design Review

A safety in design (SID) review was undertaken for the project and is attached in Appendix E. The SID performed took into consideration the assets whole life including design, construction, maintenance and decommissioning. Included in the SID was a risk assessment, as part of this process key Aurizon staff had the opportunity to add identified risks, raise concerns and provide feedback to the SID. A record of the SID was kept and was regularly updated throughout the projects lifecycle to ensure if new risks arose due to scope change that it could be amended to include these.

7. Implementation

The implementation process of this project included the transformation of the completed design into the resultant system. The main activities included:

- Formulating an Implementation plan
- Procurement materials and equipment
- Development of software
- Manufacture/fabrication/construction and installation

The outputs of the implementation phase included:

- Risk assessments
- Manufactured items
- Software
- Updated design artefacts

7.1. Implementation Plan

The Implementation plan focuses on the Verification and Validation process to run in parallel. This was chosen to minimise the amount of errors and rework required in the implementation phase. This plan is detailed in 5 steps:

1. Purchase/gather all required materials and equipment
2. Using flowcharts from section 6, complete writing code
 - a. Confirm code was completed correctly to flowchart (See section 8)
3. Using schematics from Section 6, complete construction
 - a. Confirm construction was completed correctly (See section 8)
4. Load code onto newly constructed device
5. Program Gateway to required configuration
6. Set up Virtual Machines and cloud services
7. Connect device to EBI Track 200
 - a. Complete tests to confirm that the code integrates with hardware as intended (See section 8)

7.2. Procurement of materials and equipment

Appendix B details the resource plan that was developed for the project. It lists the required materials and tools that were determined in section 6 and 7.1.

During the project, approved funding to purchase a gateway was revoked. As a result, testing of the system was completed with a multichannel gateway that was owned by an employee of Aurizon who graciously provided access to the gateway.

7.3. Development of Software

The Arduino IDE was installed and the LMIC and LPP libraries were added as per section 6.2.1.

The specific versions installed were:

IBM LMIC framework by IBM Version “1.5.0+arduino-2”

CayenneLPP by Electronic Cats Version “1.0.1”

Two different modules were built and tested individually comprising of the RS-485 functions and the LoRaWAN functions. Once both modules were built and tested, they were combined and extended to include the full functionality of the design. A copy of this code can be seen in Appendix L.

7.3.1. RS485 Module

A simple program was written to message the EBI Track 200 device and return a message. The program utilised an onboard LED to light up if messages were being sent and received properly. During testing of this module, it was found that the device was not sending/receiving messages properly. Additional items were procured to allow for analysis of the module this included

- 2x extra TTL to RS485 Protocol converters
- 1x USB to RS485
- 1x USB to TTL

Appendix J details the fault-finding steps for this module to locate and then fix the problem. Once the fault was located an adjustment to the code was made to allow for the serial message to be wholly transmitted before swapping the module into “receive” mode. To achieve this a delay was calculated using the following formula

$$ASCII \times bits \times \frac{1}{BAUD} \times 1000 = delay$$

Where: ASCII is the number of ASCII characters in the message being sent

<i>ASCII</i>	The number of ASCII characters in the message being sent	“example message\r” 17 characters including the spaces and carriage return
<i>bits</i>	The number of bits per ASCII character	30-200m
<i>BAUD</i>	The BAUD rate of the Serial connection	1-10m
<i>delay</i>	The delay in milliseconds	1-20km

7.4. Construction

Once all the separate components and required equipment were purchased and delivered construction commenced on the data logging device.

7.4.1. Connecting the Arduino Uno

The LoRa Shield was connected to the Arduino Uno and the antenna attached via the SMA connector on the LoRa Shield. Two breadboards were utilised for the initial build to sit the TTL to RS485 module. Header wires were then used to make the required connections as per the circuit diagram in Section 6.4.1.

To confirm that the device had been connected the schematic was then used to bell test the connections between the Arduino Uno/LoRa Shield and the RS485 module. Using the power supply the Arduino Uno was connected to a 5V supply to test that the board turned on. LEDs indicated operation on the Arduino board, LoRa Shield and RS485 module.

7.4.2. Preparing the Serial Cable

With this complete the serial cable was then modified to connect to the RS485 module to the EBI Track 200 Receiver. The serial cable was put through bell testing with a multimeter to confirm the cores and the pins matched the pinout table.

7.4.3. Connecting the system

The EBI Track 200 Receiver was then connected to the RS485 module via the serial cable. The final circuitry was completed for data logging device and power was applied to the EBI Track 200 Receiver. With the Arduino Uno now relying on the 5V output of the EBI Track 200 Receiver the LEDs were seen on the Arduino Uno, LoRa shield and RS485 module.

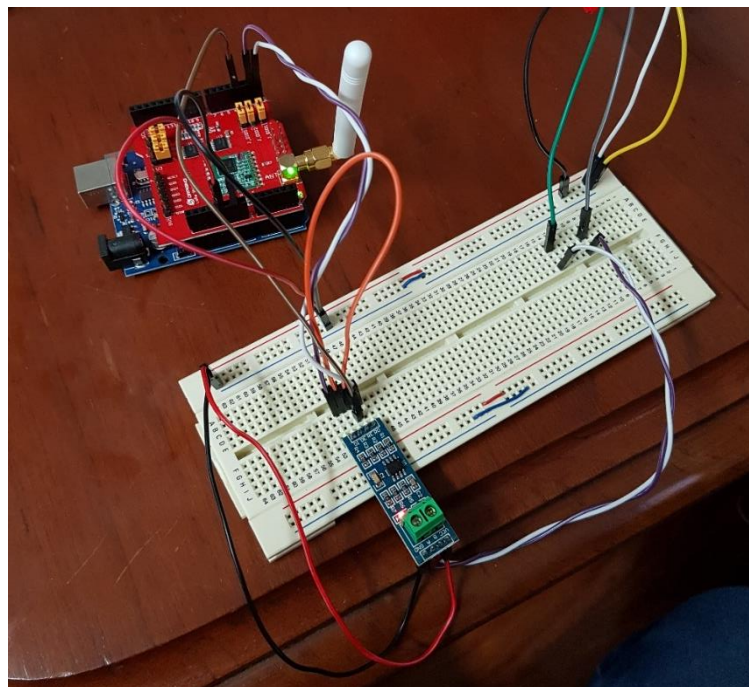


Figure 18 - Arduino connected to RS-485 during testing

7.4.4. Device Setup for Uploading program

In order to prepare the device for the upload of the program from Section 7.3. Pins 0 and 1 were required to be disconnected to ensure the USB serial connection running through these pins was not interfering with the upload. In order to prevent damage to equipment. All connections to the Uno were removed (leaving the shield connected) and the Uno was plugged via USB to the computer with the Arduino IDE and program on it. Once the program was successfully uploaded to the Arduino Uno the USB connection was removed from the Uno and the circuitry was connected again.

7.4.5. Configure Gateway

The gateway used for this project was a Raspberry Pi based LoRaWAN gateway provided by an Aurizon employee when funding for the purchase of a gateway was revoked. The gateway configuration was modified to operate on the specified channels in Table 6. The configuration code is attached in Appendix K.

A packet-forwarder is required to allow the gateway to forward any received network packets. For this project LoRa Gateway Bridge was chosen as it transforms the Semtech UDP protocol into MQTT messages. This was chosen as it allows a secure connection between the gateway and network.

LoRa Gateway Bridge was installed on the gateway and this was configured to connect to LoRa Server and LoRa App Server, which were set up on a Virtual Machine hosted in Microsoft Azure.

7.4.6. Set up Virtual Machines and Cloud Services

Microsoft Azure is Aurion's preferred cloud computing platform. Within Azure a virtual machine was set up to host both LoRa Server and LoRa App Server.

LoRa Server is responsible for the de-duplication of messages from multiple gateway. It also is responsible for managing the authenticated devices. Upon receiving a valid packet forwarded from the gateway LoRa Server will authenticate the message with the NwkSKey. If the message is successfully authenticated LoRa Server will forward the message to the Application Server. In this case the Application Server is LoRa App Server.

LoRa App Server was integrated with an InfluxDB database where the packet messages could be recorded and stored. InfluxDB was set up to create a proof of concept dashboard to display the test data.

7.5. Implementation Output

7.5.1. Risk Assessment

Detailed in Section 3.6 the Risk assessment was completed as part of the SID process and is attached in Appendix E.

