International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:12, No:1, 2018

Development and Range Testing of a LoRaWAN System in an Urban Environment

N. R. Harris, J. Curry

***Abstract*—**This paper describes the construction and operation of an experimental LoRaWAN network surrounding the University of Southampton in the United Kingdom. Following successful installation, an experimental node design is built and characterised, with particular emphasis on radio range. Several configurations are investigated, including different data rates, and varying heights of node. It is concluded that although range can be great (over 8 km in this case), environmental topology is critical. However, shorter range implementations, up to about 2 km in an urban environment, are relatively insensitive although care is still needed. The example node and the relatively simple base station reported demonstrate that LoraWan can be a very low cost and practical solution to Internet of Things type applications for distributed monitoring systems with sensors spread over distances of several km.

***Keywords*—**Wireless sensor network, LoRa, internet of things, propagation.

I. Introduction

WIRELESS sensor networks have been the subject of a significant amount of research in recent years, and have been finding application in many diverse areas [1], [2]. One of the drawbacks of previous implementations has been the trade-off between the power used by sensor nodes and their range. As nodes tend to be power constrained (e.g. battery powered or solar powered), it is not usually feasible to use high power radio or mobile telephone modems, and conventional low power radio systems such as Bluetooth and Zigbee have a reliable range restricted to a few 10s of metres. In order to implement an effective LPWAN (Low powered wide-area network), both range and power need to be acceptable.

Wireless sensor networks have many more requirements than networks such as Wi-Fi. Primarily, for extended battery operation, they need to be intelligently operated, often through the application of scheduling, to minimise the power required for two-way data transmission.

LoRa modulation is a variant of Chirp Spread Spectrum (CSS) modulation [3]. It is a proprietary modulation scheme, owned by Semtech Incorporated. Operating in the physical layer it provides features such as an adaptive data rate and high range performance. Being at the lowest layer in a network implementation, it can act as the base layer for protocols such as the LoRaWAN MAC layer amongst others. When using LoRa as a physical layer, the data rate used can have a significant impact on the range of transmission. These data rates are defined in terms of their spreading factor. In this study, DR_SF7 (5470 bits/second) and DR_SF11 (440 bits/ second) [4] are used, as they represent a large difference in data rate. Others, both higher and lower, are also available.

LoRaWAN is a data link layer which can operate on top of a physical LoRa layer. The LoRaWAN specification defines three classes of node endpoints [5]. Class A covers all end devices, and defines a downlink window after every uplink from a node, which greatly reduces the power requirements for single transactions. Class B specifies a beacon, sending packets at fixed intervals. Class C defines a node with a constant receive window, able to receive a downlink at any time.

LoRaWAN can potentially be used as the link layer for proprietary data encoding schemes, or standards such as IPV6 [6]. All data in LoRaWAN networks are encrypted with AES128 encryption, and also include anti-replay mitigation using frame counters [5]. This makes it the perfect candidate for secure data gathering networks, such as smart city technology [7], and scientific projects [8], and also demonstrating its great promise for improving the range of existing projects which operate over a wide area [9].

With a high potential performance in a variety of environments, many studies have documented the effects of LoRaWAN in a variety of different settings [10], [11]. In this paper, a Class A LoRaWAN node is created with the intention of long-term deployment. This node is then range tested in an urban environment, showing how far data can really travel in non-ideal conditions.

II. System Architecture

The LoRaWAN system studied consists of a variety of different elements, which are described as follows.

A. Base Station Construction

Many different LoRaWAN base station designs exist, using a variety of different hardware. It was decided to utilise a design featured in RS DesignSpark [12], due to the availability of components and detailed nature of the design.

The base station was constructed using a combination of an iC880a LoRaWAN Concentrator board and a Raspberry Pi 3. The system was designed to fit inside a standard waterproof housing for deployment. Fig. 1 shows the base station in construction showing the modular construction. Partially due to safety requirements, and also to allow flexibility, the power supply is a separate module. In this case a 240V to DC module is used. It is possible to replace this with alternative power supplies, such as Power over Ethernet.

