Evaluation of LoRa and LoRaWAN for Wireless Sensor Networks

Andrew J Wixted[1,2](Member IEEE), Peter Kinnaird[2], Hadi Larijani[1], Alan Tait[2], Ali Ahmadinia[3], Niall Strachan[2]

[1]*Glasgow Caledonian University,* [2]*Stream Technologies, Glasgow UK,* [3]*California State University San Marcos*
andrew.wixted@gcu.ac.uk

***Abstract*— LoRa is a new ISM band wireless technology designed for low power, unlicensed, Long Range operation. LoRaWAN is a Wide Area Network protocol that incorporates the LoRa wireless into a networked infrastructure. The indoor and outdoor performance of these technologies, the physical layer wireless and multi-gateway wide area network, was evaluated across the central business district (CBD) of Glasgow city (Scotland). The results indicated that this technology can be a reliable link for low cost remote sensing applications.**

I. Introduction

When providing M2M (Machine to Machine) networking for sensors and other equipment there are numerous technologies available depending on the circumstances. For nearby equipment, where 'nearby' could be metres to hundreds of metres, networking can be achieved using cabling, Bluetooth, WiFi zones, Zigbee or other short range technologies. If a site is remote and cabling is not an option then, if the equipment or data is of sufficient value, connections can be made using cellular mobile network modems or satellite modems. Between these scenarios, the *nearby* verses the *remote high value*, there is a plethora of sensing opportunities where the cost-benefit is insufficient to justify the cost of mobile network connection but the distance is too great for existing ISM band technologies. As the expansion of M2M networking, or as it has become known 'the Internet of Things' (IoT), continues, there is competition between technologies in this low-cost long-range space.

A. Competing technologies

The LoRa technology, LoRa is a trademark of Semtech[1], is one of a number of new ISM band long-range, low-power technologies. Other new technologies include SigFox[2], a subscription based network service where the SigFox company has erected base stations in numerous cities and regions. Low cost Sigfox radio devices can be incorporated in a sensor system and can transmit tens of bytes in a packet to the base station. Sigfox can then route the traffic to the owner of the data. The number of data packets transmitted per day depends on the level of paid subscription. Other competing technologies include On-Ramp[3], a fully propriety networking solution that claims a significant advantage in base station requirements compared to either LoRa or Sigfox. There is also longer range Zigbee, nWave – an ultra narrow band software defined radio [4], and a number of smaller players. The imminent or already occurred shut-down of the 2G and /or 3G mobile networks in many countries has focused attention on 4G networking with proposals for NB-IoT[5] a Narrow Band service for M2M communications using space in licensed mobile network bands, LTE-MTC (Long-Term-Evolution Machine-Type -Communications, now LTE-M) and NB-LTE-M[6], all competing mobile technologies. These mobile network technologies are necessary to fill the gap left by the demise of low power, low cost 2G M2M technology.

B. LoRa and LoRaWAN Operation

The LoRa wireless uses a chirp-spread-spectrum (CSS) modulation with options for different Spreading Factors (SF) and bandwidth to optimise the modulation to meet the range and data requirements. LoRa uses ISM bands 433MHz, 868MHz or 915MHz depending on jurisdiction with the band divided up into channels. The combination of SF and bandwidth trades off speed for range[7]. In Europe transmitted power is limited to 14dBm EIRP with a duty cycle limit of one percent on-air time. Depending on the modulation and transmission power the link budget can be as high as 156dB.

LoRaWAN (a trademark of the LoRa Alliance) involves a protocol stack with the LoRa wireless as the physical layer. The LoRaWAN mote communicates over the air with a gateway which incorporates a receiver concentrator capable of decoding 10 concurrent transmissions. The gateways communicate with the 'Network Server'.

