Calculation of link budget from LoRa ground sensor to IoTs satellite †

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Abstract: Long Range (LoRa), the low-power wide-area network technology for Internet of Things (IoTs) application. Its advantages are low power consumption, inexpensive equipment and most importantly, appropriate for long range communication. Currently, LoRa networks was extensively use worldwide, so that soon, LoRa gateways may not be able to provide sufficient coverage for the ever-increasing use. A solution was to move LoRa gateway to satellites. We evaluated successful communication between LoRa ground sensor and gateways mounted on a satellite. LoRa communicates in the 923 – 925 MHz frequency band in Thailand. We report link budget calculations, using certain assumptions and showed that for a satellite up to 2302 km communication would be feasible. Nevertheless, these were theoretical results and experiments are needed to confirm them.

Keywords: LoRa; Low-Power Wide-Area Network; Internet of Things (IoTs); link budget

1. Introduction

In the new era of IoTs, communication technology has developed to allow use of communication technology to reach a diverse set of scenarios, but there are some scenarios or areas, where traditional IoTs fail to meet needs, therefore, LoRa, the spread spectrum modulation technique, derived from chirp spread spectrum technology [1], has been applied to this problem, due to its long-range communication capability, low power consumption and long lifetime. LoRa networks will increasingly used all over the world and LoRa gateways may not be able to support comprehensive use. So, if a LoRa gateway can be developed to operate on Low Earth Orbit (LEO) satellites and we can design LoRa ground sensors, that can transmit data to satellites, it will solve this problem.

We investigated the feasibility of successful communication between a LoRa ground sensor and a LoRa gateway, mounted on an IoT satellite, considering the geometry and link budget components, that communicate, based on the AS923 plan or the LoRa frequency band 923 – 925 MHz [2], that provides the LoRaWAN regional specification and can function in Thailand.

This paper is organized as follows: Section 2 explains the basics of LoRa, including the Spreading Factor (SF), transmission power and LoRaWAN uplink channel. We describe the equations for calculating the distance and elevation angle of the ground sensor at an earth station to satellite, in section 3. Section 4 calculates the Free Space Path Loss (FSPL) Receiver Sensitivity for creating the link budget model and found the theoretical maximum distance that can transmit data to a satellite. We conclude in section 5.

2. Basic of LoRaWAN

Here, we set out the basic theory of LoRAWAN, that is needed for link budget calculation with a LoRa module as the transmitter.

2.1. LoRaWAN Limitation

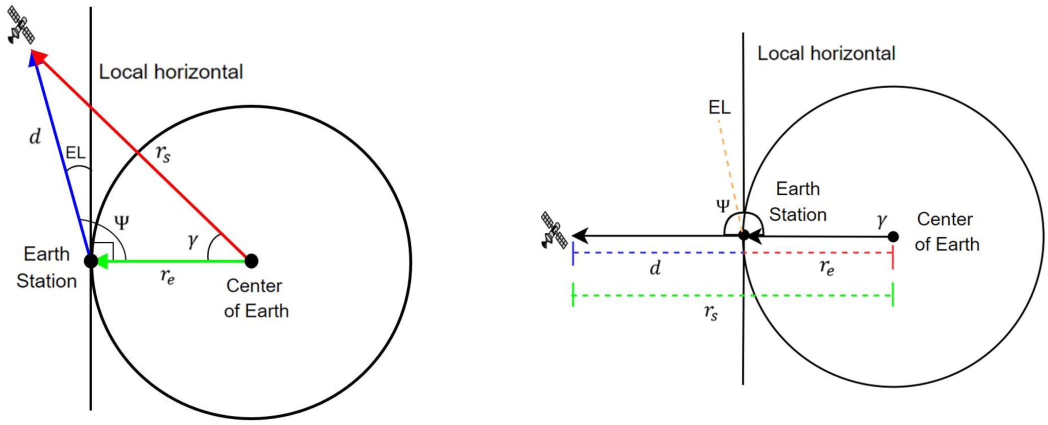
In a LoRaWAN, the bandwidth required are 125, 250 and 500 kHz, depending on the region or the frequency plan, a Spreading Factor (SF) in the range 7 to 12. A high SF is suitable for long distances. Transmission power, if lower power, can save battery, but the range of the signal will obviously be shorter [3]. Transmission power should be suitable for a LoRa module, most have 20 dBm, which can be increased but must keep below domestic communication restrictions.