N.R Harris and J. Curry are with the School of Electronics and Computer Science, The University of Southampton, Southampton, SO171BJ, UK (e-mail: nrh@ecs.soton.ac.uk, jsc3g14@soton.ac.uk).

Once the base station had been constructed and tested with the appropriate software, it was deployed on the roof of the Zepler building at the University of Southampton (50.937336, -1.397558), point X on Fig. 5. In order to site the antenna as high as possible, a standard 3dBi antenna was affixed to the top of a 5 m pole and connected via an SMA extension to the base station assembly below.

Fig. 1 Base Station in development

B. System Topology

In order to parse data from the iC880a LoRaWAN Concentrator into meaningful information which is easily accessible for a variety of projects, a large software stack was implemented.

Primarily, a packet forwarder from Semtech Inc [13] captured packets from the iC880a LoRaWAN Concentrator over its SPI interface and made them available as raw I/Q data over UDP. From here, *lora-gateway-bridge* [14] was used to abstract the packet forwarder data into JavaScript Object Notation (JSON) over Message Queue Telemetry Transport (MQTT), in conjunction with the MQTT broker *mosquito* [15]. Finally, *loraserver* [16] was used to decrypt and parse this data into MQTT channels for each LoRaWAN node.

As MQTT is a lightweight messaging protocol, it does not provide any inherent logging capabilities. Data are merely presented to an MQTT topic, which the user then has to subscribe to. In order to simplify the usability of the base station for non-technical users, a *tracker* was created to log and display data about currently connected LoRaWAN devices.

In addition to logging and parsing the relevant MQTT channels outputted by *loraserver*, this software also provided a mechanism to process raw node data into meaningful elements. This was implemented using a JavaScript sandbox, into which users could place custom functions which were run by the tracker on the receipt of data, effectively acting as a local MQTT processor, allowing processed data to be published on a different MQTT topic, or stored. From here, users can choose to subscribe to this alternate MQTT stream with their processed data values or download a collection of logs in the form of an SQLite database or CSV file for further processing, making basic data collection and analysis very straightforward.

Users interact with the tracker through a custom web interface, which shows all nodes currently connected to the base station, and allows for the modification of sandbox code for each. This allows a user to easily parse data which has been compressed or simply encoded before traversing the LoRaWAN link, into meaningful values for export or real-time use.

A visual representation of the software stack in use can be found in Fig. 2.

C. Node Construction

In order to communicate with the base station, a low powered, ARM-based node was created. An ARM M0+ MCU (MKL46Z256VLL4 from Freescale Semiconductor Inc.) was chosen as the main processor, due to its wide supply voltage range and very low power consumption both during operation and sleep. This was combined with a HopeRF RFM95W LoRa radio, which was linked over SPI to the MCU. In addition to these two elements, supporting peripherals such as an oscillator, an RGB LED for debugging and a 2.5V Voltage reference to preserve ADC stability were added. In addition to this, space was included for a DS18B20 I2C temperature sensor to simplify temperature measurement. Pins were made available for connection to user defined boards for other sensors, similar in concept to the Arduino shields, allowing reuse of the node hardware/software for different applications.

A block diagram of the node can be found in Fig. *3*.

In order to simplify initial software development, LoRaWAN functionality was provided by the LMIC (LoRa MAC In C) library in combination with the ARM mbed bindings. This provided a proven implementation which could be used and expanded upon in order to conduct range and power usage tests.

In terms of cost, this type of node costs a fraction of currently available commercial implementations, and provides much more flexibility. A standard build in volume consisting of a PCB with all components (not including construction or antenna) is estimated to cost £10.00 (Euro 12.00). In comparison, a currently retailing solution such as a WaspMote Pro [17] and the appropriate wireless connectivity module can be in excess of £100 (Euro 120) although this does have many extra peripherals as standard.

III. Power and Range Testing

A. Range Testing Methodology

In terms of apparatus, two nodes were constructed and attached to a 2m PVC pole. One node was attached with the base of its antenna 20 cm above ground level, and another was attached with the base of the antenna at 2 m above ground level. These nodes were programmed with firmware which transmitted a packet of fixed length upon being reset, with the data rate used to transmit set by reading a GPIO pin. A Waspmote Pro development board [17] was then also attached to the pole with control of the relevant GPIO lines on each node. This was combined with a GPS module and SD card to record timestamps and locations of transmission. Fig. 4 shows a system level layout of the range test apparatus.