7.5.2. Manufactured Items

As a result of the implementation the board was fully connected to 2x EBI Track 200 Receivers and was set left set up and running in a test environment to collect data from both devices over LoRaWAN.

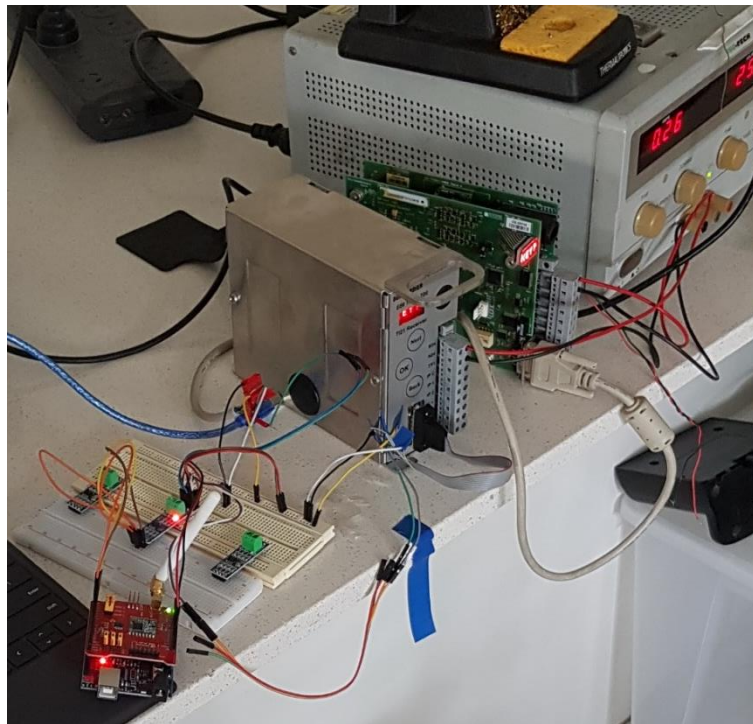


Figure 19 - Arduino connected to two EBI Track 200 Receivers

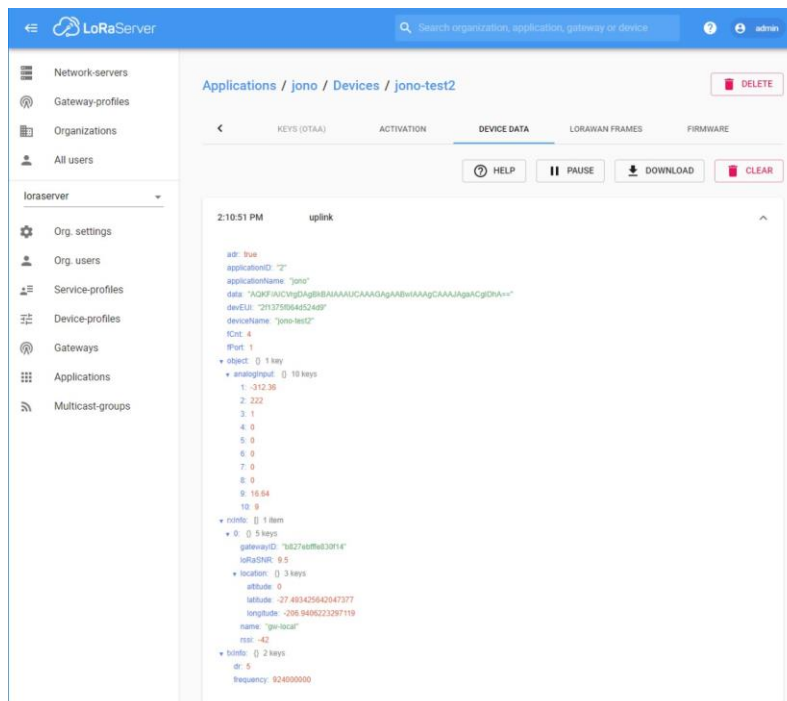


Figure 20 - Received Packet in LoRa App Server

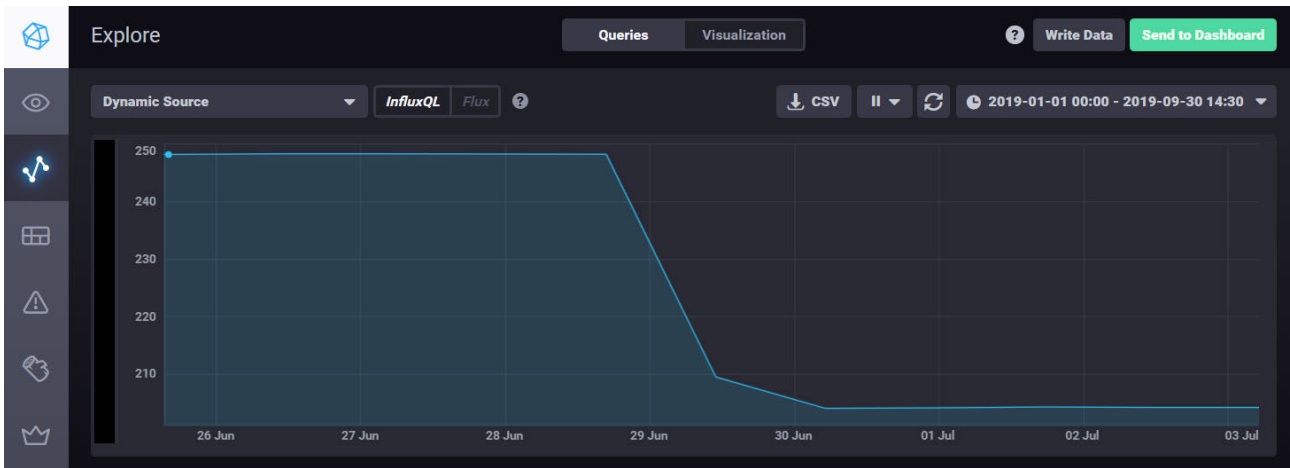


Figure 21 - InfluxDB Dashboard

7.5.3. Software

A copy of the final code used for testing can be seen in Appendix L. The implemented testing code sent messages 5 seconds apart to speed up testing and data collection this was changed to be 1 minute apart to meet requirement 4.

7.5.4. Updated Design Artefacts

During implementation updates were made to the system overview as a result of using a private gateway. This gateway was not able to be connected to Aurizon servers due to security concerns. The updated system overview can be seen below in Figure 22.

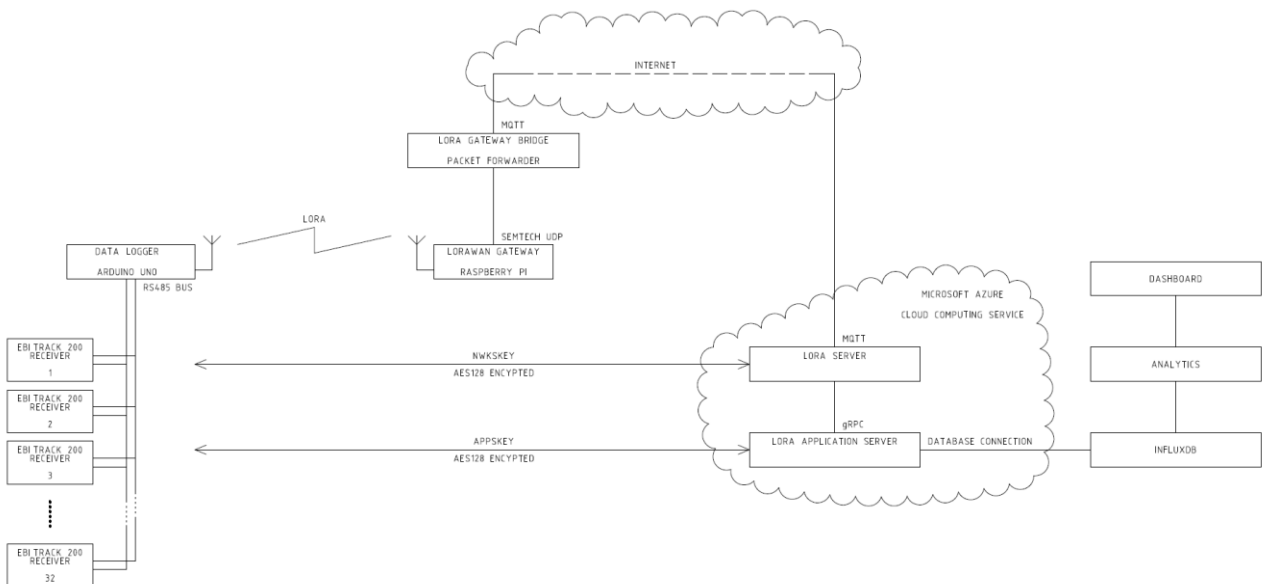


Figure 22 - Updated System Overview

8. Verification and Validation

Verification and Validation processes should be performed at an appropriate level of independence from the Requirements and Design processes to minimize the risk of errors being introduced from bias. Thus the Verification and Validation process consisted of proving to the Stakeholder that the resultant system was successful. System verification activities consisted of checking by analysis, review, inspection and test that the system met the design requirements and was traceable to the stakeholder requirements. Specifically, Verification confirmed correct execution was followed and the resultant system is compliant to the design and in turn the design is compliant to the stakeholder requirements.

