UQ

Project Proposal

LPWAN environment monitoring at UQ lakes

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Problem Definition

The environmental monitoring systems around UQ, specifically the Lake, currently do not work together or on the same network. This is a major roadblock for monitoring of vital information, as the information is not centrally collated or even centrally received. Some systems such as the exosonde do not currently have any long-distance communications at all, requiring technicians to retrieve the device and its data through its datalogging function. This is highly inefficient and can be costly, seeing as the exosonde is desired to be stationed somewhere in the middle of the lake and can only be accessed by light boat.

In an age where the Internet of Things (IoT) is becoming increasingly more common place, these archaic techniques need to be rethought. Solutions involving the establishment of centralised data hubs need to be discussed, so that environmental incidents can be prevented or nurtured back to good health. An example incident occurred at the beginning of 2017 when a heatwave struck while the fountain was turned off, resulting in heating of the water to the point where a large population of the fish died. If there had been better monitoring methods in place, this situation may have been prevented or at least reduced in impact.

Introduction

LPWAN and Environmental Sensing

Environmental sensing usually implies a network of sensors placed strategically in an area that requires monitoring, whether that be air quality, water quality, soil quality, temperature etc. This inherently means the system will require the ability to send messages over long distances, possibly kilometres depending on the monitoring strategy, and receive data packets from many low power smart devices in around the same timeframe.

Communication systems such as Zigbee seem like a possible solution here, as they are designed for the connection of smart devices and have a proven track record in the IoT industry. However, Zigbee and other mesh IoT topologies require sensors to be close and have sufficient power to possibly act as a router so fringe devices can be connected to the network. This is not quite what is desired for Environmental Sensing applications, as sensors would ideally like to be able to lie dormant for a hibernation cycle and then send a single, low power message rather than the possibility of being woken up to route another node's message or reroute a new network when a device falls from the mesh.

This is where LPWAN begins to show its necessity in this sensing platform, literally standing for Low Power Wide Area Network. Although these communication standards can be more complex than Zigbee, Wifi, Bluetooth etc., they tackle the issues posed by nodes stationed off the grid hundreds to thousands of metres away from a base station. Some examples of these LPWAN systems are LoRaWAN, Nwave, Ingenu and SigFox. [1] [2]

Spread Spectrum

This communication system stretches the signal over a larger bandwidth, while maintaining the same signal power. When the signal is spread out, the signal's peak of power spectral density will become closer to the noise floor. This was originally used in the military for protection against jamming by preventing a distinguishable peak in the spectrum. [3]

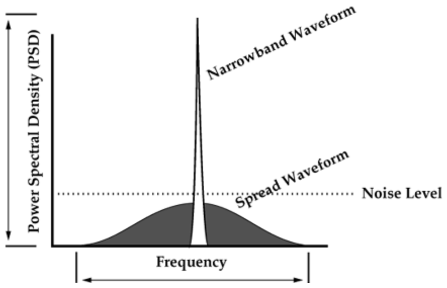


Figure 1. DSS Spread Spectrum [4]

There are multiple forms of spread spectrum technology, the most well-known being Direct Sequence spread spectrum (DSSS). By modulating a bit sequence with a pseudo-random line code of bursts that are much smaller in duration than the bitrate, the transmitted signal's symbol duration is decreased. These symbols are called chips, and as the 'chip rate' increases, so too does the used bandwidth. [4]

There are also systems that hop between frequency and time. The former switches between carrier frequencies dependant on a pseudo random code sequence and the latter changes duty cycle and frequency (not carrier frequency, but symbol frequency) according to a pseudo random code. The two are usually joined into a hybrid system well known as time-division multiple-access systems. [4]

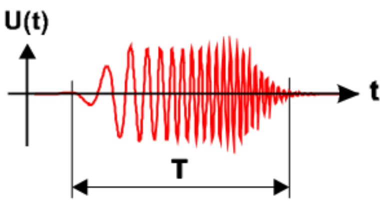


Figure 2. Up-chirp [5]

Apart from systems that switch between static carrier frequencies or symbol durations, there are also systems that linearly increase and decrease their frequency over the duration of a symbol, a chirp system. Modulation techniques might include setting an up-chirp (linearly increasing frequency) to represent a 1 and a null period to represent a 0, allowing 2 independent coexisting networks [5]. There is also the possibility of encoding 4 states (00,01,10,11 for example) into superpositions of up-chirps and down-chirps, increasing bit rate (symbol rate would remain static, each symbol is now 2 bits so data rate doubled).

LoRaWAN

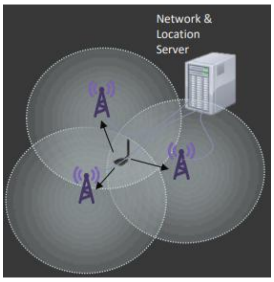


Figure 3. Basic Star of Stars localisation [7]

LoRaWAN is a Low Power Wide Area Network (LPWAN) specification designed by the LoRa alliance with sensor and IoT applications in mind. Battery powered devices out in the field are the main target of LoRaWAN, promising stable bidirectional communications between devices and a server [6].