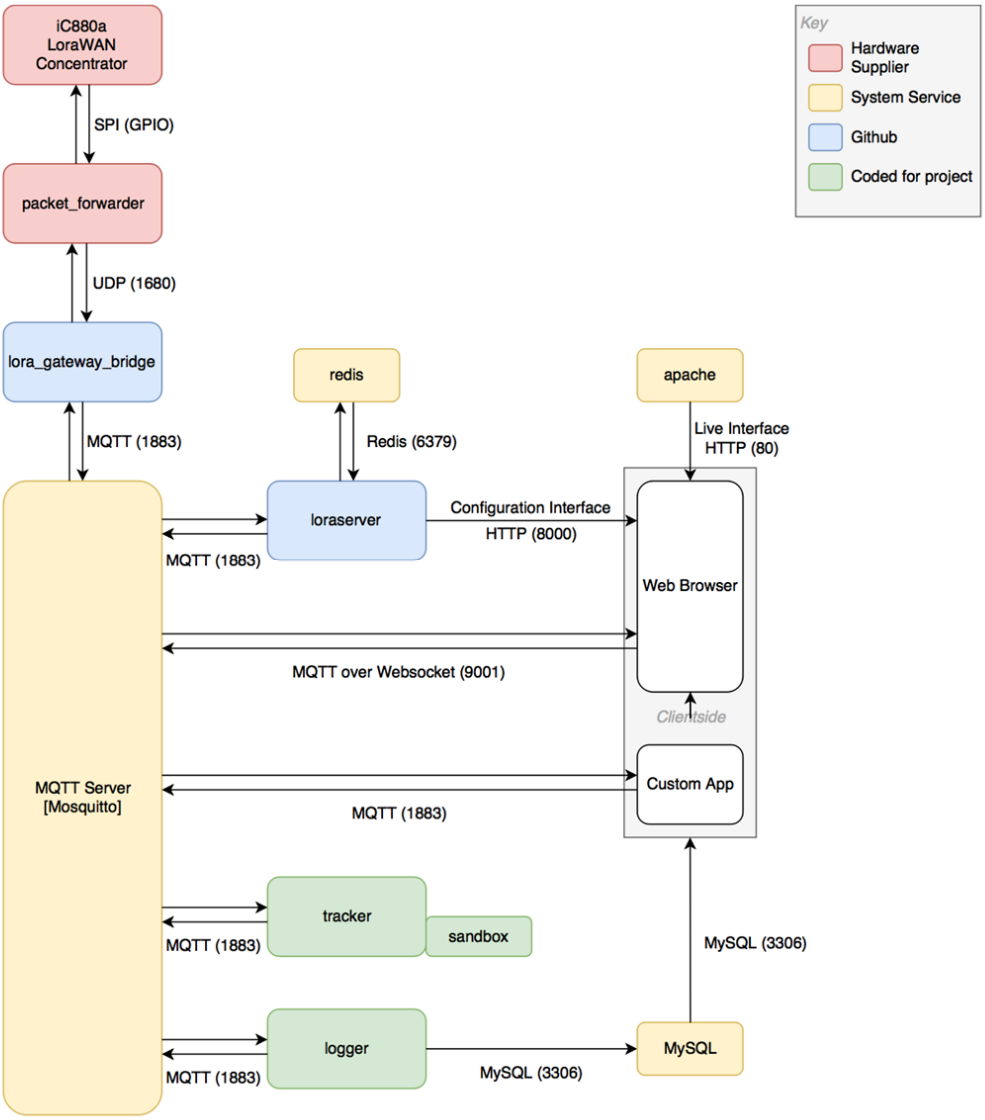

Fig. 2 Base Station Block Diagram

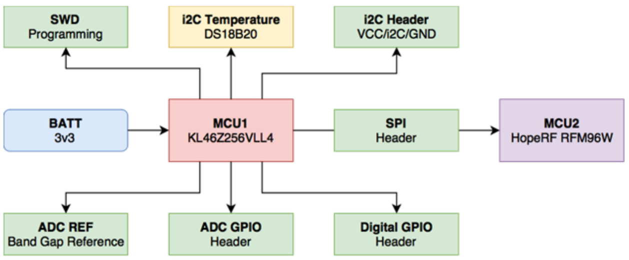

Fig. 3 Node Block Diagram

On the base station, a Python program was created to subscribe to the relevant MQTT channels in order to extract RSSI and signal-to-noise ratio information for each packet. The server was also time-synchronised using Network Time Protocol (NTP) which in turn synchronised it to a GPS clock source. This ensured that the data collected by the base station would be able to be easily matched to that gathered by the range testing apparatus.

Data from the SD card and the base station were then combined using timestamps as an index, allowing resultant information concerning reception to be generated and plotted.

B. Range Testing Results

Primarily, data were gathered, collated and plotted onto a map, using the Google Maps API. This provides a helpful visualisation of the areas in which tests were conducted, and more importantly, the areas in which a reliable signal could be established. Through comparison of this type of map for each different node and data rate, a useful evaluation of usability can be established, aiding in the deployment of future installations, and potentially more base stations to increase coverage. Fig. 5 shows these results. In this case, the colour of each data point is representative of the Received Signal Strength Indication (RSSI) of that point, with red being higher signal strength and green/blue being lower strength.

At extreme range, for instance in Otterbourne (Point Y on Fig. 5), which is approximately 8.5 km away from the base station location, it can be observed that the received signal depends greatly on height, as moving just a few metres away resulted in loss of signal. For instance, Fig. 7 shows the elevation at a sample far-point where data was successfully transferred (50.999801, -1.354890) on Fig. 6. Here, it can be seen that there is a clear line of sight from the point of interest to the base station location, but at intermediate points, such direct viewing is lost. This can cause reception results to vary greatly with very little variation in position. Also, in terms of the local height of the node on the range test apparatus, many more successful transmissions occurred from the top node compared to the bottom node. This shows that at extreme range, a small amount of extra height can make a large difference to signal integrity.

