Technical White Paper

Evaluating LoraWAN in an Urban Environment

Steve Roderick 2018

The Internet of Things (IoT) is a pillar of a fourth industrial revolution. A revolution based on the way we collect and process information. Central to its successful realisation is the need for a robust, scalable and secure radio network.

Low Power Wide Area Networks (LPWANs) and LoRaWAN in particular, have been proposed as a candidate communications stack.

LPWANS MAY EVENTUALLY ACCOUNT FOR A QUARTER OF ALL CONNECTED DEVICES.

Watford Borough Council, United Kingdom is in the early stages of a city-wide LoRaWAN rollout. This white paper details a drive survey and propagation study of their LoRaWAN network.

For the purposes of this project, ICS telecom EV was chosen. This software is developed by ATDI and was used for radio network planning and modelling.

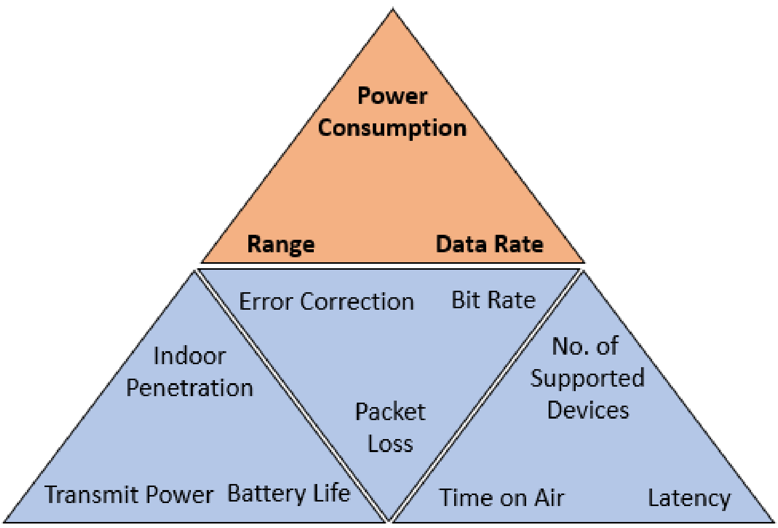
In this white paper we address the following questions:

- **What is LoRaWAN?**
- **What propagation effects are significant?**
- **What steps are required to create a fully validated propagation model of a LoRaWAN network?**
- **How can ICS Telecom EV be used to meet network planning objectives?**

INTRODUCTION

3GPP IoT standards such as LTE-M and NB-LTE have yet to be widely deployed. The current LPWAN market leaders are LoRa, Zigbee and Sigfox. Other technologies exist but are mainly targeted at niche applications.

IoT technologies can be positioned by considering engineering trade-offs present in their development. Products, such as LoRa and Zigbee directly extend IEEE 802.15.4. Bespoke higher layer implementations are then employed to target specific applications. Key engineering trade-offs are shown in the figure below:



Engineering Trade Offs in IoT Networking Protocols

LORAWAN TRADES DATA RATE FOR INCREASED POWER EFFICIENCY AND RANGE.

Specifications are impressive: Typical ranges are 2 to 3 km in an urban environment and greater than 10 km in mixed and open terrain. LoRa devices can be powered for years using a single AA battery. A single base station can serve 10,000 nodes. In the UK, LoRa operates in unlicensed ISM bands at 868 MHz.