The network is usually laid out in a star topology, or star-of-stars depending on the desired use and size of the network. For example, if the network is intended to be used for localization of targets a star-of-stars network and mutilateration techniques could be employed (see Figure 3). whereas if the application is related to sensor networks a single star topology could be used to gain access to multiple devices readings [7].

The network protocol is based on chirp spread spectrum technology, spreading channels and data rates to create many virtual channels. This is beneficial as the desired communications target is low power transmitters on embedded platforms. The virtual channels will equate to less interference between devices which may be easily drowned out by each other in shared channel systems, so the small devices in the field will not require much transmission power. The data rates range between 300 bps to 50 kbps, fine for gathering data from sensors.

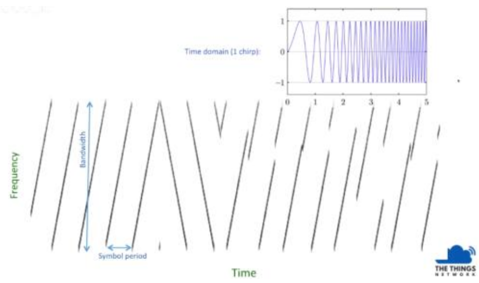


Figure 4. Lora modulation

LoRa modulation and demodulation works by multiplying received chirps to an array of pre-set chirps. Whenever the chirp switches between up-chirp rates, this is data that has been encoded.

When demodulating via the multiplication discussed previously, we get back our decoded symbols. More importantly, if there is narrowband noise or other communications interfering, they are washed out by the multiplication with the set chirps and easily distinguishable from our signal.

See the webinar at [8] for a more detailed discussion.

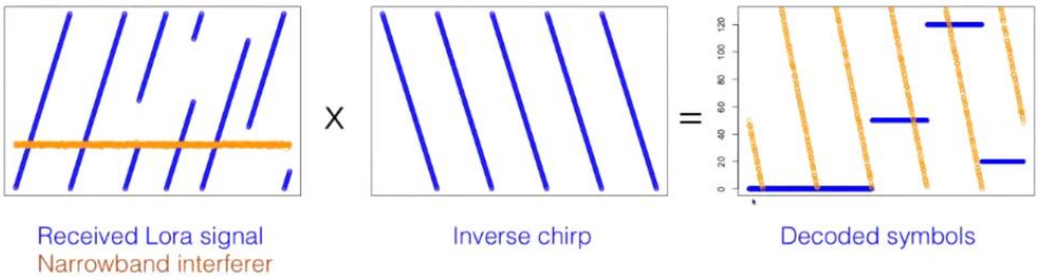


Figure 5. Demodulation LoRa [8]

Ingenu

Ingenu is less of a communications standard and more of a fully encompassed IoT infrastructure [9], however it does still have its own proprietary communication system based on spread spectrum. The standard has been called Random Phase Multiple Access (RPMA) which is at its core based on DSSS technology.

RPMA utilises the 2.4 Ghz spectrum which is available unlicensed all over the world, allowing for faster rollout of systems with the need only for a single carrier frequency design. The capacity is claimed to be gargantuan, with a single infrastructure location able to support hundreds of thousands of nodes with a link capability of ‘video data rates’. These features are claimed to be able to reach up to 1250 square kilometres non-line-of-sight [10]. The system is targeted to apply solid communications with the possibility for fast and reliable OTA (over the air) firmware updates to many consumers at once. In worst case scenarios, the throughput per device is 100 kBytes per day.

The standard is able to deal with 1200 overlapping signals simultaneously by getting the endpoint nodes to choose a number of chips (time segments) to delay the signal by. Assuming the sum of the intentional chip delay of each node and number of chips required for propagation results in unique values, the high processing gain of the system allows all links to be demodulated. As the system is unaware of the node’s delays, every chip arrival slot must be checked for a signal, processed via a system of dispreading, de-interleaving, Viterbi decoding and CRC checks, where the CRC unconventionally checks for whether a transmission was actually sent on the chip slot rather than checking for an error in the signal [10]. Spreading factors are chosen depending on them perceived signal strength at the end node, and Figure 6 shows a basic representation of these being 'scheduled' for decoding, but rather than a schedule it's more like a cyclic run through chips reserved by nodes, not necessarily in order of time sent.