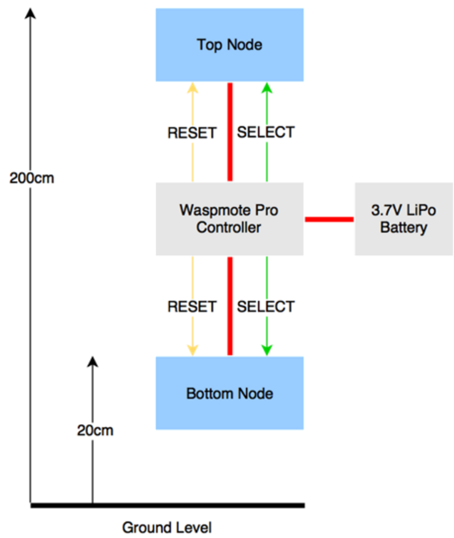

Fig. 4 Block diagram of range test apparatus

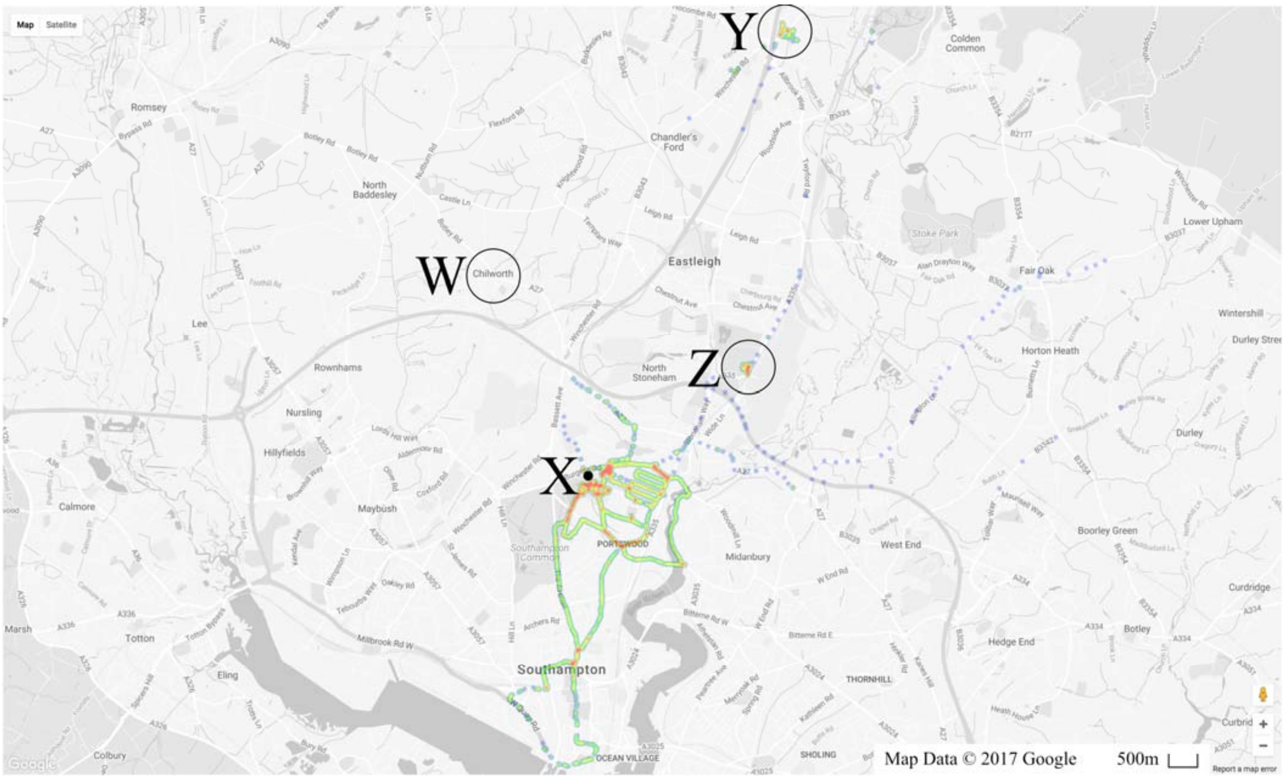

Fig. 5 Range tests in the Southampton area (Data taken from the Top Node, using DR_SF11)*Extreme Range*

Fig. 6 Range tests at sample far point.

Fig. 7 Long range elevation. (Left: Point Y, Right, Point X)

1) Medium Range

At medium range, there was not much variation between the top node and ground level node. Reasons for this difference compared to long range tests can be found in the elevation profile to that location. Fig. 9 shows the elevation profile to (50.952386, -1.362541), where it can be seen that a clear line of sight can be established from the transmit location (point Z) to the receive location (point X). This leads to the very small variation between received signal quality from either node, as both have an unobstructed path of transmission. However, this was not totally consistent in all directions. For instance, at a point to the North West of the base station location, (50.965539, -1.419575) (Point W) a totally different elevation profile can be observed. Fig. 10 shows this. Here, it can be seen that signal is lost relatively quickly (moving from the right) after 1 km of displacement from the base station location, due to a small but significant hill in the terrain.

2) Short Range

In terms of short range accessibility, the results showed that the wireless link was very reliable. In the short-term distance of approximately 2 km around the base station, the results showed that the wireless link was very reliable, which is perfect for many applications such as wireless sensing and metering.

Fig. 8 Tests at Medium Range (Point Z)

Fig. 9 Elevation at medium range (Left: Point Z, Right, Point X)

Fig. 10 Elevation at medium range (Left: Point W, Right, Point X)

Fig. 11 Tests at short range about point X

C. Power Usage

In order to measure the power usage of the node over time, an 11.597 Ohm resistor was placed in series with the power supply to the sensor node. The potential difference across this was then measured and can be plotted on a graph (Fig. 12). DR_SF7 was used during transmission, as this gives allows for more of an emphasis on node performance rather than radio efficiency.