Network Architecture

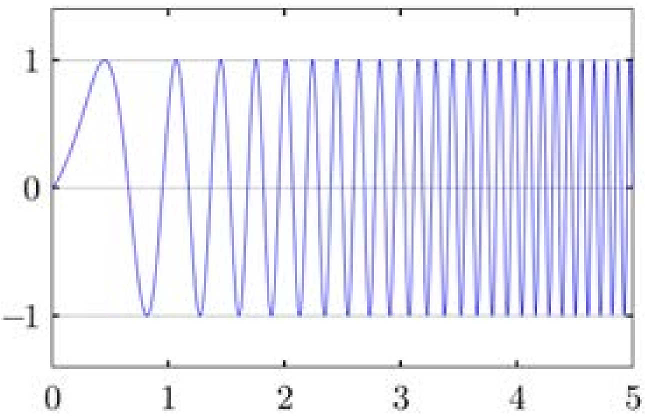
LoRaWAN supports various network topologies. The most common is a *star of stars*. This is similar to a traditional cellular network:

- End user devices (nodes) send and receive data from sensors or actuators.
- Packets of data are transmitted to base stations (gateways) using LoRa radio modulation.
- Gateways act as relays between nodes and one or more network servers.
- Network servers aggregate and process the data packets.
- Data is forwarded to application servers where end users consume the information in applications.

Modulation

A MODULATION SCHEME VARIES ONE OR MORE WAVEFORM PROPERTIES. FOR EXAMPLE: AMPLITUDE, FREQUENCY OR PHASE.

LoRa modulation is proprietary to Semtech. It is a derivative of Spread Spectrum Modulation. In common with other spread spectrum techniques, full channel bandwidth is used to encode the signal. Modulation is achieved using frequency patterns called chirps. It is the unique nature of the chirp or frequency shift that allows it to be distinguished from channel noise.



Linear Up-Chirp

APPLICATIONS

The figure below lists current UK applications of LoRaWAN technology:

UK Applications of LoRaWAN

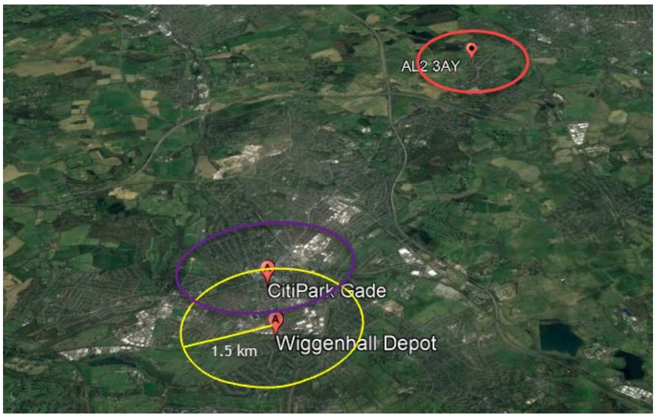
MEASUREMENT CAMPAIGN

Field measurements are essential in characterising a radio channel and in understanding the significance of different propagation effects. Results are also useful for testing radio equipment and determining *quality of service parameters.* In the present study, data from an extensive drive survey was used to tune and validate a LoRaWAN propagation model.

The project area is defined by the boundaries of Watford Borough.

Project Area

Three smaller areas were targeted for a drive survey. Two in central Watford and one to the north of the borough.



Surveyed Areas

To perform the drive survey, GPS enabled devices were fitted to council operated recycling vehicles as shown below:

Positioning the Node for the Drive Survey

Lee Criteria

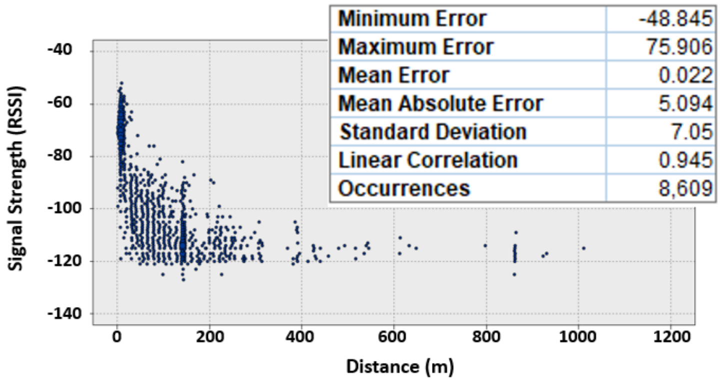
In urban environments, reflection from buildings (structural attenuation) is significant. Reflected signals cause multipath propagation. In such systems differences in path length result in signals arriving at a receiver with different phase. This causes fading and distortion. At high frequencies, such as 868 MHz, small changes in position can result in large differences in signal strength.