Validation confirmed that the resultant system functions, performs and is safe as intended according to the Stakeholder requirements. Validation included inspections, tests and acceptance reviews to demonstrate the correct configuration and ability of the system to meet the stakeholder functional, performance and safety requirements.

8.1. Verification

The design requirements determined in Section 5 were:

1. Develop a proof of concept data logging device
 - a. Utilize RS485 to interrogate multiple Receivers from one device
 - b. Power can be sourced from EBI Track 200 Unit, locally available power or batteries
 - c. Build using development board initially
2. Collect Data
 - a. Collect new diagnostic data from each receiver at maximum intervals of 1 minute
3. Broadcast Data
 - a. Send Data over LoRaWAN as soon as it is ready.
 - b. Low Power Sleep until device needs to start again

During the implementation of the hardware bell testing occurred to test a solid electrical connection between components. Received data packets were inspected alongside the expected output of the software to confirm that the operation of the device was as anticipated. The device was left set up and broadcasting for a period of days to observe whether there were unexpected operations. From these inspections and observations, it was confirmed that all requirements have been met.

8.2. Validation

The stakeholder requirements that were determined in Section 5 were:

1. Develop a proof of concept condition monitoring device data logger;
2. Collect EBI Track 200 condition monitoring output data with the device;
3. Broadcast the data over a LoRaWAN connection.

By inspection, a proof of concept condition monitoring device data logger was created. This device was able to collect the EBI Track 200 condition monitoring output data and broadcast this information over LoRaWAN. This inspection shows that requirements 1 and 2 and 3 were met. Comparing the end solution shown in Figure 22 to the system proposal shown in Figure 1 the underlying intentions of these requirements have been met.

9. Acceptance and Handover

Acceptance and Handover was the transition of the System from being developed/implemented under a project into the 'in-service' / operational environment from which point the system is operated, maintained and assets managed. It is not intended that this project be placed into service in an operational environment. Due to the revised project requirements were to create a proof of concept device The proof of concept however allows for a smoother development, testing and transition into service for a fully realized system now that there is confidence that the solution can be implemented successfully.

Key parties at Aurizon have given a copy of all project records, design artefacts and borrowed equipment has been returned to the original owners. All newly purchased equipment has been handed over to the relevant recipients. A copy of this report will be provided after it has been finalized.

10. Conclusion and Further Works

The aim of this project was to identify and procure a device that could collect the condition data output from the EBI Track 200 Receivers Track Circuit devices and send this data back to central Aurizon data servers over the LoRaWAN protocol. After completing a comprehensive literature review and formulating an in-depth requirement analysis through stakeholder engagement, a market analysis was undertaken to review available solutions. As a result, the market analysis identified a gap in the availability of suitable devices. Leading to a concept end device being developed to collect the condition data output from the EBI Track 200 Receivers Track Circuit devices.

The end device consisting of an Arduino Uno, fitted with RS-485 Serial and LoRaWAN was developed into a proof of concept device and implemented in a test-bed. Testing was carried out using two EBI Track 200 devices. The condition data from these devices was successfully captured and transmitted over LoRaWAN to a gateway based on a Raspberry Pi. This gateway was configured with LoRa Gateway Bridge to forward received messages over a traditional network, to a virtual machine hosted in Microsoft Azure. This virtual machine, running both LoRa Server and LoRa App Server authenticated and unencrypted the messages, forwarding the data onto an InfluxDB database, where it is stored and displayed.

It is recognised that the use of a prototype gateway limited the success of the project. In order to complete the rest of the objectives, including connecting the system to the Aurizon network a more suitable gateway that meets the cyber security requirements of Aurizon would need to be procured. Suitable gateways were identified as part of the market analysis however removal of funding during the project restricted their purchase.

It is noted that further work must be undertaken in order to integrate the system with the Aurizon network. In addition, access to this gateway would also allow for proper testing of the range of the LoRaWAN within the CQCN. The next step at Aurizon is to complete a business case in order to further develop the system. The results of this project will form part of this business case aimed at implementation before June 2020.

Further work to be completed for this project is:

1. Set up gateway to connect to Aurizon network
2. Perform site range testing
3. Trial end device on in-service EBI Track 200 Receivers
4. Improve/Extend user interfaces

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12. Appendices

12.1. Appendix A – Project Specification

ENG4111/4112 Research Project

Project Specification

For: Jonathon Ball

Title: Condition Monitoring using a Low Power Wide Area Network based on LoRaWAN

Major: Electrical and Electronic Engineering

Supervisors: Alexander Kist

Dylan Willis, Aurizon

Sponsorship: Aurizon

Enrolment: ENG4111 -EXT S1, 2019

ENG4112 - EXT S2, 2019

Project Aim: Investigate, design, build and evaluate a private LoRaWAN network to connect existing infrastructure to enable condition monitoring.

Programme: Version 1, 20th March 2019

1. Research background information on IoT radio technology, relevant condition monitoring applications and investigate applicable standards and regulation.
2. Undertake a comprehensive literature review of relevant topic.
3. Complete a comprehensive requirements analysis and specify relevant use cases.
4. Critically evaluate alternative option against a set of defined selection criteria.
5. Design the system and build a test-bed implementation that reports back to Aurizon central data server.
6. Test the system and evaluate its performance against the established requirements.

If time and resources permit:

7. Deploy a gateway at an Aurizon site.
8. Test the system, collect operational data and evaluate its performance.

12.2. Appendix B – Resource Plan

This project requires material resources to complete the core elements. Personnel input will also be required for different stages. For the stretch goals included in the site trials key personnel will also be required to complete the project. Below is a breakdown of the required resources, which were acquired over the course of the project.

Table 7 - Resource Plan

Item	Comment	Status
Personnel		
Asset Manager (Signalling)	Asset Manager will need to approve on site trial of new technology.	Steve Jaksic to approve site trial and location
Principal Engineer (Control Systems)	Provide support for new technology rollout, provide funding for project costs	Jeff Wimberley
Signalling Engineer	Provide access to Engineering Build Lab and support with Internal Network access	Dylan Willis
Principal Infrastructure Architect	Provide advice on gateway requirements.	John Cameron
Leader of Infrastructure Solutions	Provide advice on company requirements for new technologies on site. Provide remote access to gateway once installed on site.	Simon Lawrence
Electricians	If site trial is approved will require electricians to be available to install new equipment at designated location	TBA
Areas		
Engineering Build lab (Office)	Require access to build lab, and reserve space for storage of equipment before and during testing	Access to room completed. Space reserved for storage. Space to be organised for office testing once build complete.
Site Trial	Require access to chosen site location for install and testing of trial network	Site to be confirmed by Asset Manager
Node		

Arduino Uno	Require 1x Arduino Uno per receiver to be tested	1x Genuino Uno procured.
Arduino Uno LoRa Shield	Require 1x LoRa shield per Arduino Uno compatible with 915MHz	1x Dragino LoRa Shield procured
RS232 level converter	Required 1x RS232 level converter per Arduino Uno	1x RS232 to TTL UART converter module
Antenna	915MHz antenna with SMA connection	Using antenna that came with the Dragino LoRa Shield
Enclosure	Enclosure with sufficient IP rating to fit equipment at a site	Not ordered wait until office-based testing is complete.
Power Supply	DC power solution yet to be determined for site solution. Office based testing to use a variable PSU.	1x variable power supply procured
EBI Track 200 Receiver Unit	EBI Track 200 Units required for office-based testing	2x EBI Track 200 Units procured.
Connection Cable	1x RS232 cable (Male to Male) per Arduino Uno	Yet to be procured. Consider making cable for office testing.
Consumables	Various components, wires, breadboards etc.	Procured
Gateway		
Gateway Device	Raspberry Pi multichannel gateway	Gateway on loan until 1 st November
Antenna	915MHz Antenna	Antenna on loan until 1 st November
Network Connection	Ethernet	Not set up due to gateway constraints
Test Equipment and tools		
Hand Tools	Side cutters, screw drivers, etc.	Accessible through build lab
Soldering Station	Soldering Iron and consumables for office test builds	Accessible through build lab
Multimeter	For circuit analysis	Accessible through build lab

12.3. Appendix C – Project Plan

Project Planner

Select a period to highlight at right. A legend describing the charting follows.