During transmission, a peak of 140 mA was observed, for a short period for the high data rate, and a much longer period for the low data rate. (This has an impact on power consumption as discussed later). This was followed by a reduced current of approximately 10 mA during radio reception, before a sleep state was entered. During these tests, the lowest obtainable sleep current was 810 μA. This was in part due to the ported library implementation running on the microcontroller. Using datasheet values, the node should be able to achieve a much lower total sleep current of approximately 5μA. A breakdown of this is shown in

TABLE I. In this case, during range testing, power was abundant so the sleep current did not significantly affect the time of operation. Work is ongoing to investigate the discrepancies between the currently measured values and the data sheet values. When this is rectified, the node will be a practical basis for long range, long mission, IoT sensing applications.

Much of the on-time of the node is spent awaiting a potential downlink from the base station, as per the LoRaWAN specification. Potentially, with some software modification, this could be altered to convert the node into a Class-B device, which could sleep immediately after beaconing data. This would greatly reduce the power required to transmit data, at the expense of any downlink functionality. However, there is scope for designing a mixed mode node with listening programmed in in a predetermined pattern, effectively swapping between type A and B.

TABLE I
POWER CONSUMPTION (DATASHEET VALUES)

Component	Sleep Current
MKL46Z256VLL4	2μA
RFM95W	0.2μA
DS18B20	3μA
Total	**5.2μA**

Using the currently attainable duty cycle, some simple power calculations can be performed. Due to the nature of LoRaWAN, the time-on-air changes with data rate [18]. This will have an impact on battery life, leading to a shorter time of deployment. Currently, when a high data rate (DR_SF7) is used, an average deployment time on a set of 2 AA batteries at 3 V with 2800 mAh of capacity, transmitting periodically every 10 seconds, is approximately 14 days. If instead, a lower data rate (DR_SF11), the time-on-air dramatically increases, reducing battery life to 7 days.