FAST FADING EFFECTS REQUIRE AVERAGING OVER MULTIPLE SAMPLE POINTS TO DETERMINE A LOCAL MEAN SIGNAL STRENGTH.

The Lee criteria establishes the sampling frequency required.

It is strictly valid only where Rayleigh statistics apply. However, it can serve as a base line figure for other situations. The criteria states that between 36 and 50 samples are required for distances of 40 wavelengths. The wavelength of LoRa signals is 34 cm. Traversing paths of length 3 km from a gateway, the number of samples required to validate a model is 11,000.

Data points were collected as shown below:



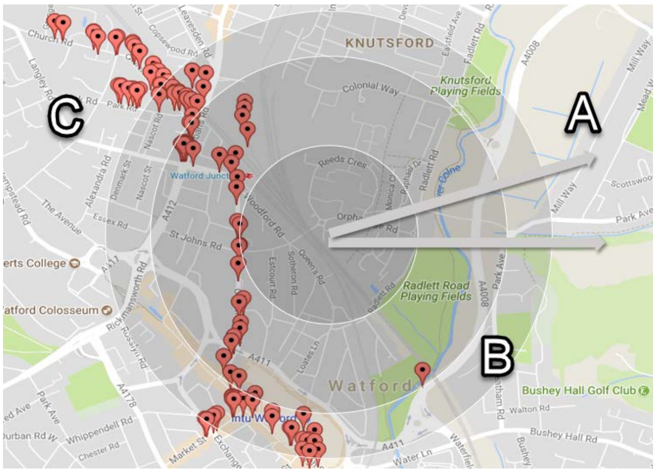
RSSI vs Distance

Conducting the Drive Survey

The following points were considered when planning the measurement campaign:

- Signal strength (RSSI) and packet loss were selected as primary response variables.
- Shadowing has a major impact on far field signal propagation. Test base stations were sited in locations as far away as possible from local clutter.
- Routes were selected that contained a mix of line-of-sight and non-line-of-sight locations.
- Routes chosen were representative of all types of environment present for example, dense urban, suburban and open areas.
- Maximum transmit power and transmission rate were used.
- Modulation rate (spreading factor) was cycled at fixed intervals.

The figure below shows different options when selecting drive survey routes:



Route Selection

Option A (radial approach) has the advantage of closely following path profiles predicted in the planning software. In option C (circumferential) distance is removed as a predictor. This means that propagation will vary solely due to topology and clutter. Although there are advantages associated with both these options they are difficult to accomplish within the confines of the public road network and local access restrictions. Option C (randomized route on adopted roads) was therefore selected.

PROPAGATION MODELLING

Propagation models can be categorised as:

Deterministic - models consider 3D path profiles from the transmitter to a receiver. A physical understanding of electromagnetic wave propagation together with models of attenuation are used to predict how path loss differs from that of free space.

Empirical - models are statistical in nature. They are created from detailed field measurements. A well-known example is the *Okumura-Hata* model. Empirical propagation models are only valid for specific environments and frequencies.

In this work we use deterministic models. These models modify the free space path loss (FSL) given by the *Friis transmission formula* below:

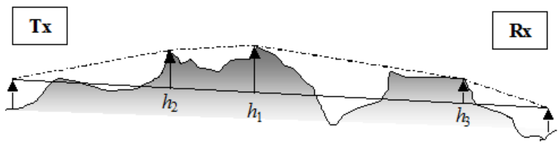
$$Path\ Loss\ (dB) = -10\ log \frac{G_t G_r \lambda^2}{(4\pi)^2 r^2}$$

Substituting typical values for LoRa yields a theoretical free space range of 300 km for a transmission power of 14 dBm.