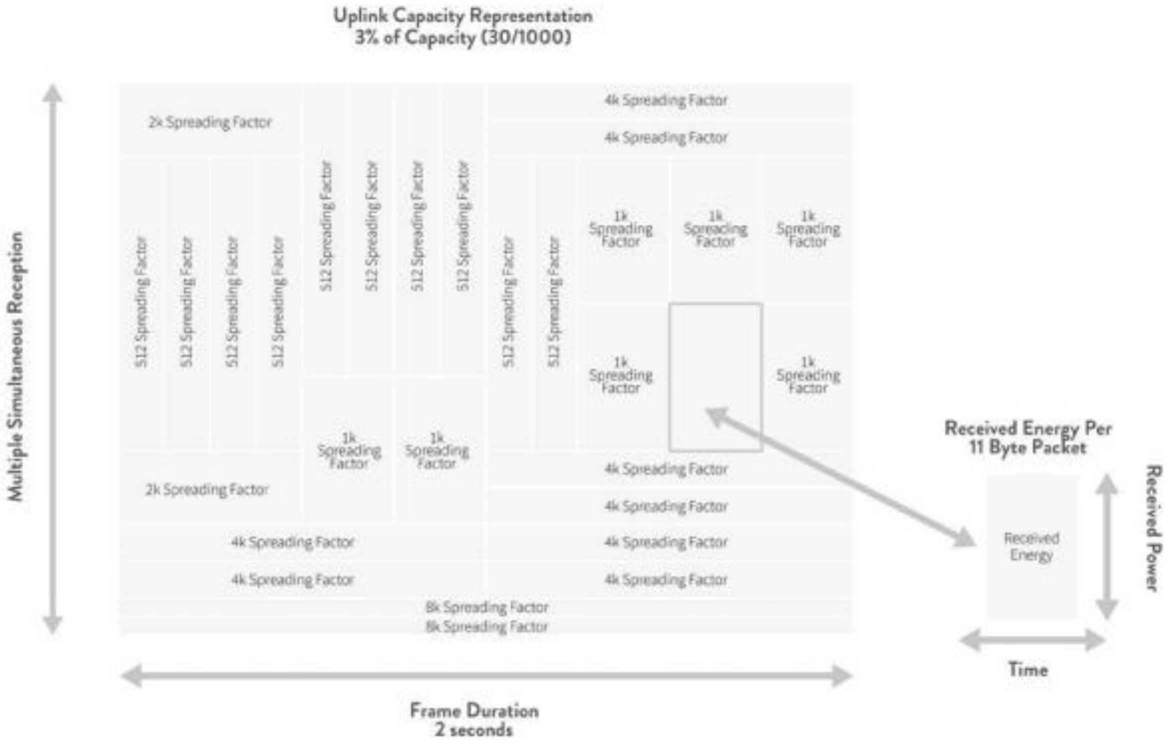


Figure 6. RPMA capacity model

Nwave

Nwave is based on a combination of ultra narrow band (UNB) communications and the cutting edge in software defined radio techniques designed for IoT applications requiring one way communications. With the capability of 10 kilometre signal reach to a supposed 1 million devices on a single base station, Nwave is one of the biggest contenders in the private IoT infrastructure market [11].

The idea behind UNB is to concentrate as much of the signal energy into the smallest band possible, typically less than 1 kHz (other standards such as LoRa can use around 200 kHz [12]). This pushes the power spectral density of the link much higher than the noise floor, permitting longer range communications with less complex decoding architecture. This also creates a resistance towards jammers and interference on the same channel, a common problem within IoT Infrastructure that may contain hundreds to thousands of devices trying to communicate simultaneously [13].

Nwave's communication standard's UNB functionality is the basis for the open standard and easily accessible Weightless-N [14] [15]. In order to deal with in-band interference, the system employs a frequency hopping modulation technique known as differential binary phase shift keying. As well as creating a better channel between router and end user, this standard also provides encryption and security measures.

Sigfox

Sigfox is another UNB type network, each message containing the majority of its spectral content in a bandwidth of only 100 Hz of the systems 200 kHz of usable bandwidth. Spectral components beyond this bandwidth are so miniscule compared to the peak that the neighbouring messages do not interfere with each other (see Figure 7). These messages are transmitted at rates of either 100 or 600 bits per second depending on the region of operation [16].

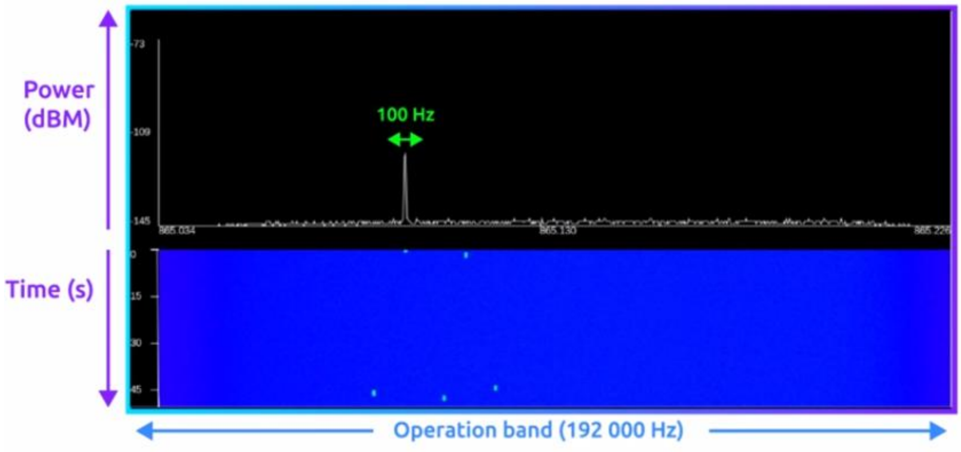


Figure 7. Sigfox message, snapshot from [17] at 35 seconds

This form of modulation is well known as Differential Phase Shift Keying, where data is interpreted by adjusting the phase of the carrier wave. Every phase section that is sent is compared to the previous phase section (or chip) to demodulate data from the carrier [18].

