Optimising LoRa Parameter Choice for Low Energy Networks

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Abstract

LoRa (Long Range) is a radio technology that facilitates low power communications over a large distance. The long range of communication means that a simple single hop transmission to a centralised node is sufficient for most applications. To supply this performance, the LoRa physical layer offers a range of transmission parameters to tailor the capabilities to different applications. With over 6000 parameter combinations, it is difficult to select the most effective combination. This paper presents a methodology for selecting the optimum parameter set for a given application. We demonstrate that our process, which combines experimental and modelled data, is able to find optimal settings for a given communication channel. We also identified areas of uncertainty for both the models and experimental procedures.

1. Introduction

Telemetry is the practice of remotely monitoring and reading sensors. Some typical examples of where this could be used are: remote residential water meter reading, water tank level reading and bore monitoring. The effectiveness of wireless telemetry systems is heavily dependent on the network's transmission range and energy usage. LoRa (Long Range) is a promising type of Low Power Wide Area Network (LPWAN) technology designed for long range and low power applications. In order to provide this performance, it has over 6000 parameter combinations available to configure the performance to the desired standard. This paper presents a methodology for selecting the parameter combination that minimises energy use, while achieving reliable communication for a given application. We demonstrate that our process, which combines experimental and modelled data, is able to find optimal settings for a given communication channel. We also identify areas of uncertainty for both the models and experimental procedures.

The optimum parameter selection tool has three inputs and one output. The output from the tool is the LoRa parameters best suited to the specific application characterised by the three inputs. The three inputs are: available transmission energy budget, receiver sensitivity and expected path loss. For each of these inputs, there is the option to input an assumed value, or to use an experimentally determined value. We propose a methodology where an initial estimate using the assumed values is then experimentally refined.

2. Process

2.1 Transmission Combination Energy Requirements

The energy required to transmit a message of a certain length depends on the LoRa transmission parameters that are selected. The available parameters are briefly described in Table 1 below.

Parameter	Description
Transmission Power	The available values depend on the transmitter hardware. The SX1272 can be set to integer values between -2 dBm and 20 dBm (Semtech, 2017). Increasing Transmission Power will increase the energy usage and transmission distance (Voigt, 2016).
Carrier Frequency (CF)	The physical layer of LoRa is a proprietary spread spectrum technique derived from Chirp Spread Spectrum (CSS) (Bor, 2016). This means that the transmitted information is encoded in frequency sweeps (or "chirps"). The carrier frequency is the centre frequency of the chirps (Augustin, 2016). The CF can be set between 137 MHz and 1020 MHz in 61 Hz steps. Available ranges for CF are controlled by government regulation.
Bandwidth (BW)	Bandwidth is the frequency range swept over during a chirp. In LoRa, the chirp rate is equal to the bandwidth (one chirp per second per Hz of bandwidth) (Augustin, 2016). For standard LoRa network hardware, the BW can take the values of 125kHz, 250kHz or 500kHz (Voigt, 2016). Increasing BW decreases sensitivity, but increases data rate (Augustin, 2016).
Spreading Factor (SF)	There are 2^{SF} chirps in a symbol (Augustin, 2016). Increasing the SF by one will double the duration of the symbol (Augustin, 2016) and increases the number of bits in the symbol by one.
Coding Rate (CR)	LoRa includes an inbuilt Forward Error Correction (FEC) in the physical layer (Augustin, 2016). The CR is the amount of FEC applied to the message. Increasing the CR provides protection against burst interference, but increases the message length, time on air and energy usage (Voigt, 2016).

Table 1 LoRa parameters that can be varied to tailor the physical layer performance

Semtech data sheets (Semtech, 2017) specify how the parameters affect power use. Semtech also offer a Calculator (Semtech, n.d.) that may be used to test individual parameter sets. For the sake of large scale comparisons between different parameter combinations, the calculator provided is too cumbersome. To overcome this, a python program was written to replicate the information provided in the data sheet. The python program can be used to quickly and efficiently compare parameter combinations.

The physical transceiver modules may differ from the operating characteristics provided by Semtech. Testing the accuracy of the quoted energy models experimentally would be a useful area of further research. A concurrent CEED project conducted by Benjamin Sinclair is investigating the physical profile of the power usage.