ATTENUATION IS COMPRISED OF ABSORPTION, DIFFRACTION, SCATTERING AND REFLECTION.

Buildings and the earth itself are reflectors. If the earth is present in the 1st Fresnel Zone this can cause significant attenuation. This is more likely in IoT applications because ranges are long with nodes transmitting close to the ground. To predict reflection, a two-ray model is used. It can be shown that power varies with the inverse fourth power of distance. Obstruction loss is estimated by modelling peaks in the terrain as a series of knife-edges. For some terrain profiles, better results are achieved by modelling peaks as cylinders.

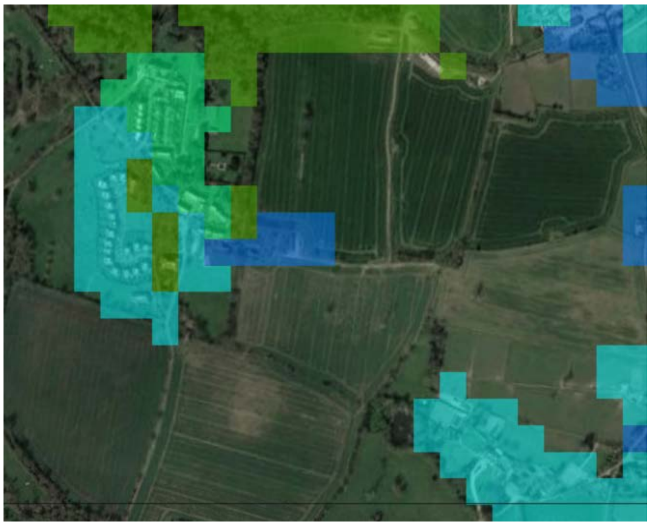
The number of intrusions into the Fresnel Zone that can be accounted for depend on the model. The principle of knife edge diffraction is illustrated below:



Knife Edge Diffraction
[from Antennas and Propagation for Wireless Communication Systems, Wiley 2007]

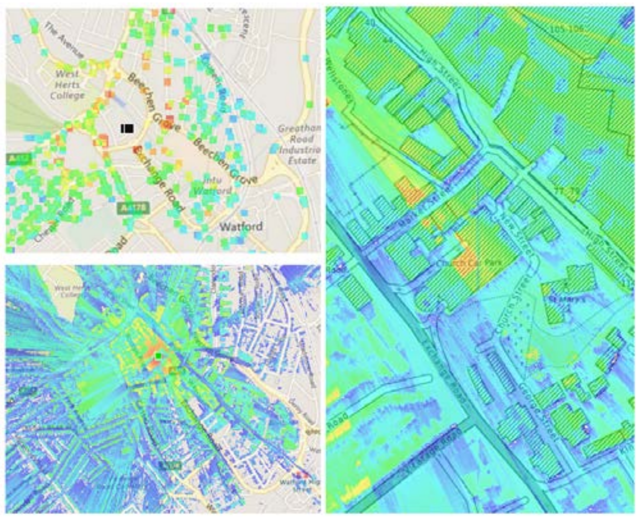
Creating a Model

Digital terrain and clutter maps of Watford at 25m resolution were used. Clutter is any object natural or manmade that exists on top of bare earth topology. Type and height of the clutter is significant. Dynamic effects such as trees moving in the wind can also affect the absorption. For modelling purposes different types of clutter are assigned a category. These were manually adjusted in ICS Telecom EV using satellite imagery.



Example of Clutter Categorization (ICS Telecom EV)

Models of propagation were created and then calibrated against results from the drive survey.