Figure 23 - Project Plan

12.4. Appendix D – Ethics and Consequences

Both Aurizon and Engineers Australia expects that ethical and consequential effects of all engineering work to be considered and reviewed as part of all stages of engineering work.

In reference to the Code of Ethics guideline published by Engineers Australia (2018), the most applicable section regarding the project itself is contained within the expectations of section 4 Promote sustainability while the other sections are focused on the engineer undertaking the work. Contained in this section are the following subheadings:

- 4.1 Engage responsibly with the community and other stakeholders
- 4.2 Practise engineering to foster the health, safety and wellbeing of the community and the environment
- 4.3 Balance the needs of the present with the needs of future generations

For this project, the following review of consequential effects throughout the asset lifecycle considers the needs of the public, various stakeholders, the environment and the economy by examining the impact on public safety through reduction of track faults; the necessity for additional staff training in using the new technology; cybersecurity; waste and energy use.

Reduction of Track Faults

There are distinct benefits to the reduction of track faults that can improve relationships with the public and with Aurizon customers. The reduction of track faults will allow for planned train movements to occur more reliably. In general, this will lead to less trains stopping in previously undesignated stowage locations, specifically stopping trains across level crossings.

The reduction in level crossings being blocked by parked trains will increase the public's perception of being able to reliably use the level crossings and will in turn prevent illegal crossing of operating level crossings. This will allow for the public to traverse level crossings. This has a major impact on improved public safety and public relations. Similarly increasing the availability of the track will allow for the on time running of customer deliveries. This in turn will allow more train paths to be sold to customers which will allow them to meet demand.

Both facets of these benefits meet current Aurizon objectives in:

- Improving Level Crossing Safety
- Improving availability of the Network Asset.

Using new technology

As this project is a trial of a new radio technology, the requirements and expectation of staff to be educated on the new technology is reduced from the level a permanent introduction of a new technology requires. There

still is, however, a requirement to provide training and advice to immediate affected stakeholders who are likely to be impacted by the trial of the new technology, including key maintenance and construction staff. In addition, prior to a site trial being rolled out there will be a 'Change of Infrastructure Advice' communicated that will describe the new technology, new devices and key contact information during the trial period.

Cyber Security

There are two important facets of cyber security that have been considered and addressed.

Firstly, there is the consideration of the security of the broadcast data. This data can be received by any LoRa compatible gateway in range of a transmitting device. However, the configured NwkSKey on the devices will prevent unauthorised nodes from connecting to gateways. In addition, the AppSKey prevents the unauthorised access of messages sent by nodes. Both layers of security utilise AES 128 encryption coupled with key exchanging which utilizes an IEEE EU164 identifier.

The second facet is whether the connected condition monitoring device that is connected can affect the safe operation of trains, by modifying or affecting the EBI Track 200 Receivers which they are monitoring. There is not potential for the EBI Track 200 Receiver to be affected by the connected condition monitoring device as the condition monitoring outputs of the EBI Track 200 Receivers has been intentionally isolated from safety critical operations within the device. This is an advertised feature of the EBI Track 200 Receiver, and no additional work will be required to ensure that these functions remain separate.

The installation of the devices will be undertaken by qualified personnel further supporting these key cyber security features.

Waste

Through the successful implementation of this project further works will allow for proactive maintenance to EBI Track 200 units installed in Aurizon's network. With proper maintenance activities it can be expected that the lifecycle of the EBI track 200 units can be maximized resulting in less units failing and being disposed of.

However, the installation of new devices to monitor EBI track 200 units will result in increased waste through the condition monitoring devices themselves. The responsible disposal of all waste generated by this project either directly or indirectly will be managed through Aurizon's Waste Management policy.

12.5. Appendix E - Safety in Design

Table 8 - Safety in Design

ID	Activity and/or Hazard	Risk	Control	Consequence	Likelihood	Level of Risk
1	DESIGN					
1.01	Design affects safe operation of the EBI Track 200 RX units	Danger of track circuit failure or wrong side track failure	Condition monitoring interface is galvanically isolated from safety critical functions. Final Design to be reviewed by Senior Signalling Engineer to confirm. Devices won't be field or remotely programmable.	4	1	Low
1.02	Gateway position	Risk that position is unsuitable from construction/maintenance ongoing.	Design to include allowance for remote access and proposed install location to be agreed with Maintenance and Construction representatives. Telescopic antenna could be used to eliminate mounting the gateway/antenna at dangerous heights. Work could be done in advance to minimise the amount of work at height.	3	3	Moderate
1.03	Data logging device position	risk that the position of the device creates dangerous conditions for maintenance and construction	Design to describe fixed mounting position of node and antenna. To be reviewed by maintenance and construction representatives	2	2	Low

1.04	Electromagnetic compatibility (EMC)	Risk that low EMC drives or affects the safe operation of interlocking or related equipment (track circuit)	Design the device to be located near the equipment for physical connection but maintain as much separation of antenna equipment. Antenna not to encroach on exclusion zone. Check the EMC certificate of the EBI Track 200	3	1	Low
1.06	Power of device to come from 110 AC bus to 5V converter in Location case	affecting the 110AC bus could affect the safe operation of the extended signalling interlocking equipment	Use an isolating AC/DC converter	2	1	Low
1.07	Device to be mounted inside an IP rated enclosure to fit into a 1Q size space	Damaging other equipment in loc, harm to someone installing it. Not properly managing heat tolerances of equipment adjacent to mounting position. EMC effects to other equipment mounted next to it.	Engineering design and sign off including appropriate type approvals to be completed ahead of construction. Correct installation techniques to be followed by qualified persons.	2	1	Low
2	CONSTRUCTION / IMPLEMENTATION					
2.01	Driving/travelling (to and around site)	The Risk of vehicle incidents (crashing, etc) due to driving	Reduce driving, share driving, safe driving course, IVMS, etc.	3	1	Low

		on highways and on the rail corridor, resulting in injury, damage to plant or death				
2.02	Electrocution	The risk of electrocution while working on live equipment resulting in injury, damage to plant or death	Never working on live equipment, only installed by qualified people.	2	1	Low
2.03	Slips trips and falls	slips trips and falls on uneven ground	Existing Controls What existing precautionary controls do I currently have in place and how effective are they? Confirm the Hierarchy of Control (HOC) and justify Consider the following in order: 1. Regulations 2. Codes of Practice 3.	2	1	Low
2.04	Vermin/Pests	injury from vermin/pest	Leave any vermin/pest undisturbed. Be mindful of their presence.	3	1	Low

2.05	Working from heights	Falling from height/dropping tools from height	only to be undertaken by qualified persons	3	1	Low
2.06	Working in the corridor	Danger of Rail Traffic on active railway	never enter danger zones, work with Train Control and Protection Officers to maintain safety	3	1	Low
2.07	Device to be installed in correct location	Devices to be pre assigned to locations before sent to site and constructed risk that the intended device location changes	Once programmed devices to be correctly labelled.	1	3	Low
2.08	Installing Antenna connection through Location case	Modifications derate the location case IP rating	Location cases are IP rated to prevent water and dust ingress. Cables are to exit through the bottom of the location case through concrete pad. Use an IP rate grommet for cables that exit through the side of the location case. Cables to exit on the eve side of loc. Cables not to exit the loc through the roof.	3	1	Low
3	IN SERVICE LIFE/MAINTENANCE					
3.01	Working from heights	Falling from height/dropping tools from height	Works only to be undertaken by qualified persons. Design to allow for remote accessing	3	1	Low

			at height equipment to reduce requirement to work at height			
3.02	Working in the corridor	Danger of Rail Traffic on active railway	Never enter danger zones, work with Train Control and Protection Officers to maintain safety	3	1	Low
3.03	Serial Numbers of EBI Track 200 receivers and Keys	Risk that maintenance crews need to change receiver or serial keys resulting in device no longer reporting information	Devices to be programmed with serial number of keys for minimised risk of device changes. If keys are swapped device will need to be reprogrammed for new serial number	1	2	Low
3.04	Correct and valid data to be sent and received	Risk that the data is modified or corrupted between the EBI Track 200 Receiver and the Aurizon servers during broadcast	Testing to be performed to ensure that the device data is valid. Trial to be performed before full rollout. Verify data once installed. LoRaWAN CRC should ensure data is correct between device and gateway. LoRaServer.io will track data validity from gateway to server.	1	2	Low
4	DECOMMISSIONING					
4.01	Sealing any entry holes into SER or Location case	Risk of derated IP ratings	Seal any holes that are no longer being utilised	3	1	Low