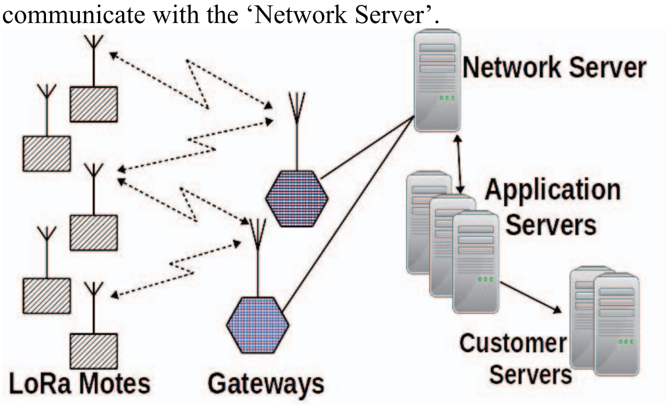

Fig.1 LorWAN Topology. Motes can belong to anyone.

If a LoRaWAN mote transmission is detected by multiple gateways the network server decides which gateway to use to send an acknowledgement (if required). The network server passes the data package to an 'Application Server' and the application server passes the data through to the 'Customer Server'. When using Over the Air (OTA) authentication the authentication happens at the application server. The application server allows the grouping together of numerous motes into an 'application'. Where a customer may have

978-1-4799-8287-5/16/$31.00 ©2016 IEEE

numerous motes of different types and in different locations, the 'application' is an administrative grouping of related motes. An 'application' has its own encryption key.

C. *Evaluation Purpose*

Considering that this is a new technology, while there are many press releases and joint venture announcements, there is little practical experience in the use and effectiveness of this technology. This evaluation was planned as a practical exercise to develop familiarity with the performance and reliability of both the LoRa wireless and the LoRaWAN in a typical environment.

II. Testing

The evaluation of the LoRa wireless and LoRaWAN was performed in the CBD of Glasgow, an environment with a mix of newer concrete and glass buildings but also with many older sandstone buildings of up to seven stories. The terrain includes a flat river plain backed with a number of hills rising to about 50 metres above the river flat.

A. *LoRa Wireless Testing*

The LoRa wireless was tested for range using a symmetrical RF network link comprising two Semtech SX1272 transceivers with identical antenna. One transceiver was installed above the lift housing on the top of a seven story building on the campus of the Glasgow Caledonian University. This unit was controlled by an Arduino processor and used as a beacon transmitter while the other transceiver was used in a mobile unit. The mobile unit comprised a Raspberry Pi, a 3G-GPS module, the SX-1272 and a TTi portable Spectrum Analyser. The SX1272 used a Libelium USB adapter. The Raspberry Pi logged the connection data and GPS data using a Python script. The spectrum analyser was used for a related research project measuring available ambient RF energy[8]. The logging unit was carried in a backpack. It received and logged sequentially numbered beacon messages, it also recorded the received signal strength (RSSI) and the location. To maximise the range a modulation mode with a higher receive sensitivity was used. The resultant data was plotted across a map of the CBD. Data collection was conducted on foot and was limited at times due to the weather. User feedback was made available using GPS and RSSI information posted by the Raspberry Pi via a 3G network connection to a web server with the information displayed using open street maps viewed via a smart phone .

B. *LoRaWAN Testing.*

LoRaWAN testing was conducted using Multitech mDot[9] devices as the 'mobile' device. The mDot comprised a LoRa wireless chip, an ARM processor, the LoRaWAN protocol stack and, in this case, an 'AT' command interface. For testing across the city an mDot was interfaced to a Raspberry Pi using a FTDI 5V USB cable. The Raspberry Pi was also interfaced with a 3G/GPS unit which was used to record the current location. Gateways were Kerlink [10] devices comprising a Semtech LoRa SX1301 concentrator chip, a processor and a mobile network modem. Gateways could be connected to the network server using cabled networking or via the mobile network. In these tests there was a cabled gateway and two gateways using mobile network connections via different mobile operators. Gateways were located on top of the George Moore building (Glasgow Caledonian University), the James Weir building (Strathclyde University) and 'Skypark 1'. Unfortunately for some testing the Skypark gateway had been temporarily moved inside due to roof work. Mote devices were activated via the Stream Technologies IoT^{X} platform operating as the front end to the application server. The mobile unit was set to transmit sequentially numbered packets and log the success or failure to receive an ACK. The packets alternated between two modulation modes that gave both a moderate range and a modest repetition rate. The network server recorded all packets received from the various gateways including considerable meta data describing the transmission. Data was collected by walking through the city carrying the logger unit in a backpack. Data was also collected within a building with the time and position within the building recorded manually. The data collected from the network server was logged and subsequently loaded into a database along with the data logged from the mobile device.

