The LoRaWAN link budget for UWB anchors data management

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Abstract. Ultra-wideband positioning systems are widely used in such safety-critical industries as underground mining, open pit mining, metallurgy and others. The network of UWB anchors becomes large due to harsh industrial environment, making deployment time-consuming. In order to collect range measurement data and transmit it to the management server it is proposed to use the LoRa technology, allowing the UWB anchors be wireless and delivering robust deployment of the integrated system.

1. Introduction
Regular tightening of safety regulations and search for ways to improve efficiency in the mining industry requires expanding the functionality of information and telecommunications systems that provide the necessary reduction in personnel injuries and economic returns from the use of mobile equipment and technological units of mines. One of the most recent trends in improving efficiency and safety in underground mines and mines that support both regular operation and smooth operation of production units is the growing need for accurate local positioning of equipment and underground personnel.

The implementation and deployment of a high-precision local positioning system based on ultra-wideband signals requires the development of a methodology for deploying such systems in closed, semi-open and extended spaces, including the infrastructure for transmitting information about the locations of mobile objects [1].

To solve the problem of high-precision navigation of a large number of subscribers in a closed space for the mining complex, it is proposed to use a number of technologies and methods, the main of which are ultra-wideband signals, a difference-range method for determining coordinates and a query-free mode of operation of the system with active navigation tags.

As a rule, information is transmitted to the computer server that solves the navigation problem using Wi-Fi networks. However, the volume of data and, consequently, the speed of its transmission allow you to use data networks that are more resistant to complex conditions of radio wave propagation [2].

For the task of building a distributed data collection and management network, it is proposed to use the well-proven LoRa technology. The choice of this technology is primarily due to the long battery life of the devices due to the low radiated power, which is achieved by expanding the spectrum using linear frequency modulation (CSS). Also, in conjunction with the methods of error-correcting coding, this extension of the spectrum leads to an increase in transmission power, the increase of concurrent devices at the expense of code division of channels, increase of noise immunity and electromagnetic compatibility with other radio systems, increasing reliability of the communication channel.
The use of the "star" network topology implemented in the LoRaWAN network, instead of the mesh topology, is also aimed at reducing the power consumption of end nodes by reducing the number of messages transmitted.

2. Propagation model selection

The main parameter of LoRaWAN network in order to coverage and link budget calculations is receiver sensitivity. This parameter depends from necessary signal to noise ratio (SNR) on receiver input for given bit error rate (BER).

BER from SNR relationship can be determined for different link channel types such as additive white Gaussian noise (AWGN) channel or Rayleigh fading channel. AWGN channel is a simple radio link channel which works for line-of-sight conditions with no obstacles. For urban environment with non-line-of-sight and multipath signal propagation more suitable Rayleigh fading channel model. The official documentation for LoRa modules and ICs gives receiver sensitivity calculated for AWGN channel with no Rayleigh fading loss, so we need to determine this loss.

Analytical equations for BER from SNR relationship for both AWGN and Rayleigh channels given in [3]. Graphical relationship has shown on figure below.

Let the target BER is $10^{-6}$. So for given BER Rayleigh fading loss is approximately 50 dB for all spreading factors (SF). Besides the Rayleigh fading channel there are a lot of empirical radio propagation models for urban environment such as Okumura [4] or Hata model [5]. So these models is needable to be compared. Figure below shows path losses vs range at 868 MHz band for free space with Rayleigh fading loss and Hata model for following conditions:

- base station antenna height $H_{BS} = 5$ m;
- node antenna height $H_{node} = 0.1$ m;
- intense buildings environment.

![LoRa BER performance](image_url)  
**Figure 1.** LoRa BER performance.
As we can see, Rayleigh fading model has greater path loss for small ranges, hence it represents the worst case for link budget calculation.