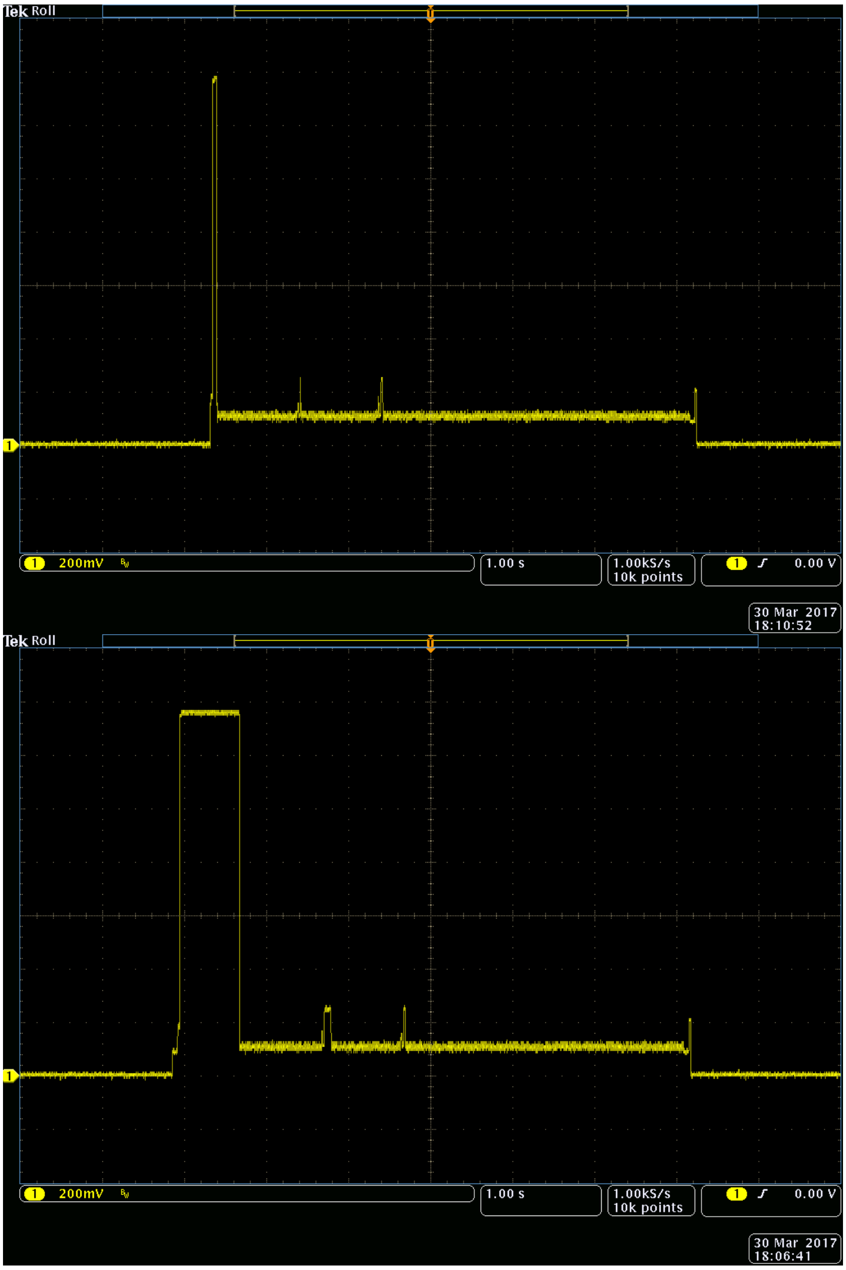

Fig. 12 Power usage against time. (Left:DR_SF7, Right: DR_SF11)

IV. Future Work

A. Extend Range Testing Apparatus

During the experimental stages of this project, a very large distance had to be traversed on foot to gather enough data to draw relevant conclusions. It is planned to develop a simple community-sourced range-testing solution consisting of nodes which will be attached to personal belongings or vehicles. This would greatly simplify the data gathering process, and would aid the surveying of new LoRaWAN base stations by collecting data through the normal activities in people's everyday lives, rather than requiring specific survey journeys to be undertaken. It will also allow for repeatable data to be gathered from commonly visited locations. This could be used to catalog the effect of atmospheric differences such as temperature and humidity on signal integrity, and the node design is being modified to allow such a deployment.

B. Refine LoRaWAN ARM Node

The reasons for the high sleep current are under investigation. When the sleep power usage is brought closer to the datasheet-specified values, to the system will be a very useful standard data-collection device, and will be combined with software on the base station to allow for user-configurable logging of sensors and signals by non-technical persons. This will lead to a universal data-logging solution, which could work as a backbone for many future projects, allowing projects to focus more time on data selection and interpretation.

C. Catalogue Effects of Improved Antennas