2.2. LoRaWAN Frequency Plans

The frequency plan is specified in the LoRaWAN regional parameters document. here, we used AS923 (923 - 925 MHz) that consisting of 8 LoRa uplink channels, where frequency bands ϵ {923.2, 923.4, …, 924.6 MHz}. All channels operated using an SF12 spreading factor and 125 kHz bandwidth [2].

3. Elevation angle and Distance of ground sensor to LEO satellite

The elevation angle and distance of ground sensor at earth station to the LEO satellite was calculated from basic geometry principles (sine and cosine laws and formulae for a triangle sides and angles) - see figure 1(a).



(a) (b)

Figure 1. Geometry between earth station and satellite. (a) Triangle between earth station and earth center and the satellite. (b) Geometry showing the elevation angle (EL) perpendicular to local horizontal (EL = 90°).

From figure 1(a), we see a triangle, with sides, consisting of distances from the earth station to the satellite, d, from the center of the earth to the satellite, r_s, (about 6973 km) and the radius of the earth, r_e (about 6371 km). The angles are labeled, Ψ the angle from the earth station angle to the satellite relative the radius of the earth ($\geq 90°$), that includes the elevation angle, EL = Ψ - 90°, γ is the angle subtended by the center of the earth to the earth station and the direction from the center to the satellite.

We can compute the distance from the ground station to the satellite, using the properties of the triangle in figure 1(a) and the cosine law:

$$d = \sqrt{r_s{}^2 + r_e{}^2 + 2r_s r_e \cos(\gamma)} \quad (1)$$

From the sine law, we calculate Ψ from:

$$\Psi = \sin^{-1}\left(\frac{r_s \sin(\gamma)}{d}\right) \quad (2)$$

Initially, we set d = 600 km, the distance to a satellite directly over the earth station, where γ = 0° and EL = 90° see figure 1(b). If calculate from equation (2), found that Ψ = 0° because its the result of calculation with $\sin^{-1}$ function but if consider from figure 1(b), it can express that in this situation, Ψ = 180°. Therefore, we calculate Ψ from:

$$\Psi = 180 - \sin^{-1}\left(\frac{r_s \sin(\gamma)}{d}\right) \quad (3)$$

4. Link budget calculation

4.1. Receiver sensitivity

In the LoRa module, we use the SX1276 transmitter which has a 6dB noise figure, NF [4]. The receiver sensitivity, S, is the minimum signal level required at the receiver to achieve a target performance, depending on bandwidth. It is calculated from [5]:

$$S = -174 + 10\log(BW) + NF + SNR_{\lim it} \quad (4)$$

where BW is the bandwidth (Hz) and $SNR_{\lim it}$ is the limiting Signal to Noise Ratio (dB) (which has a lower value when communicating with higher spreading factor). We assumed SF12 (i.e., spreading factor = 12) and $SNR_{\lim it}$ = -20 dB.

4.2. Free Space Path Loss (FSPL)

The path loss in free space (dB) defines the loss during propagation from transmitter to receiver, it was calculated from [6]:

$$FSPL = 20\log(d) + 20\log(f) + 32.45 \quad (5)$$

where d was distance from earth station to satellite (km) and f was frequency band (MHz) for transmission. FSPL values for several elevation angles, EL ϵ {90°, 80°, …, 0°} and transmit in channel 1 (923.2 MHz), are shown in table 1.