Measured RSSI vs Coverage Calculations (ICS Telecom EV)

Various industry standard propagation models were used. Standard deviation was calculated against field measurements. The table below shows example results:

Model Name	Standard Deviation
Deygout 66	5.92
Bullington	2.92
ITU-R 526 (cylinders)	6.23
Hata Costa 231 (150-2000 MHz)	6.73
Extended Hata (30-3000 MHz)	4.19

Industry Standard Models

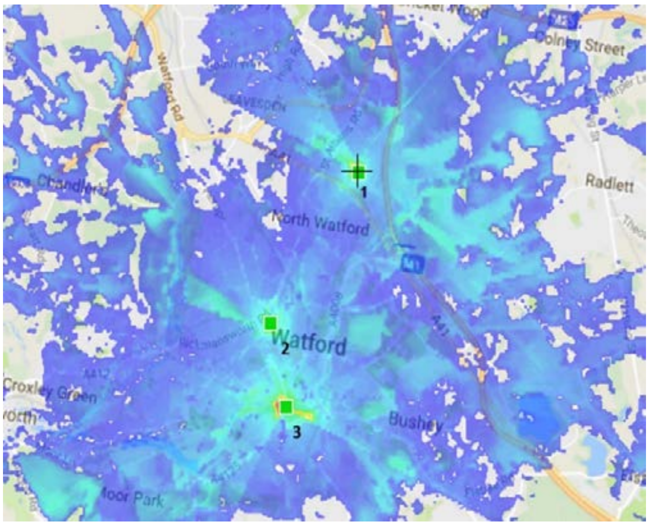
THE BEST PERFORMING MODEL AGAINST DRIVE SURVEY DATA WAS FOUND TO BE BULLINGTON.

NETWORK PLANNING

The objective of the planning exercise was to determine the number and optimal position of LoRaWAN gateways. 90% coverage across Watford borough is required. A subsidiary goal was to identify areas of poor coverage.

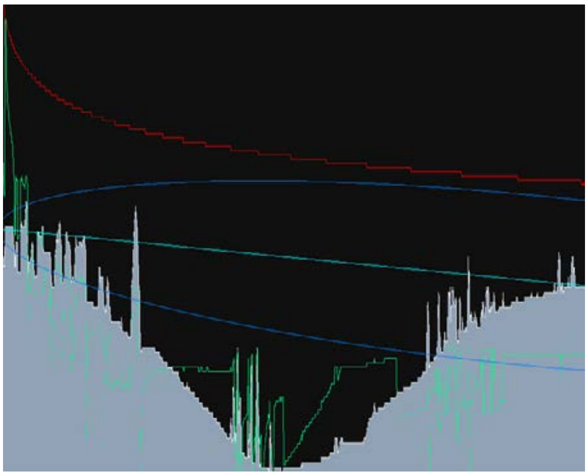
Composite coverage calculations were performed for three operational sites and seven candidate locations. Percentage coverage figures were recorded for each combination.

THREE SITES WERE IDENTIFIED THAT YIELDED A BOROUGH WIDE LORAWAN COVERAGE FIGURE OF 90%



Site Search / Composite Coverage (ICS Telecom EV)

Not spots were analysed using path profiles in ICS Telecom EV. The figure below shows predicted signal strength in an area of low elevation in North Watford.



Path Profiles (ICS Telecom EV)

CONCLUSIONS

- Good coverage can be achieved with relatively few LoRaWAN gateways. In the present study, a 21 km2 area of Watford required three gateways to achieve a composite coverage of 90%.
- Mean distance between a node and gateway should be specified so that packets can be sent using a spreading factor of 7 or 8. This reduces time on air and hence network contention.
- Packet loss of around 20 to 30% should be regarded as typical when using a single LoRaWAN gateway. IoT applications intolerant to high levels of loss will require receipt of packets by multiple gateways.
- Far field coverage is highly dependent on elevation and local clutter. Where possible, aim for line of sight communication.

ATDI Ltd The Beehive, City Place Gatwick Airport, West Sussex, RH6 0PA. United Kingdom Tel. +44 (0)1293 522052
www.atdi.co.uk E-mail: sales@atdi.co.uk