The range of the system is around 5-10 km in urban areas or 100 km in Line of Sight areas. This impressive range is mainly achieved through the systems low bit rate, which may be a determining factor with some certain wide area sensing applications that require more than the available 140, 12 byte messages per day [19]. The protocol also supports 4, 8 byte downlink transmissions to nodes each day, mainly to inform the system of an impending firmware upgrade or some other large data downlink transfer needing to take place on a different communication standard such as GSM [20].

Exosonde ‘Exo2’

Developed for datalogging multiple water quality indicators, the Exo2 is designed for continuous usage in the field for up to 90 days assuming log intervals of 15 minutes [21]. The device is resistance to corrosion and suitable for deployments up to 250 metres deep, making it ideal for measurements in small bodies of water such as the UQ lake. It can house up to seven sensors, however the central sensor can be replaced with a de-fouling wiper system that comes stock with the device to ensure measurements can be taken as accurately as possible without the need for human intervention to clean the sensors, increasing deploy time by up to 25% [22]. A list of sensors is shown in Figure 8.

Sensors		Calculated Parameters
Ammonium	ORP	Salinity
Chloride	pH	Specific Conductance
Conductivity	Temperature	Total Dissolved Solids
Depth	Total Algae (Chlorophyll + BGA-PC or PE)	Total Suspended Solids
Dissolved Oxygen	Turbidity	
Fluorescent Dissolved Organic Matter (fDOM)	Vented Level	
Nitrate		

Figure 8. Sensor List [22]

There are multiple mechanisms available to retrieve the data from the platform out of the box, mostly involving devices running YSI's proprietary data acquisition program KOR. These immediate options include; PC running KOR connected via USB adapter, serial or Bluetooth connection to a YSI handheld device or a serial communications device connected through the DCP Signal Output Adapter. The latter is the most versatile form of communication, as the entire system can be controlled by commands sent via RS232 or SDI-12 as listed in [23] pages 5 to 8.

mDot

This RF module is a cheap and reliable LPWAN module that is LoRaWAN ready. It has class A LoRaWAN support, so it is capable of duplex communications and is controlled via basic "AT" commands passed over serial lines. The system is based on an ARM Cortex-M4 Processor preinstalled with ARM's mbed Operating System. The system is made specifically for low power scenarios, running at 40 microamps in sleep mode and a maximum transmit power draw of 42 milliamps [24].

Project Aims

By the conclusion of this project we plan to have set up an expandable LoRaWAN based network at UQ with at least one exosonde and camera system and all the plug and sense module switched from the outdated ZigBee network to the new LoRaWAN network. Ideally, these systems will be able to function without human intervention (cleaning, corrosion testing etc.) for at least 3 months at a time for the exosonde system excluding retrieval of camera footage and at least 9 months for the plug and sense modules. These time frames do not consider severe weather events and we assume that servicing and redeployment of modules may be necessary after these incidents.

To integrate these systems onto the same network, there is also a need for a communications protocol to be implemented so that the devices' sensor readings can be stored together. This also allows for new systems, not necessarily plug and sense or exosonde, to be connected to and supply information about the environment at UQ.

By doing this, UQ's environmental monitoring services will be more streamline and more easily accessible. This will lead to faster and more precise evaluations of possible environmental and health hazards, leading to preventative measures.

Ingenu Pre-Review Discussion

Before any past literature is examined, it is a good idea to eliminate any completely unsuitable LPWAN standards. Ingenu's RPMA technology is currently unusable due to poor rollout in Australia and as such does not require any further review. This doesn't mean the technology will forever be unusable for this project and as such, the author believes it should be discussed in some detail in the introduction for possible future implementation.

RPMA claims to be able to simultaneously demodulate 1200 fully overlapping signals, immediately breaking the first barrier of LoRa's ability to only decode a single user per data rate at one time. Its range is also touted to be many times better than Sigfox and LoRaWAN. Unfortunately, Ingenu do not sell base stations and plan on rolling out RPMA publicly, making it unusable in the current setting. [10]

Literature Review

LoRaWAN has already been used in multiple projects around the world, running from thesis level to major city implementations. Such an example of the latter is discussed in some detail by inteliLIGHT, a developer of streetlight controllers, about their deployment of a LoRaWAN system in a small Hungarian town Szada. The deployment was reportedly extremely efficient, requiring only three days to fit controllers to 4 of the city's 19 feeder pillars and connect successfully to a LoRaWAN network run through a Kerlink gateway [24]. There are 6 other fully reported cases from this company alone of the successful implementation of LoRaWAN networks spanning cities, spanning from the control of 775 streetlights in Dubai's Water Canal to the upgrade of 25 000 lamps in Riyadh, Saudi Arabia. [25]

LoRaWAN has also found use in environment monitoring in the past, such as in the case of [26] and [27]. In the case of the former, a research team from Beijing University of Technology was tasked with designing a low power network designed for reading and reporting pollution over a large distance. Zigbee is also discussed as a potential communications solution, but its tested reach of 270 metres was considered inadequate. As can be seen in the document's figures 4 and 5, multiple sensors were run at high precision for at least a week without loss of information, seemingly LoRaWAN is stable enough to support small packet sensor communications free of error.