During this project, only standard 3 dBi antennas have been used at both ends of the implementation. Potentially in the future, the effects of a greater antenna gain, or more directionality of the antennas used could be catalogued. This can potentially push the boundaries of the maximum range of the system, and may provide more flexibility in situations where a direct line of sight cannot be established.

V. Conclusion

LoRaWAN is a very effective technology, both across long and short ranges. In many cases during this project, the range far surpassed expectation, potentially opening up many new possibilities for practical IoT projects around the university.

At short ranges, LoRaWAN has been shown to be very reliable, potentially facilitating long-term deployments such as smart metering and environmental sensing. At longer ranges, LoRaWAN can still be an effective technology, however it is very terrain dependent, and there is a lot of variance in results with a very small variation in distance and altitude. In this case, a survey similar to what has been conducted here would be invaluable for both deciding where to position nodes and deciding on data rate parameters for returning data to the base stations.

With refinement, the ARM based LoRaWAN node discussed here shows real potential as a low-cost, low-power internet of things sensor, which has the capability to transmit over wide ranges for long periods of time. Custom node designs such as this cost a fraction of the price of currently available commercial implementations, meaning many more of these nodes could be positioned in an environment.

This urban study has catalogued and tested an active LoRaWAN implementation, and shows great promise for the technology in the future of the IoT, especially for long range outdoor projects. The system described here will continue to be in active use, and will provide a valuable tested resource for future projects.