4.02	Front cover for the EBI Track 200 Receiver serial ports are replaced once cable removed	Risk that the exposed terminals can be shorted out by ingress of dust or water	Replace the covers on serial port	3	1	Low
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12.6. Appendix F – Gateway Requirements

Specific criteria for a gateway have been set by Aurizon for this project through the discussion with both the Principal Infrastructure Architect, John Cameron, and the Leader of Infrastructure Solutions, Simon Lawrence. These requirements include consideration to design, construction, maintenance and ongoing commercial strategy. The gateway will also need to comply with Australian regulations as well as the LoRa standard. To determine the most suitable gateway an evaluation will be performed to critically analyse available LoRa gateways on the market. These criteria will need then be properly weighting to ensure that the most suitable gateway is found.

Australian Regulation

While the Australian regulation for the operation of a LoRaWAN device are covered in the LoRa standard it is important to understand that the LoRa standard also allows different frequency ranges around the world. When purchasing a gateway, the operating frequency must be checked to ensure that device complies strictly with the Australian requirement of operation in the ISM band between 915MHz and 928MHz.

LoRa Standard

The LoRa standard stipulates that gateway must comply with the LoRaWAN specification and be compatible with at least Class A devices.

Aurizon Requirements

The gateway must be powered over Ethernet. This allows for a simplified installation. It will also benefit a gateway that utilises an ethernet backhaul through the Aurizon network. While an ethernet backhaul is not mandatory for this installation, for simplicities sake it should be assumed that this will be the preferred backhaul. Alternative supported backhaul technologies will also need to be documented.

The gateway must have a management platform allowing for remote access to allow for modification of settings remotely. This will benefit performing updates to a gateway that is installed in an out of reach location, such as at the top of a tower as well as a gateway that has been installed at a site that is potentially hours travel from the nearest maintenance depot.

The device must comply with IP65 requirements or better. IEC 60529 dictates it must be Dust Tight, which limits the ingress of dust as well as provides complete protection against touch potential. It also needs to be protected from the harmful ingress of projected water from any direction

Ideally the chosen gateway should also be commercially available through existing suppliers and supportable through existing agreements.

Weighting

Weighting will be given between 1 and 3, where 1 is of vital importance, such that without this requirement the project would cease to continue. 2 is important to have, if this is not available a lesser alternative may be

acceptable. 3 is a last consideration, where there will be no major impact to this project, and it would be ‘nice to have’.

The Australian Regulation requirements have been given a 1, without conformance it would be illegal to operate the devices in Australia and would leave Aurizon at significant risk. If no device is found to comply the project will not be able to continue.

The LoRa standard requirements have been given a 1, without conformance to the LoRa standard the project would no longer be investigating a trial of the LoRa technology and would not benefit from continuing.

Power over Ethernet has been given a 2, without PoE, power would need to be given from another source. This would not break the project however may impact the rollout of a suitable trial.

Remote management platform has been given a 2, without a remote management platform the device will be difficult to update if there are changes to network settings. This would not break the project, however may impact the rollout of a suitable field trial.

The IP65 rating has been given a 2, without the proper IP rating the device will need to be installed at a weather proof location, this may impact antenna performance or device reliability. This would not break the project but may impact the rollout of a suitable field trial.

The availability of the device through existing suppliers has been given a 3. For the trial these devices could be purchased outside of a preferred supplier. This may impact ongoing project development and expansion, however will have no impact on this project.

The support of the device through existing agreements has been given a 3. For the trial these devices will be set up, installed and managed wholly by myself, unless otherwise specified. This may impact ongoing project development and expansion but will have no impact on this project.

Comparison

Gateways that will be put through comparisons to the above requirements and weighting are the:

1. MultiTech Conduit
2. Lorix One
3. Cisco LoRaWAN gateway
4. F8L10GWQ

The comparisons undertaken and the results have been tabulated in Appendix G. By applying the weighting described in the last section we can determine that the most suitable device is the Cisco LoRaWAN gateway. The MultiTech Conduit and Lorix One would also have been suitable except they were not available through existing contracts.

Recommendation

Based off the comparisons completed in Appendix F for a suitable gateway show that all the devices would be suitable. However, the Cisco LoRaWAN gateway would be supported by existing contracts and would be the best choice commercially. This recommendation was passed to Aurizon.

12.7. Appendix G – Gateway Comparison Table

Gateway	915-928MHz Operating Frequency	Channels	RX sensitivity	TX Power	Antenna Connector	Antenna	Class A devices support	Power over Ethernet	Available Backhaul technology	Remote Management	Operating Temp (Ambient deg C)	IP Rating	Commercially available through existing suppliers	Supportable through existing contracts
MultiTech Conduit	Yes	8	-	27dBm	N-Type	3dBi	Yes	Yes	4G LTE, 3G, 2G, Ethernet	Yes	-40 to +70	IP67	No	No
Lorix One	Yes	8	-135dBm	27dBm	N-Type	4.15dBi	Yes	Yes	Ethernet	Yes	-30 to +55	IP65	No	No
Cisco LoRaWAN gateway	Yes	16	-139.5dBm	30dBm	N-Type	5dBi	Yes	Yes	Ethernet, Fibre, 4G/LTE, Wi-Fi	Yes	-40 to +70	IP67	Yes	Yes
F8L10GWQ	Yes	8	-140dBm	25dBm	N-Type	2dBi	Yes	Yes	3G, 4G, Ethernet	-	-40 to +85	IP65	No	No

12.8. Appendix H – End Devices (Node) requirements

Specific criteria for an end devices (nodes) have been set by Aurizon for this project. These requirements include consideration to design, construction, maintenance and ongoing commercial strategy. The chosen node will also need to comply with Australian regulations as well as the LoRa standard. To determine the most suitable node an evaluation will be performed to critically analyse available LoRa nodes on the market. These criteria will need then be properly weighting to ensure that the most suitable node is found.

Australian Regulation

While the Australian regulation for the operation of a LoRaWAN device are covered in the LoRa standard it is important to understand that the LoRa standard also allows different frequency ranges around the world. When purchasing a node, the operating frequency must be checked to ensure that device complies strictly with the Australian requirement of operation in the ISM band between 915MHz and 928MHz.

LoRa Standard

The LoRa standard stipulates the operating conditions of class A devices it is critical that the selected node complies with these requirements.

Aurizon Requirements

The node must be battery powered to allow for installation in areas that may not have access to reliable power. The battery would ideally be replaceable, however due to the intended lifespan of the end device it is more important that the battery is capable of a 5-year lifespan. As such a low self-discharge battery will be required. The battery will need to handle hot temperatures upwards of 45 degrees ambient and in the case of battery failure, fail in a safe manner. The battery will ideally be readily purchasable from local distributors for replacement. The lifetime of the battery will need to be greater than 5 years. To calculate battery lifetime, it will be expected that worst case conditions will be used with the device transmitting 12 times a day and waking to collect data from the receiver every 15 minutes. In addition, it would be ideal if the device was capable of being powered by a secondary power source.

The working range of the device is expected to be at least 5km, ideally 10km range at these distances. Exceptions for this condition will be dependent on equipment mounting positions. Ideally antennas will be located at least 2m from the ground.

Ideally a device will come with an antenna but if it does not. Antenna connections will need to be a standard well-established connection type.

Similarly, although less restrictive than the gateway, the device must comply with IP55 requirements or better as it will be mounted internally with EBI Track 200 Devices.

Preferably the device has an RS485 9way connector, however an RS232 interface will be considered acceptable. Ideally the device will have allowances for at least two such connections, but 1 connection will be

required to allow the device to correctly interface with the EBI Track 200 receiver. Aurizon have requested and additional DS18B20 interface be made available if possible.