[27] Goes into more detail about the pros of using the MAC layer provided by LoRaWAN rather than just the physical layer provided by LoRa as well as some statistics on deployment time and efficiency. The buoy was positioned 4 metres above sea level and 3 kilometres from a gateway elevated 55 metres above sea level and another 13 kilometres away at 580 metres above sea level. The monitoring area and the first gateway were both considered in urban areas of high population density, and the second gateway was considered near Line of Sight. The deployment lasted for 8 months unimpeded with measurements taken every 10 minutes delivered successfully through both gateways. The payloads are only 64 bytes long, but this is shown quite comfortably as all that is necessary to effectively communicate all the required readings in an environment monitoring system such as this.

 Of course, there are also those who have found limitations and issues with large scale IoT implementations of LoRaWAN. Collisions within channels is a major issue for large scale systems of any kind, and LoRaWAN is evidently no exception when devices try to send too many messages per second. As discussed in [12] with a transmission rate of nd/T_a where $n = channels = 3$, $d = 0.01\ (1\%\ duty\ cycle)$ and $T_a = time\ on\ air$ depends on spread factor and payload size, described in greater detail in Figure 10.

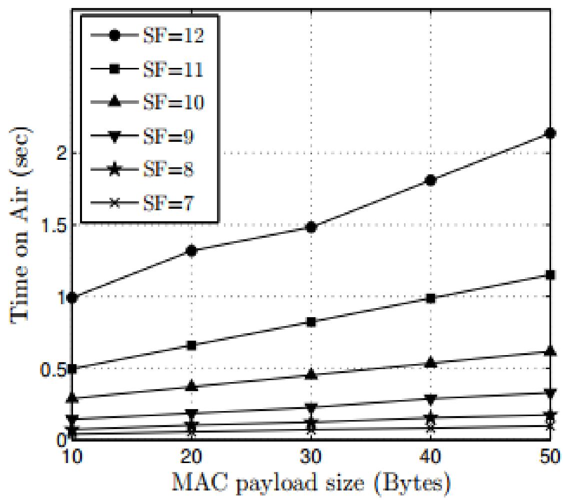


Figure 10. Time on air vs payload vs spread factor

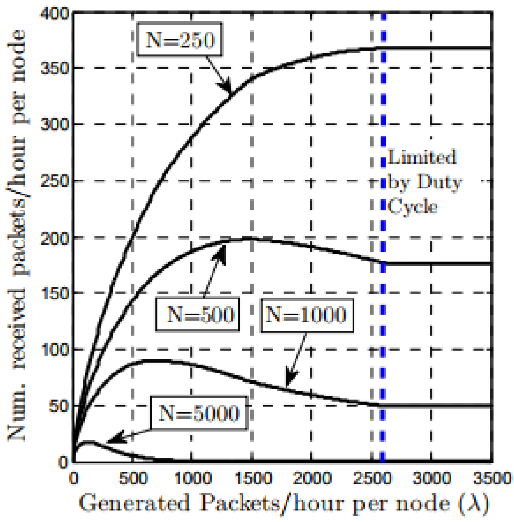


Figure 9. packets received vs packets sent

Once these parameters were chosen, the authors developed an illustration of how the network as a whole was running under certain λ, a measurement in units of generated packets/hour per node vs. the number of packets received/hour per node. Figure 7 also contains multiple curves for different N values, corresponding to the number of nodes in the network. As can be seen, as the number of messages per hour increases the gradient of the curves decrease very rapidly. At the bottom of the curves near $\lambda = 50$, it appears that the majority of the messages will have gotten through all the way up to 1000 nodes on the network, and around half of the messages get through on a 250 node system when around 200 messages are sent per hour per node. The conclusion from this research piece is to ensure that the maximum nodes per 3 channel system doesn't exceed 1000 nodes, and that the nodes are set up in a way that they won't send messages every minute and clog the system.

The report [28] discusses a very similar topic and backs up the results shown above from [12]. On page 14, the authors quite clearly state the limitations for reliable communications on a 3 channel, 6 data rate (see Figure 11) network. In order to achieve a loss ratio of less than 10^{-3} we would need to ensure that every mote in a 100 node network sent a packet no more than every 20 minutes to prevent what has been dubbed a "collision avalanche".