C. *Reliability Testing*

This testing was performed by leaving motes to repeatedly send messages over long periods of time. The units were programmed to continuously iterate through a number of spreading factors and channels. This was later changed to just testing spreading factors. Transmission rates were determined by the spreading factor and the duty cycle. Initially data from one mote to one gateway was used for analysis then the testing was changed to a multi-gateway scenario with the mote located 1.9 km from one gateway and 2.1 km from another gateway.

III. Results

A. *LoRa Wireless Performance*

For full results refer to the online interactive map[11], an extract appears below as figure 2. Moving down hill and away from the beacon transmitter the remote unit was still receiving transmissions at 2.2km (southerly direction). Going north reception was lost at approximately 1.6 km after passing over a hill.

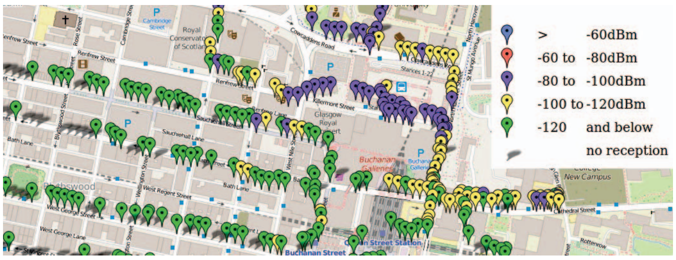

Fig. 2. Extract of mapped results from LoRa range testing. For the full map see [11] and select LoRa from the menu.

The eastern and western directions were not fully explored but a 2km wide strip was mapped. Hills tended to block the signal although it was still possible to capture some packets. Pedestrian underpasses or streets that ran orthogonal to the line back to the transmitter had less reception than streets that aligned with the line of propagation. Open areas had better general reception than streets with high buildings.

B. LoRaWAN Performance

With multiple gateways in operation many locations were detected by more than one gateway. Several trouble spots were visited including a 100m pedestrian underpass (Argyle St, Central Station). While the GPS failed to operate the LoRaWAN could communicate with this location.

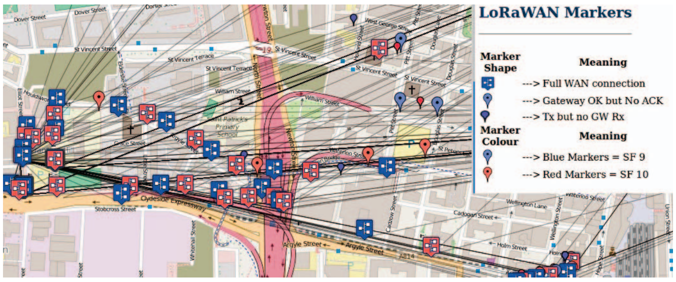

Fig. 3. LoRaWAN network operation, extract from interactive map [12]. The markers are the location of the mote and the lines link to the gateways that received the transmission. Clicking on a marker shows the RSSI.