This project has shown that it is straightforward to set up a simple yet highly capable LoRaWAN infrastructure, and together with low-cost node design, a long range (up to at least 8.5 km), low power data collection system is feasible for distributed sensors. It is concluded that as range is increased it becomes more critical to carry out site surveys, but the open nature of the described system allows a simple site measuring tool to be developed. This allows detailed measurements to be taken easily, including small local variations in antenna height. As it is apparent that node positioning is the critical feature of successful implementations, the more information that can be gathered on signal strength, the better the information, and the importance of this has been demonstrated in this project. We conclude that a specific application to log signal strength data continuously from urban environments by specific mobile nodes is a useful feature, and can be easily integrated into the architecture discussed.

References

[1] G. Xu, W. Shen and X. Wang, "Applications of Wireless Sensor Networks in Marine Environment Monitoring: A Survey," *Sensors,* vol. 14, no. 9, pp. 16932-16954, 2014
[2] Fadel, Etimad; et al, "A survey on wireless sensor networks for smart grid," *Computer Communications,* vol. 71, pp. 22-33, 2015.
[3] "LoRa Modulation Basics," Semtech Inc, (Online). Available: http://www.semtech.com/images/datasheet/an1200.22.pdf.
[4] Semtech Inc., "LoRaWAN Specification," (Online). Available: https://www.lora-alliance.org/portals/0/specs/LoRaWAN%20Specification%201R0.pd.
[5] "LoRaWAN Specification," Semtech Inc, (Online). Available: https://www.lora-alliance.org/portals/0/specs/LoRaWAN%20Specification%201R0.pdf
[6] X. Vilajosana, M. Dohler and A. Yegin, "Transmission of IPv6 Packets over LoRaWAN," (Online). Available: https://www.ietf.org/proceedings/96/slides/slides-96-lpwan-5.pdf.
[7] M. Centenaro, L. Vangelista, A. Zanella and M. Zorzi, "Long-range communications in unlicensed bands: the rising stars in the IoT and smart city scenarios," *IEEE Wireless Communications*`, vol. 23, no. 5.
[8] D. Ilie-Ablachim, G. Cristian Pătru, I.-M. Florea and D. Rosner, "Agriculture, Monitoring device for culture substrate growth parameters for precision," in *RoEduNet Conference: Networking in Education and Research*, 2016..
[9] N. Harris, A. Cranny, M. Rivers, K. Smettem and E. G. Barrett-Lennard, "Application of Distributed Wireless Chloride Sensors to Environmental Monitoring: Initial Results," *IEEE Transactions on Instrumentation and Measurement,* vol. 65, no. 4, pp. 736-743, 2016.
[10] P. Neumann, J. Montavont and T. Noël, "Indoor deployment of low-power wide area networks (LPWAN): A LoRaWAN case study," in *Wireless and Mobile Computing, Networking and Communications (WiMob), IEEE 12th International Conference on*, 2016.
[11] S A. J. Wixted, P. Kinnaird, H. Larijani, A. Tait, A. Ahmadinia and N. Strachan, "Evaluation of LoRa and LoRaWAN for wireless sensor networks," *SENSORS, IEEE,* 2016 .
[12] A. Back, "Building a Raspberry Pi Powered LoRaWAN Gateway," (Online). Available: https://www.rs-online.com/designspark/building-a-raspberry-pi-powered-lorawan-gateway. (Accessed 01 08 2017).
[13] Semtech Inc, "Github | Lora-net/packet_forwarder," (Online). Available: https://github.com/Lora-net/packet_forwarder.
[14] O. Brocaar, "Github | brocaar/lora-gateway-bridge," (Online). Available: https://github.com/brocaar/lora-gateway-bridge.
[15] "Mosquitto: An Open Source MQTT Broker," (Online). Available: https://mosquitto.org/.
[16] O. Brocaar, "Github | brocaar/loraserver," (Online). Available: https://github.com/brocaar/loraserver.
[17] Libelium Comunicaciones Distribuidas, "Waspmote - Open Source Sensor Node for the Internet of Things," (Online). Available: http://www.libelium.com/products/waspmote/.
[18] F. Adelantado, X. Vilajosana, P. Tuset-Peiro, B. Martinez and J. Melia, "Understanding the limits of LoRaWAN," arXiv, vol. 1607.08011.