#	Spreading factor	Channel width, kHz	Code rate	PHY bit rate, bps	RF sensitivity, dBm
0	12	125	4/6	250	-137
1	11	125	4/6	440	-136
2	10	125	4/5	980	-134
3	9	125	4/5	1760	-131
4	8	125	4/5	3125	-128
5	7	125	4/5	5470	-125
6	7	250	4/5	11000	-122

Figure 11. Data rates displayed as # values

In terms of comparison between Sigfox and LoRaWAN in the field, [20] discusses the drawbacks and high-notes of each protocol. A major drawback of Sigfox to LoRaWAN is its high latency and poor ability for continuous messages as discussed in the introduction. For applications where data needs to be constantly streamed, Sigfox may not be the best option compared to Lora, considering anyone can build their own LoRaWAN network and regular messages are supported to a certain point. The authors of [20] state the current doubt on how LPWAN systems currently handle being collision free and interference free, stating there is no specific winner as there is no trivial way to evaluate their practicality.

Zigbee, LoRaWAN and sigfox have been compared in multiple documents, for the most part favouring the LPWAN technologies. This is mainly due to their lower power consumption and higher range thanks to zigbee's multihop technique, which can drain a lot of battery from nodes that need to retransfer messages for another node [29] [30]. LoRa has several features that push it ahead of Zigbee, including a lower cost, better range with higher coverage and around half the battery usage at the node when transmitting [26]. Remembering also that a zigbee network more than likely will require nodes closer to the router to send much more than just their own packets, so this battery life may be quadruple or even eight times more than a LoRaWAN system.

The exosonde has been shown to meet rigorous standards for the majority of its sensors within a specific range. The main sensor issue was with turbidity, deviating around 23% percent from measurements taken by a known and trusted source [29]. It was also noted that the SOA DCP connector is susceptible to moisture, and as such the final design will need to ensure it is kept in the same watertight conditions as the rest of the water sensitive components. These conditions, although not great for the turbidity measurements, are not too much of an issue for the project, as we are more concerned with checking change in measurements during weather events rather than precise measurements.

Research Plan

In order to implement a universal IoT infrastructure at UQ as well as specifically lake water and air sensing, the chosen protocol is LoRaWAN. This decision is based on a number of reasons, including

- Adaptability: The network has the option to expand to many nodes in the future with this technology, especially seeing that the infrastructure will be based around measurement systems that take half hour to hourly measurements over a long period of time
- Usability: There are currently many devices on the market capable of connecting to a LoRaWAN system. The MDOT is a great example of this, as it allows the designer to connect to a system through basic UART commands
- Availability: Currently, there is already a LoRaWAN base station set up at UQ and proven to be accessible with the MDOT chips in past courses
- Simplicity: The only requirement to connect to the network is a microcontroller or some form of UART control system and an MDOT

Connection of the exosonde to the infrastructure is planned to be implemented with the design in Figure 12. The power for the MAX232 circuit is to be delivered by Nucleo's 3v3 rail, and the MDOT will be powered by the Nucleo's 5v rail. The Nucleo will be powered via a deep cycle battery charged by a solar panel and a charge controller with constant 5 volt output.

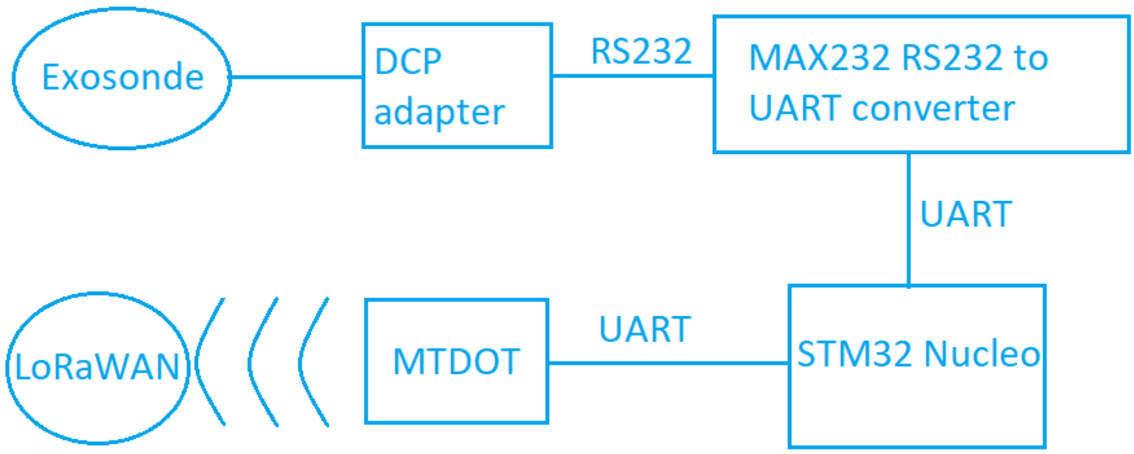


Figure 12. Exosonde design

The air quality sensor system will require porting of the current zigbee waspmote system over to LoRaWAN. Fortunately, the Libelium waspmote boards are not program locked and already have compatibility out of the box for solar charging and full self-containment once in the field. The only physical change necessary is to swap out the zigbee chips for MDOT chips, both of which use a standardised 20 pin socket. As for the code, Libelium provide a free and fully functional API and code generator for retrieving air sensor readings [29] as well as documentation on how to use the API for serial communications to a device such as the MDOT, which only requires simple UART commands to be set up and transmit.