C. Reliability Testing

The initial results from the reliability testing indicated a successful connection of mote transmission and ACK reception across all spreading factors of less than 42% over a 1.9km link. Initially it was unknown if this was good or bad. From the RSSI data it seemed that a higher percentage should have been successful. Analysis of the time of connection showed large blocks of no connection for an hour or more. This connection loss normally occurred in the hours around midnight. The test was repeated using two gateways and connection rates rose to 70% but the large time gaps still existed. The gateways were operating over the mobile network but no mobile network outages had been advised and the drop outs occurred every night. A number of causes were suspected including mobile network latency, RF interference and network server issues. Since the network server was handling traffic from other gateways it was discounted as the cause. The RF interference was monitored using spectrum analysers and the gateway IP latency was monitored using ICMP pings from the gateways to the network server. Immediately after pings were implemented the LoRaWAN connection rate rose to 95.5% for full connection and another 2.5% where the data arrived at the destination but the mote did not receive the ACK. The cause of the outages appeared to be an aggressive inactivity disconnect policy by mobile network providers. While the results from the SF tests are useful they are not reported here as the percentages are potentially misleading given the issues with the mobile network connection. These tests will be repeated in the future.

D. In-building Connections

If a gateway was located on the same floor, internal reception was quite high with reception better than -70dBm . Where the gateway was mounted on the roof, the floor immediately below got service from a gateway some 600 metres away. On lower floors service was shared across the local roof gateway and the distant gateway. Connection was lost in some completely enclosed stairwells. Exterior rooms had better reception than the central corridors.

IV. Discussion

The testing identified some important but peripheral issues that affected the LoRaWAN functionality. The unreliability of the gateway's mobile network connection and the use of UDP between the gateway and network server meant that not just sensor data but information about the functioning of the network was lost. Of less importance was a small residual packet loss of around 1%. This could possibly be attributed to some long duration (10s), wide-band (2MHz) modulated signal centred around 868MHz that was observed on several occasions. The source of this signal has not yet been identified. At different times gateways were observed demodulating concurrent transmissions as designed.

V. Conclusion & Future Work

Overall the results were extremely encouraging. With multiple gateways the network coverage reached into places that were considered problematic. Topography played a significant role in signal propagation as did building density. The mobile network connection issue is currently being assessed and different solutions considered. As soon as this is resolved a more in depth study of the operation and performance of the network will be conducted. This will include a study of the power use on the motes and the ability to tailor the modulation method and the transmission power to optimise mote power use.

Acknowledgement

The authors wish to acknowledge the support of Innovate UK, West Scotland KTP office and Stream Technologies for their financial and in kind support for this project.

References

[1] http://www.semtech.com/wireless-rf/lora.html
[2] http://www.sigfox.com/
[3] http://www.ingenu.com/technology/rpma/
[4] http://www.nwave.io/nwave-network/
[5] K. Flynn, *NarrowBand IOT*, 3GPP, Phoenix, US, 2015. [Online]. Available: http://www.3gpp.org/news-events/3gpp-news/1733-niot
[6] *LTE-M & 2 Other 3GPP IoT Technologies To Get Familiar With*. 2015 [Online]. Available: http://www.link-labs.com/lte-iot-technologies/
[7] LoRaWAN: What is it? A technical overview of LoRa and LoRaWAN, Lora Alliance, San Ramon, US 2015 [Online]. Available: https://www.lora-alliance.org/portals/0/documents/whitepapers/LoRaWAN101.pdf
[8] A. Wixted, *RF Energy Harvesting Study* , Stream-Technologies, 2016. [Online]. Available: http://www.stream-technologies.com/whitepapers/rf-energy-harvesting-study/
[9] *Multitech mDot Long Range RF Modules, 2015* [Online] Available: http://www.multitech.com/brands/multiconnect-mdot
[10] *LoRa IoT Station* Kerlink, 2015 [Online] Available: http://kerlink.fr/images/Kerlink/fiches_produit/LoRa-IoT-Station.pdf .
[11] *Mapping of RF Signal Strength* (includes LoRa), 2016 [Online] Available: http://www.stream-technologies.com/maps/rf_mapping.html
[12] *LoRaWAN Networking*, 2016 [Online] Available: http://dev.stream-technologies.com/maps/networking.html