2.2 Receiver Sensitivity

The Receiver Sensitivity is the signal strength required to receive a message. The sensitivity of a LoRa receiver is dependent on the BW and the SF (Augustin, 2016). A selection of receiver sensitivity values for the SX1276 transmitter module quoted by the manufacturer is shown in Table 2 (Semtech, 2017). Though the experimental setup is not defined, these LoRa settings are given with a payload of 64 bytes, CR of 4/6, Packet Error Rate of 1% and bandwidth of 125 kHz (Semtech, 2017).

SF	7	8	9	10	11	12
Sensitivity (dBm)	-123	-126	-129	-132	-133	-136

Table 2 Quoted SX1272 LoRa receiver sensitivity for a Bandwidth of 125 kHz (Semtech, 2017)

These assumed sensitivities can be refined by measuring the signal strength of packets that are successfully received. It can be assumed that if the received signal strength is greater than or equal to this minimal value, then the message will be successfully received (Augustin, 2016). It would be beneficial to relax this assumption by experimenting with the packet delivery reliability associated with different received signal strengths close to this threshold value, but that is beyond the scope of this project.

2.3 Propagation Loss Model

The power experienced by the receiver is dependent on the power transmitted, and the gains and losses along the path (Voigt, 2016). If the received signal power is greater than the receiver sensitivity, then the transmission will be successful (Voigt, 2016). A caveat of this assumption is that desired reliability (i.e. packet reception probability) is taken into account in the quoted sensitivity. The transmit power, receiver sensitivity, and antenna gains are all independent of range, and can be used to determine the maximum acceptable propagation loss for a successful transmission (Saunders, 2007).

For a line of sight transmission near flat ground over d metres, from receiver and transmitter heights of h_R and h_T metres respectively, the plane earth model predicts path loss as:

$$L_{PE}(dB) = 10n\log_{10}(d) - 20\log_{10}(h_R) - 20\log_{10}(h_T)$$

A baseline plane earth model has $n = 4$, but in realistic environments n is chosen to be higher (Huebner, 2013).

For further refinement, a testbed comprising a portable transmitting node connected to a GPS enabled mobile phone and a centralised receiver, has been constructed. The transmitting node sends the current GPS location to a stationary centralised node where the message and the received signal strength indicator (RSSI) are recorded. Using a linear polynomial fit and logarithmic distance (Petajajarvi, 2015), an experimental value for n can be determined.

The flexibility of this process allows this experiment to be replicated, in order to get the real path loss model for different terrains, times of day and weather conditions. The assumption here is that the path loss model will not depend on the LoRa parameter combination, but only on the environment. This means that the path loss experiments do not have to be repeated for different parameter selections.

3. Results and Discussion

3.1 LoRa Transmission Parameters

As an initial estimate the energy usage and receiver sensitivity were assumed to be those quoted in the Semtech Data sheet (Semtech, 2017). The plane earth model exponent was assumed to be the baseline value of 4 with transmitter and receiver heights at 4 and 1 meters. Each point in Figure 1 shows the estimated energy usage and transmission distance of a 32 Byte message for different parameter selections. For an arbitrary desired transmission distance of 5 km, the tool selects the parameters that satisfy the distance criteria with the minimum energy, in this case {SF = 7, BW = 250 kHz, TP = 14 dBm, CR = 4/5}. This setting required 4.7 micro-joules per 32 Byte message.

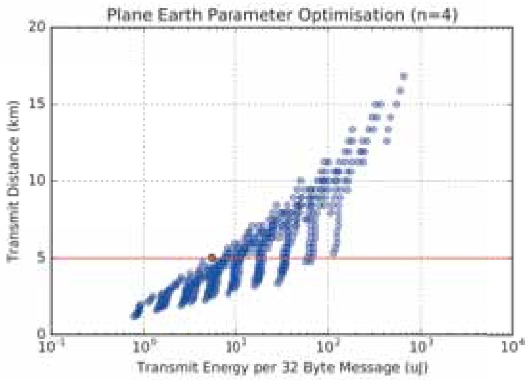

Figure 1 Theoretical transmission distance and energy usages for all possible parameter combinations assuming a plane earth model with n=4 and datasheet sensitivity. The optimum parameters for a desired distance of 5 km is the left most point on the horizontal line.