The payload of a LoRaWAN message is going to be 11 bytes (DR0) to ensure that the sub Mhz duty cycle limit is not breached, however there is the possibility to expand this to 242 bytes (DR4) (US communication standard) [30]. In this case, rather than taking a single measurement, sending it, and going to sleep; the system will instead store readings until the packet limit has been reached and send a single very large message with around 20 readings. [27] implemented a LoRa physical layer system that transmitted successfully with 64 byte packets every 10 minutes, so the 53 byte payload (DR1) may be the best choice for this situation.

The packet will be made up of several possible elements each with unique alphabetic identifiers, shown below in Figure 13.

Measurement Type	Identifier	units
Air temperature	A or a	Degrees celcsius
Humidity	B or b	g/m^3
NO2	C or c	μg/m^3
O3	D or d	g/m^3
CO	E or e	g/m^3
CO2	F or f	Ppm
Air battery	G or g	Volts
Water temperature	H or h	Degrees Celsius
Conductivity	I or i	mS/cm
Salinity	J or j	Ppt
pH	K or k	pH units, 0 to 14
Dissolved oxygen	L or l	mg/L
Water battery	M or m	Volts

Figure 13. Measurements and identifiers

The structure of the payload will be of the form

Payload number|Identifier|:|value|,|Identifier|:|value|

and so on. The values read will be converted to a string and the entire payload will be stored in another single string. When sending, the payload number will be used to identify which part of the entire packet we are looking at, assuming that the data was big enough to be broken up. There is also the possibility of adjusting data rate depending on the size of the payload, but this assumes that the payload maximum size is 242 bytes, which is more than likely true considering the readings are mostly on the range of 0 to 1000 or less (see sensor specifications [22]).

Research is also planned for adding a camera and/or a weather station to the exosonde system. This will allow for visual monitoring of severe weather events and predictions of these weather events. By using prediction, we will be able to make frequent measurements when they matter and save power the rest of the time. Another solution for this prediction problem is to send information to a node from the gateway or server, seeing as the mdot is a class A node there are receive windows directly after a successful send that can be utilised.