Table 1. Relation of Free Space Path Loss, elevation angle and distance from earth station to satellite

EL (Degree)	d (km)	FSPL (dB)
90	600.00	147.9189
80	608.47	147.4407
70	634.71	147.8074
60	683.23	148.4473
50	760.62	149.3793
40	881.98	150.6651
30	1075.53	152.3884
20	1391.49	154.6255
10	1930.97	157.4471
Closer to 0	2829.80	160.7910

4.3. Link budget model

The feasibility of successful communication between transmitter and receiver, requires that signal power at the receiver power was greater than or equal to the receiver sensitivity, the difference is called the link margin. We ignore loss from environmental factors (*e.g.*, rain, temperature, *etc.*) and calculate receiver power from [7]:

$$\text{Receiver power} = \text{Tx power} - \text{Tx Connection loss} + \text{Tx Antenna gain} + \text{Rx Antenna gain} - \text{Rx Connection loss} - \text{FSPL} \quad (6)$$

where Tx was transmitter, Rx was receiver, connection loss (dB) was the loss between device, antenna connection and antenna gain (dBi) was the value that increase signal power of device.

For example, Tx power 20 dBm, connection loss 1 dB, antenna gain 2 dBi, transmit in channel 1 (923.2 MHz) to LEO satellite and ignoring loss from environment factors. At d = 600 km, EL = 90°, we will find the maximum link margin ~11.7 dB as shown in figure 2(a). The maximum d that can transmit was ~2302 km (minimum EL = 5.2895°), with link margin closer to 0 dB as shown in figure 2(b).

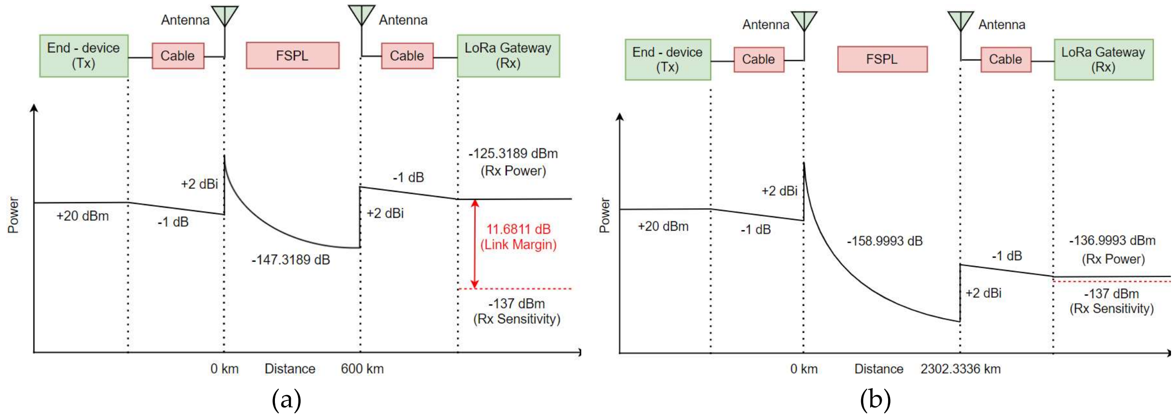


Figure 2. Link budget model of LoRa communicate with LEO satellite. (**a**) transmission distance 600 km. (b) Maximum transmission distance 2302 km

5. Conclusion

We calculated the distance between LoRa ground sensor to IoT satellite at LEO and calculated components of the link budget to determine communication feasibility. From calculation, distance communication and link budget model, it was shown that it was feasible to communicate with an IoT LEO satellite. We could communicate with a satellite at up to 2302 km. However, in actual use, there may be loss from environmental factors, *e.g.*, rain or temperature. Some of these factors can be overcome by increasing transmission power, but this is generally limited by domestic communication constraints, or designing antennae with higher gain. Nevertheless, these conclusions have been drawn from theory and experiments are needed to confirm them and guide future development.

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