Cost of each device is to be less than \$120. This allowance includes the purchase of a battery and antenna if they do not come with the device. Ideally the chosen gateway should also be commercially available through existing suppliers and supportable through existing agreements.

Requirements Weighting

Weighting will be given between 1 and 3, where 1 is of vital importance, such that without this requirement the project would cease to continue. 2 is important to have, if this is not available a lesser alternative may be acceptable. 3 is a last consideration, where there will be no major impact to this project, and it would be 'nice to have'.

The Australian Regulation requirements have been given a 1, without conformance it would be illegal to operate the devices in Australia and would leave Aurizon at significant risk. If no device is found to comply the project will not be able to continue.

The LoRa standard requirements have been given a 1, without conformance to the LoRa standard the project would no longer be investigating a trial of the LoRa technology and would not benefit from continuing.

Selecting a node that is battery powered has been given a 1, without a battery power source to run the node the project would not be able to reach a site installation due to large costs of labour involved with modifying existing power circuits and the associated documentation.

A battery with 5-year life has been given a 2, with a lesser battery the project would still be able to be run, however serious consideration to the expected benefit to Aurizon allowing the project to continue would need to be discussed.

A working range of 5km has been given a 2, with a lesser range the project would still be able to be set up, however with lower range capabilities the ongoing benefit to Aurizon will need to be assessed.

The antenna connection has been given a 2, with a nonstandard antenna connection there comes project risk that a suitable antenna will not be found in time and that in future any replacement of an antenna would be extremely difficult.

The IP55 rating has been given a 2, without the proper IP rating the reliability of the device and the lifespan would be dramatically decreased. This would not break the project but may impact the rollout of a suitable field trial.

The availability of an RS485 connector on the device has been given a 1. Without an RS485 supported connection to the device the condition monitoring of receiver units cannot be achieved. This would prevent the project from continuing. If an RS485 connection is not available on the device but an RS232 connection is

available this would allow the project to continue, however it is not the preferred connection type and would be given a lower weighting.

The availability to connect a DS18B20 one-wire temperature sensor to the device has been given a 3. If this is supported it will help Aurizon meet other business targets, however will have little to no impact on this project.

The availability of the device through existing suppliers has been given a 1. For the trial these devices could be purchased outside of a preferred supplier. This may impact ongoing project development and expansion, however will have no impact on this project.

The support of the device through existing agreements has been given a 1. For the trial these devices will be set up, installed and managed wholly by myself, unless otherwise specified. This may impact ongoing project development and expansion but will have no impact on this project/

Comparison

At the time of the project no devices on the market were found to have a serial RS232 or RS485 connection that also supported LoRaWAN within the strict budget requirements. It should be noted that a MultiTech Conduit equipped with a Serial mCard and LoRaWAN mCard could act as suitable end device, however the cost of doing so was nearly 20 times the set budget for this project. Through consultation with Aurizon it was decided not to no longer pursue an End Device from the market and to instead create a proof of concept device using a suitable microcontroller.

12.9. Appendix I – RAMS Analysis

Reliability	Availability	Maintainability	Safety
Mean time before failure	Replacements and spares are readily available	Battery replacement	Longer battery life
How reliable is the data produced by the device?	Will device be supported throughout the expected lifetime of the device	How easily can the device be replaced or modified?	allows for less staff travelling to site to change, replace or maintain devices – biggest safety risk to the company
Ability to communicate with available gateway/network	Ability to communicate with available gateway/network	(Remote firmware updates; sensor replacement; cable repair; access to installation location)	Installation location needs to be accessible from a position of safety. Outside danger zone, outside exclusion zones and if possible, outside of corridor
Packet Error Rate of less than 5%			

12.10. Appendix J – Fault Finding steps for RS485

//Tuesday

- Confirmed wiring
- Confirmed BAUD
- Changed code to emulated receiving a message with PC (Code sends message, manually send back response, Arduino reads and writes received message back one char at a time)
- Tried 1st board with code
- Tried 2nd board with code
- Tried 3rd (previously untested) board with code
- Forced SERIAL_8N1 config (should be default - 8 message bits, no handshake, 1 stop bit)
- Tried using alternative 5V power supply
- Installed PuTTY for Windows to test PuTTY<--> USB//RS485 <--> RS485//Arduino <--> Arduino//USB <--> Serial Monitor
- Found that messages were not being received by PuTTY
- Found that messages sent from PuTTY were being received by Arduino
- Removed RE/DE connection found messages were being received by PuTTY but could not send from PuTTY to Arduino
- --suspect issue with RE/DE connection--
- Tried Swapping polarity of RE/DE connection. blocks sending and receiving of messages
- Set a pin permanently high and another pin permanently low, measured voltages (5V and 15mV respectively)
- measured voltage across RE/DE as 35mV

one serial cable stopped working had to seek alternative approach

//Thursday

- confirmed serial cable stopped working
- connected PC1 PuTTY<--> USB/serial<-->serial/RS485<-->RS485/Serial <--> Arduino <--> Serial Monitor PC2
- same issues as Tuesday were found. Considered that the message being sent was not being transmitted before RE/DE was set to Receive
- added 100ms delay between message send and receive enable
- confirmed messages sent from Arduino where received by PC1
- confirmed messages sent from PC1 where received by Arduino (PC2)
- connected system back up to EBI Track Circuit - didn't work
- connected PC1 PuTTY <--> USB//RS385 <--> EBI Track Circuit - able to send message and receive response

- connected PC1 PuTTY <--> USB/RS485 <--> RS485//Serial (Arduino)
 - in parallel... <--> EBI Track Circuit
- PC1 confirmed that RS485 messages were being converted and transmitted over RS485
- PC1 confirmed that EBI Track Circuit was receiving the message and responding via RS485 channel
- Arduino failed to receive message. likely cause in Serial.available() function?
- Checked timing of delay and adjusted to 17 bytes at 10bits/byte at 38400 baud = $(17 \cdot 10 \cdot (1/38400))$
= 0.00443 ~5ms

System working.

12.11. Appendix K – Gateway Code

Local config file:

```
{
/* Put there parameters that are different for each gateway (eg. pointing one gateway to a test server while the
others stay in production) */
/* Settings defined in global_conf will be overwritten by those in local_conf */
  "gateway_conf": {
    "gateway_ID": "b827ebFFFE830f14"
  }
}
```

Global config file:

```
{
  "SX1301_conf": {
    "lorawan_public": true,
    "clksrc": 1,
    "clksrc_desc": "radio_1 provides clock to concentrator for most devices except MultiTech.
For MultiTech set to 0.",
    "antenna_gain": 0,
    "antenna_gain_desc": "antenna gain, in dBi",
    "radio_0": {
      "enable": true,
      "type": "SX1257",
      "freq": 923600000,
      "rssi_offset": -166.0,
      "tx_enable": true,
      "tx_freq_min": 915000000,
      "tx_freq_max": 928000000
    },
    "radio_1": {
      "enable": true,
      "type": "SX1257",
      "freq": 924300000,
      "rssi_offset": -166.0,
      "tx_enable": false
    },
    "chan_multiSF_0": {
      "desc": "Lora MAC, 125kHz, all SF, 916.8 MHz",
      "enable": true,
      "radio": 0,
      "if": -400000
    },
    "chan_multiSF_1": {
      "desc": "Lora MAC, 125kHz, all SF, 917.0 MHz",
      "enable": true,
      "radio": 0,
      "if": -200000
    },
    "chan_multiSF_2": {
      "desc": "Lora MAC, 125kHz, all SF, 917.2 MHz",
      "enable": true,
      "radio": 0,

```

```

        "if": 0
    },
    "chan_multiSF_3": {
        "desc": "Lora MAC, 125kHz, all SF, 917.4 MHz",
        "enable": true,
        "radio": 0,
        "if": 200000
    },
    "chan_multiSF_4": {
        "desc": "Lora MAC, 125kHz, all SF, 917.6 MHz",
        "enable": true,
        "radio": 1,
        "if": -300000
    },
    "chan_multiSF_5": {
        "desc": "Lora MAC, 125kHz, all SF, 917.8 MHz",
        "enable": true,
        "radio": 1,
        "if": -100000
    },
    "chan_multiSF_6": {
        "desc": "Lora MAC, 125kHz, all SF, 918.0 MHz",
        "enable": true,
        "radio": 1,
        "if": 100000
    },
    "chan_multiSF_7": {
        "desc": "Lora MAC, 125kHz, all SF, 918.2 MHz",
        "enable": true,
        "radio": 1,
        "if": 300000
    },
    "chan_Lora_std": {
        "desc": "Lora MAC, 500kHz, SF8, 917.5 MHz",
        "enable": true,
        "radio": 0,
        "if": 300000,
        "bandwidth": 500000,
        "spread_factor": 8
    },
    "chan_FSK": {
        "desc": "disabled",
        "enable": false
    },
    "tx_lut_0": {
        "desc": "TX gain table, index 0",
        "pa_gain": 0,
        "mix_gain": 8,
        "rf_power": -6,
        "dig_gain": 0
    },
    "tx_lut_1": {
        "desc": "TX gain table, index 1",
        "pa_gain": 0,
        "mix_gain": 10,
        "rf_power": -3,
        "dig_gain": 0
    }