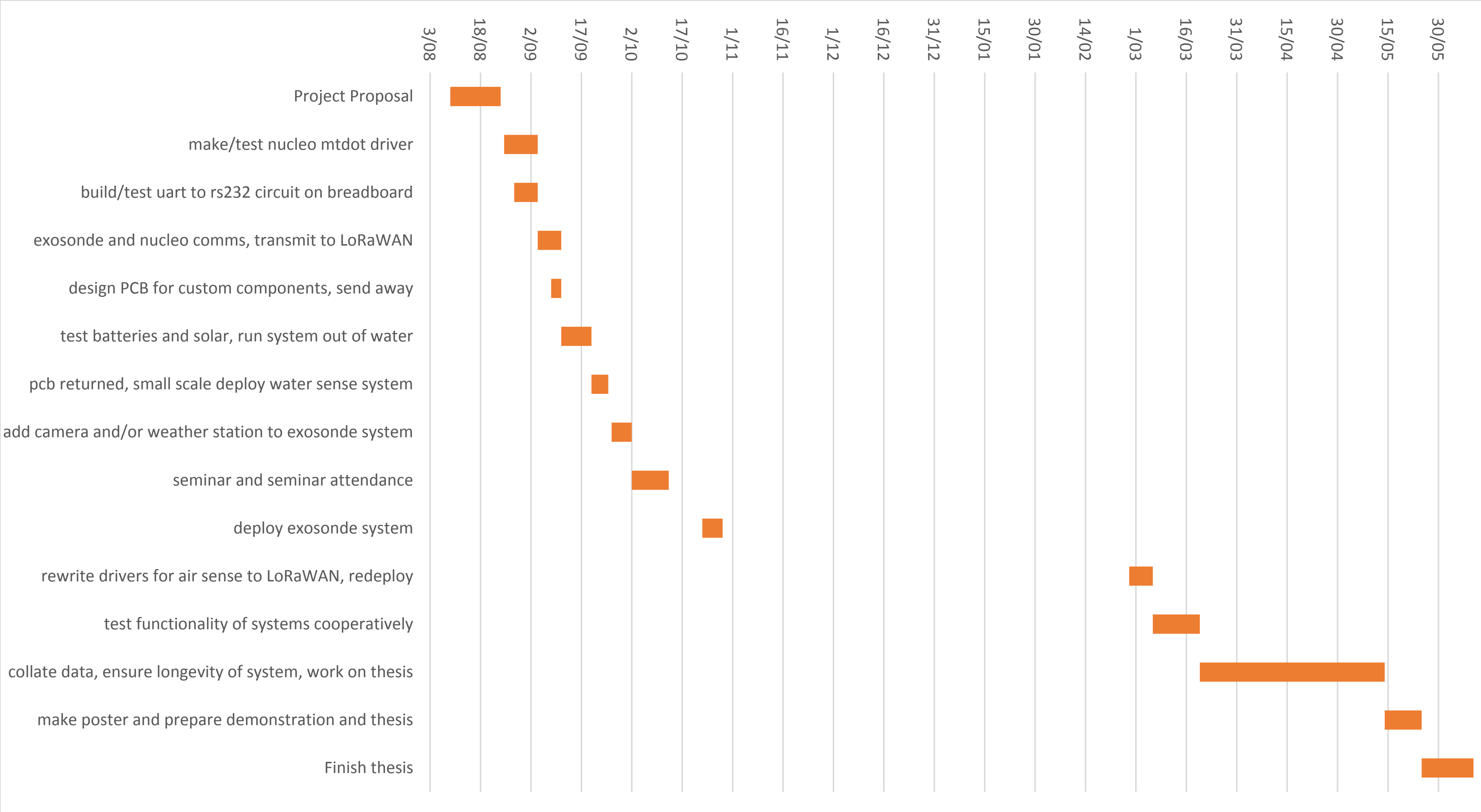
Risk Assessment

Hazard	Risk control in place	Hazard event and Risk rating	Controls after incident

Electrical Equipment: use of power supplies, function generators, oscilloscopes, programmers etc.	Equipment is regularly tested, residual current devices protect the circuits in use and projects are low voltage	Electrical Shock, possibly fatal. Considered practically impossible due to controls. Risk -Low	Call ambulance for injured person/s, secure area and ensure power has been shut off
Eye injury: in the case of hot solder, hot glue and fluxes contacting the eye, possibly through fumes and vapour	Safety glasses to be worn whenever using these items. Always use fume hood or fan when using these resins.	Irritation to eyes, possible blindness. Controls in place set this scenario as practically impossible. Risk - Low	Flush eyes with water and seek medical attention immediately
Respiratory issues: Breathing in fumes from hot glue and solder	Fume hoods or fans are to be used at all times, consult appropriate MSDS before activity	Damage to respiratory system from fumes, these activities are always well ventilated when controls are undertaken. Risk -Low	Consult doctor if breathing becomes difficult, ensure full ventilation in future
Burns: contacting body with soldering irons, hot glues, fluxes, solder, overheated components	Keep head, hands and other body parts clear of soldering/glue at all times, ensure fuses are correctly used on supplies	Minor burns, hazard is conceivable but happens very irregularly. Risk -Low	Wash area with cold water, apply burn cream and bandage if necessary
Hand tools: wire cutters, wire strippers, drills, screwdrivers etc.	Basic hand tools provided in labs, very easy to control.	Minor sratches, pinches or scrapes. Conceivable if not concentrating Risk -Low	Bandaid area if need be, if damage is any worse then consult doctor
Electrical Equipment contact with water	Ensure all electrical components are in a watertight box before deployment	Damage to nucleo and any other components exposed to water Risk -Low Medium	Allow to dry and test for any remaining functionality, dispose of and replace if necessary
Exosonde system lost during extreme weather event	Ensure system is mounted to a weighted anchor, such as a metal t-bar as was used in a previous research. Attach a large anchored towline to the shore.	Displacement has occurred before, however the device was recoverable. Large financial losses will occur upon loss of exosonde Risk -Medium	Search for system near debris areas, utilise security footage if possible to see current during weather event
Air system location lost	Ensure all deployment locations are logged properly and secured, could possibly make basic android maps app to log exact locations	With current preventative measures, this situation is practically impossible. Possibility of stolen items, must ensure items are strongly secured. Risk -Low	Consult security and even lost and found upon loss of system
Solar Panel and/or battery failure or short circuit	Ensure all connections to batteries are fused correctly and supply wires are glued and tacked	Destruction of components due to electrical fire which may expand to a larger area of	If in proximity, employ proper fire protocol including dousing of flames, and contact fire

	down firmly	the measurement location. With current controls, this is practically impossible. Risk -Low	department
Falling into water	Let the appropriate people deploy systems into the centre of the lake, don’t allow	Extremely unlikely as the deployment will be made by those who own the boat who will undertake their own safety measures Risk -Low	Exit the water and call an ambulance if a sizeable amount of water has been swallowed.

Gantt Chart



3/08
18/08
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16/12
31/12
15/01
30/01
14/02
1/03
16/03
31/03
15/04
30/04
15/05
30/05
Project Proposal
make/test nucleo mtdot driver
build/test uart to rs232 circuit on breadboard
exosonde and nucleo comms, transmit to LoRaWAN
design PCB for custom components, send away
test batteries and solar, run system out of water
pcb returned, small scale deploy water sense system
add camera and/or weather station to exosonde system
seminar and seminar attendance
deploy exosonde system
rewrite drivers for air sense to LoRaWAN, redeploy
test functionality of systems cooperatively
collate data, ensure longevity of system, work on thesis
make poster and prepare demonstration and thesis
Finish thesis

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