3.2 Receiver Sensitivity

In section 3.1, the receiver sensitivity was assumed to be the value quoted in the Semtech Data sheet of -136 dB for a spreading factor of 12 and bandwidth of 125 kHz (Semtech, 2017). To test the validity of this assumption, the Received Signal Strength Indicator (RSSI) was measured for transmission distances from 0 to 1200m in a suburban area with one story buildings at around 7 am. As seen in Figure 2, the most optimistic receiver sensitivity estimate is -134 dBm. While this is close to the published value of -136 dB, it does not take the packet reception rate into account. There may have been many packets lost at this received strength. In future tests will be done to address this question.

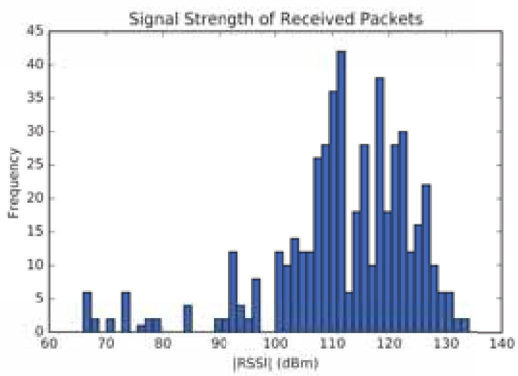

Figure 2 Received signal strength for the successfully transmitted particles for Bandwidth = 125 kHz and SF = 12

3.3 Channel Model

Experimental path loss values were measured using a typical transmission parameter combination {SF = 12, BW = 125 kHz, TP = 13 dBm, CR = 4/5}. The path loss obtained for successfully measured transmissions remained lower than 150 dBm as is expected since the receiver sensitivity and transmit power were -134 dBm and 13 dB.

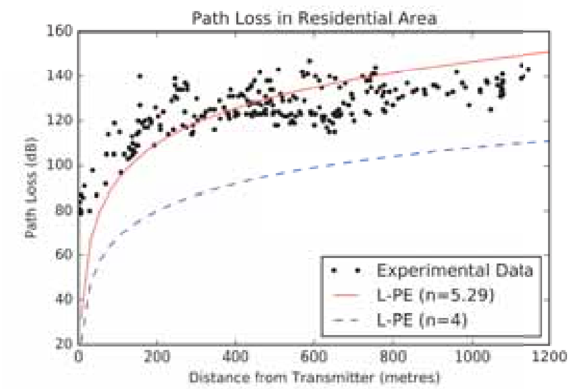

Figure 3 Path loss versus transmission distance in residential area with transmitter height 1 metre and receiver height 4 metres. Showing experimental data, experimental plane earth model (L-PE(n=5.29)) and theoretical plane earth model (L-PE(n=4))

The baseline plane earth path loss model (L-PE (n=4)) underestimated the path loss for all points in the region concerned. Least-squares regression was used to fit the path loss exponent (L-PE (n=5.29)). This resulted in the observed path loss being up to 40 dBm higher than the value suggested using the baseline plane earth model.

At very low distances (less than 100 meters) this model did not appear to be valid. The path loss did not approach zero as expected, but instead approached an 80 dBm minimum. This may be caused by some persistent interference causing the signal to decay by a constant amount. For distances above 800 meters the model tended to overestimate the path loss. In this region, it appears that the receiver sensitivity is limiting what packets are being received. One factor that may affect the results is that the number of test packets being sent at different distances varies. Least-squares regression is affected by what data is selected, future tests should take a more even number of measurements at the different distances.

4. Conclusions and Future Work

The large number of choices for LoRa transmission parameters necessitates a formal method for choosing the optimum combination. This paper provides a method for obtaining an estimate of the optimum parameters from theory and values provided by Semtech (Semtech, 2017). The experimental sensitivity was only 2 dB lower than the data sheet suggested. This does not however take the reception rate achieved at different sensitivities into account. Section 3.3 shows how an experimental plane earth path loss exponent can be fitted. The baseline plane earth exponent gave estimates up to 40 dB lower than observed distances, which was a far more significant error compared to the receiver sensitivity. This suggests that correctly understanding the environment that is being transmitted through is paramount for correctly choosing the parameters.

Future work to be completed in this project includes conducting path loss trials at higher transmission powers to find a wider range of path loss values and ensuring that a consistent number of measurements are taken from each distance. Also repeated sensitivity trials to investigate the reliability associated with different received signal strengths will be conducted. Finally, the parameter selection method and its tools will be packaged so that it can be used by other researchers for improving the design of LoRa sensor network applications.

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6. References

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