```

```

},
"tx_lut_2": {
  "desc": "TX gain table, index 2",
  "pa_gain": 0,
  "mix_gain": 12,
  "rf_power": 0,
  "dig_gain": 0
},
"tx_lut_3": {
  "desc": "TX gain table, index 3",
  "pa_gain": 1,
  "mix_gain": 8,
  "rf_power": 3,
  "dig_gain": 0
},
"tx_lut_4": {
  "desc": "TX gain table, index 4",
  "pa_gain": 1,
  "mix_gain": 10,
  "rf_power": 6,
  "dig_gain": 0
},
"tx_lut_5": {
  "desc": "TX gain table, index 5",
  "pa_gain": 1,
  "mix_gain": 12,
  "rf_power": 10,
  "dig_gain": 0
},
"tx_lut_6": {
  "desc": "TX gain table, index 6",
  "pa_gain": 1,
  "mix_gain": 13,
  "rf_power": 11,
  "dig_gain": 0
},
"tx_lut_7": {
  "desc": "TX gain table, index 7",
  "pa_gain": 2,
  "mix_gain": 9,
  "rf_power": 12,
  "dig_gain": 0
},
"tx_lut_8": {
  "desc": "TX gain table, index 8",
  "pa_gain": 1,
  "mix_gain": 15,
  "rf_power": 13,
  "dig_gain": 0
},
"tx_lut_9": {
  "desc": "TX gain table, index 9",
  "pa_gain": 2,
  "mix_gain": 10,
  "rf_power": 14,
  "dig_gain": 0
},

```

```

    "tx_lut_10": {
      "desc": "TX gain table, index 10",
      "pa_gain": 2,
      "mix_gain": 11,
      "rf_power": 16,
      "dig_gain": 0
    },
    "tx_lut_11": {
      "desc": "TX gain table, index 11",
      "pa_gain": 3,
      "mix_gain": 9,
      "rf_power": 20,
      "dig_gain": 0
    },
    "tx_lut_12": {
      "desc": "TX gain table, index 12",
      "pa_gain": 3,
      "mix_gain": 10,
      "rf_power": 23,
      "dig_gain": 0
    },
    "tx_lut_13": {
      "desc": "TX gain table, index 13",
      "pa_gain": 3,
      "mix_gain": 11,
      "rf_power": 25,
      "dig_gain": 0
    },
    "tx_lut_14": {
      "desc": "TX gain table, index 14",
      "pa_gain": 3,
      "mix_gain": 12,
      "rf_power": 26,
      "dig_gain": 0
    },
    "tx_lut_15": {
      "desc": "TX gain table, index 15",
      "pa_gain": 3,
      "mix_gain": 14,
      "rf_power": 27,
      "dig_gain": 0
    }
  },
  "gateway_conf": {
    "server_address": "localhost",
    "serv_port_up": 1700,
    "serv_port_down": 1700,
    "servers": [ {
      "server_address": "localhost",
      "serv_port_up": 1700,
      "serv_port_down": 1700,
      "serv_enabled": true
    } ]
  }
}

```

12.12. Appendix L – End Device Code

```
/*
 * Copyright (c) 2015 Thomas Telkamp and Matthijs Kooijman
 *
 * Permission is hereby granted, free of charge, to anyone
 * obtaining a copy of this document and accompanying files,
 * to do whatever they want with them without any restriction,
 * including, but not limited to, copying, modification and redistribution.
 * NO WARRANTY OF ANY KIND IS PROVIDED.
 *
 * This example sends a valid LoRaWAN packet with payload "Hello,
 * world!", using frequency and encryption settings matching those of
 * the The Things Network.
 *
 * This uses ABP (Activation-by-personalisation), where a DevAddr and
 * Session keys are precontabletbled (unlike OTAA, where a DevEUI and
 * application key is configured, while the DevAddr and session keys are
 * assigned/generated in the over-the-air-activation procedure).
 *
 * Note: LoRaWAN per sub-band duty-cycle limitation is enforced (1% in
 * g1, 0.1% in g2), but not the TTN fair usage policy (which is probably
 * violated by this sketch when left running for longer)!
 *
 * To use this sketch, first register your application and device with
 * the things network, to set or generate a DevAddr, NwkSKey and
 * AppSKey. Each device should have their own unique values for these
 * fields.
 *
 * Do not forget to define the radio type correctly in config.h.
 */
*****/

#include <lmic.h>
#include <hal/hal.h>
#include <SPI.h>
#include <CayenneLPP.h>

#define SerialTxControl 3 //RS485 Direction control pin connect to RE and DE
#define RS485Transmit HIGH
#define RS485Receive LOW

CayenneLPP lpp(53); //maximum bytes reserved by cayenne lpp
const float send_period = 5; //set send period to every 5 seconds
const byte numChars = 255; //maximum characters in message
char receivedChars[numChars];
char tempChars[numChars]; // temporary array for use when parsing
boolean newData = false;
int ti21[21]; //there are 21 outputs from the TI21 Reciever
unsigned long time_now = 0;

//enter unique serial of EBI Track 200 device or attached keys [REDACTED]
char deviceOne[] = "[REDACTED]";
char deviceTwo[] = "[REDACTED]";
char deviceThree[] = "[REDACTED]";
char deviceFour[] = "[REDACTED]";
```

```

//check if the following are actually used:
/*int f = 0;
int value = 0;
int i;
int Status=0;
*/

// LoRaWAN NwkSKey, network session key
// This is the default Semtech key, which is used by the early prototype TTN
// network.

static const PROGMEM u1_t NWKSKEY[16] = { 0x48, 0x9C, 0x22, 0xF5, 0xD4, 0x7D, 0x6F, 0x2C, 0xF9,
0x9C, 0x68, 0x97, 0x07, 0x08, 0x1D, 0x88 };

// LoRaWAN AppSKey, application session key
// This is the default Semtech key, which is used by the early prototype TTN
// network.
static const u1_t PROGMEM APPSKEY[16] = { 0x98, 0xED, 0xC8, 0x8B, 0x0B, 0xFF, 0x3D, 0xCE, 0xBC,
0x4D, 0x3F, 0xD4, 0x0A, 0xFF, 0x4F, 0x74 };

// LoRaWAN end-device address (DevAddr)
static const u4_t DEVADDR = 0x26001A02 ; // <-- Change this address for every node!

// These callbacks are only used in over-the-air activation, so they are
// left empty here (we cannot leave them out completely unless
// DISABLE_JOIN is set in config.h, otherwise the linker will complain).
void os_getArtEui (u1_t* buf) { }
void os_getDevEui (u1_t* buf) { }
void os_getDevKey (u1_t* buf) { }

static uint8_t mydata[] = "";
static osjob_t sendjob;

// Schedule TX every this many seconds (might become longer due to duty
// cycle limitations).
const unsigned TX_INTERVAL = 1;

// Pin mapping
const lmic_pinmap lmic_pins = {
  .nss = 10,
  .rxtx = LMIC_UNUSED_PIN,
  .rst = 9,
  .dio = {2, 6, 7},
};

void onEvent (ev_t ev) {
  Serial.print(os_getTime());
  Serial.print(" ");
  switch(ev) {
    case EV_SCAN_TIMEOUT:
      Serial.println(F("EV_SCAN_TIMEOUT"));
      break;
    case EV_BEACON_FOUND:
      Serial.println(F("EV_BEACON_FOUND"));
      break;
    case EV_BEACON_MISSED:

```

```

        Serial.println(F("EV_BEACON_MISSED"));
        break;
    case EV_BEACON_TRACKED:
        Serial.println(F("EV_BEACON_TRACKED"));
        break;
    case EV_JOINING:
        Serial.println(F("EV_JOINING"));
        break;
    case EV_JOINED:
        Serial.println(F("EV_JOINED"));
        break;
    case EV_RFU1:
        Serial.println(F("EV_RFU1"));
        break;
    case EV_JOIN_FAILED:
        Serial.println(F("EV_JOIN_FAILED"));
        break;
    case EV_REJOIN_FAILED:
        Serial.println(F("EV_REJOIN_FAILED"));
        break;
    case EV_TXCOMPLETE:
        Serial.println(F("EV_TXCOMPLETE (includes waiting for RX windows)"));
        if (LMIC.txrxFlags & TXRX_ACK)
            Serial.println(F("Received ack"));
        if (LMIC.dataLen) {
            Serial.println(F("Received "));
            Serial.println(LMIC.dataLen);
            Serial.println(F(" bytes of payload"));
        }
        // Schedule next transmission
        os_setTimedCallback(&sendjob, os_getTime()+sec2osticks(TX_INTERVAL), do_send);
        break;
    case EV_LOST_TSYNC:
        Serial.println(F("EV_LOST_TSYNC"));
        break;
    case EV_RESET:
        Serial.println(F("EV_RESET"));
        break;
    case EV_RXCOMPLETE:
        // data received in ping slot
        Serial.println(F("EV_RXCOMPLETE"));
        break;
    case EV_LINK_DEAD:
        Serial.println(F("EV_LINK_DEAD"));
        break;
    case EV_LINK_ALIVE:
        Serial.println(F("EV_LINK_ALIVE"));
        break;
    default:
        Serial.println(F("Unknown event"));
        break;
}
}

void do_send(osjob_t* j){
    // Check if there is not a current TX/RX job running
    if (LMIC.opmode & OP_TXRXPEND) {

```

```

    Serial.println(F("OP_TXRXPEND, not sending"));
} else {
    // Prepare upstream data transmission at the next possible time.
    LMIC_setTxData2(1, lpp.getBuffer(), lpp.getSize(), 0);
    Serial.println(F("Packet queued"));
    Serial.println(LMIC.freq);
}
// Next TX is scheduled after TX_COMPLETE event.
}

void setup() {
    Serial.begin([REDACTED], SERIAL_8N1); //set baud rate of TI21
    pinMode(SerialTxControl, OUTPUT); //sets the digital pin 3 as output

#ifdef VCC_ENABLE
    // For Pinoccio Scout boards
    pinMode(VCC_ENABLE, OUTPUT);
    digitalWrite(VCC_ENABLE, HIGH);
    delay(1000);
#endif

    // LMIC init
    os_init();
    // Reset the MAC state. Session and pending data transfers will be discarded.
    LMIC_reset();

    // Set static session parameters. Instead of dynamically establishing a session
    // by joining the network, precomputed session parameters are be provided.
#ifdef PROGMEM
    // On AVR, these values are stored in flash and only copied to RAM
    // once. Copy them to a temporary buffer here, LMIC_setSession will
    // copy them into a buffer of its own again.
    uint8_t appskey[sizeof(APPSKEY)];
    uint8_t nwkskey[sizeof(NWKSKEY)];
    memcpy_P(appskey, APPSKEY, sizeof(APPSKEY));
    memcpy_P(nwkskey, NWKSKEY, sizeof(NWKSKEY));
    LMIC_setSession (0x1, DEVADDR, nwkskey, appskey);
#else
    // If not running an AVR with PROGMEM, just use the arrays directly
    LMIC_setSession (0x1, DEVADDR, NWKSKEY, APPSKEY);
#endif

    LMIC_setupChannel(0, 923200000, DR_RANGE_MAP(DR_SF12, DR_SF7), BAND_CENTI); // g-
band
    LMIC_setupChannel(1, 923400000, DR_RANGE_MAP(DR_SF12, DR_SF7B), BAND_CENTI); // g-
band
    LMIC_setupChannel(2, 923600000, DR_RANGE_MAP(DR_SF12, DR_SF7), BAND_CENTI); // g-
band
    LMIC_setupChannel(3, 923800000, DR_RANGE_MAP(DR_SF12, DR_SF7), BAND_CENTI); // g-
band
    LMIC_setupChannel(4, 924000000, DR_RANGE_MAP(DR_SF12, DR_SF7), BAND_CENTI); // g-
band
    LMIC_setupChannel(5, 924200000, DR_RANGE_MAP(DR_SF12, DR_SF7), BAND_CENTI); // g-
band

```



```

    LMIC_setupChannel(6, 924400000, DR_RANGE_MAP(DR_SF12, DR_SF7), BAND_CENTI); // g-
band
    LMIC_setupChannel(7, 924600000, DR_RANGE_MAP(DR_SF12, DR_SF7), BAND_CENTI); // g-
band
    LMIC_setupChannel(8, 924800000, DR_RANGE_MAP(DR_FSK, DR_FSK), BAND_MILLI); // g2-
band

    // Disable link check validation
    LMIC_setLinkCheckMode(0);

    // TTN uses SF9 for its RX2 window.
    LMIC.dn2Dr = DR_SF9;

    // Set data rate and transmit power for uplink (note: txpow seems to be ignored by the library)
    LMIC_setDrTxpow(DR_SF7,14);

    // Start job
    //runs to loop()
}

void send_data(char device){
    digitalWrite(SerialTxControl, RS485Transmit); // Enable RS485 Transmit

    switch(device){
    case 1:
        Serial.write(deviceOne);
        break;
    case 2:
        Serial.write(deviceTwo);
        break;
    case 3:
        Serial.write(deviceThree);
        break;
    case 4:
        Serial.write(deviceFour);
        break;
    }
    delay(5); //wait for message to be sent before opening up recieve channel
    digitalWrite(SerialTxControl, RS485Receive); // Disable RS485 Transmit
}

void recvWithStartEndMarkers() {
    static boolean recvInProgress = false;
    static byte ndx = 0;
    char startMarker = 'p'; //REGISTER THE START OF THE MESSAGE AT THE [REDACTED]
    char endMarker = 'r';
    char space = ' ';
    char rc;

    while (Serial.available() > 0 && newData == false) {
        rc = Serial.read();
        if (recvInProgress == true) {
            if (rc != endMarker) {
                if(rc != space){ //ignore spaces
                    receivedChars[ndx] = rc;
                    ndx++;
                    //limit message to a byte

```

```

        if (ndx >= numChars) {
            ndx = numChars - 1;
        }
    }
}
else {
    receivedChars[ndx] = '\0'; // terminate the string
    recvInProgress = false;
    ndx = 0;
    newData = true;
}
}

else if (rc == startMarker) {
    recvInProgress = true;
}
}
}

```

```

void parseData() { // split the data into its parts
    lpp.reset();

```

```

    char * strtokIndx; // this is used by strtok() as an index
    int num = 21;
    //Serial.print("\n");
    strtokIndx = strtok(tempChars, ",");
    for(int i = 0; i < num; i++){
        ti21[i] = atoi(strtokIndx);
        //Serial.print(ti21[i]);
        //Serial.print(" ");
        strtokIndx = strtok(NULL, ","); //Jumps forward in character array to the end of the last used value
    }
    lpp.addAnalogInput(1, ti21[0]); // [REDACTED]
    lpp.addAnalogInput(2, ti21[1]); // [REDACTED]
    lpp.addAnalogInput(3, ti21[2]); // [REDACTED]
    lpp.addAnalogInput(4, ti21[3]); // [REDACTED]
    lpp.addAnalogInput(5, ti21[5]); // [REDACTED]
    lpp.addAnalogInput(6, ti21[6]); // [REDACTED]
    lpp.addAnalogInput(7, ti21[7]); // [REDACTED]
    lpp.addAnalogInput(8, ti21[8]); // [REDACTED]
    lpp.addAnalogInput(9, ti21[9]); // [REDACTED]
    lpp.addAnalogInput(10, ti21[20]); // [REDACTED]
}

```

```

void loop() {

```

```

    for (char i = 1; i < 5; i++){
        time_now = millis();
        send_data(i);
        while(millis() < time_now + 1000){
            recvWithStartEndMarkers();
        }
        if (newData == true) {
            //Serial.print(receivedChars);
            strcpy(tempChars, receivedChars);
            // this temporary copy is necessary to protect the original data
            // because strtok() used in parseData() replaces the commas with \0

```

```
    parseData();
    //showParsedData();
    do_send(&sendjob);
    newData = false;
}
while (millis() < time_now + 5000){

}
//Turn on LoRaWAN and broadcast message
os_runloop_once();
}
}
```