3. Link budget calculation

Link budget calculation is performed using next equation:

$$P_{RX} (dBm) = P_{TX} (dBm) + G_{TX} - L_{TX} - L_{FS} - L_{m} + G_{RX} - L_{RX}$$

(1)

for following conditions:

- central frequency $f_0 = 868$ MHz;
- transmitter output power $P_{TX} = 14$ dBm;
- transmitter antenna gain $G_{TX} = 3$ dBi;
- transmitter line loss $L_{TX} = 6$ dB;
- Rayleigh fading loss $L_{R} = 50$ dB;
- link budget margin $L_{m} = 10$ dB;
- receiver antenna gain $G_{RX} = 9$ dBi;
- receiver line loss $L_{RX} = 6$ dB;

Free space path loss $L_{FS}$ is determined from range $d$ using method described in section above. From this equation we determine free space path loss $L_{FS}$ and therefore the maximum available range $d$ for given receiver sensitivities $P_{RX_{min}}$ versus various SF. Receiver sensitivities are calculated for following parameters:

- spreading factor SF = 5 to 12;
- bandwidth $BW = 125$ kHz;
- max. bit error rate $BER = 10^{-6}$;
- convolutional coding rate $CR = 4/5$;
- receiver LNA noise figure $NF = 6$ dB;
- temperature $T = 293$ K

Using next equation:

$$P_{RX_{min}} (dBm) = 10 \log kT + 10 \log BW + NF + SNR + 30,$$

(2)

where $k$ – Boltzmann constant.

Minimum SNR values are defined for each SF using AWGN model because Rayleigh fading loss is already included in Link budget equation. SNR values for $BER = 10^{-6}$ and given SF are shown in table.
below. Also table shows baudrates for given SF, bandwidth and coding rate which have been calculated using following equation [6]:

\[ BR = \frac{SF \cdot CR \cdot BW}{2^{SF}}. \]  

(3)

This baudrate includes packet header and other transport layer overheads. Payload data rates is smaller and have been calculated in next sections.

| SF | Chips per symbol | SNR limit, dB | Baudrate, bps |
|----|------------------|---------------|---------------|
| 5  | 32               | –2.5          | 15625         |
| 6  | 64               | –5            | 9375          |
| 7  | 128              | –7.5          | 5469          |
| 8  | 256              | –10           | 3125          |
| 9  | 512              | –12.5         | 1758          |
| 10 | 1024             | –15           | 977           |
| 11 | 2048             | –17.5         | 537           |
| 12 | 4096             | –20           | 293           |

The result relation between range and baudrate calculated from link budget is shown on figure 3 and figure 4. As we can see, for given parameters LoRaWAN link inside 600 m bound can be performed using spreading factors 5 to 11 at variable ranges. Also we can plot base station coverage map shown on figure 2.
4. Synchronization
To implement the S-ALOHA, a Class B LoRaWAN device feature called a beacon will be used. Beacon is a downlink packet sent by all LoRaWAN gateways simultaneously to synchronize Class B devices. Time values of beacon windows:

- Beacon period = 128 seconds;
- Beacon reserved = 2.120 seconds;
- Beacon guard = 3 seconds;
- Beacon window = 122.880 seconds.

The class C devices under development will receive a beacon every 128 seconds, thereby synchronizing the time slots for each SF. The reason for using this approach is the smallest deviation from the LoRaWAN specification, which will allow to use any other LoRaWAN devices (class A, B, C) on this network, as well as reduce server-side development time.

5. Coverage calculation
Using spreading factor coverage areas and appropriate baudrates we can calculate base station link capacity for various nodes area distribution. The calculations are performed for 2, 3, 4 uplink gateways and 1 downlink gateway in area with topology shown in figures 5, 6. Spreading factors are used SF7 through SF12, 8 uplink (slotted telemetry data) and 1 downlink (ACK + synchronization) and 1 join frequency channels (total is 10 channels with 125 kHz BW).

Figure 4. LoRaWAN base station coverage map.

Figure 5. LoRaWAN coverage map (2 uplink + 1 downlink gateways).

Figure 6. LoRaWAN coverage map (3 uplink + 1 downlink gateways).
Calculation of network capacity and each channel utilization is performed for standard compliant packet size – 222 bytes on SF from 5 to 8, 115 bytes on SF equals 9, 51 bytes on SF from 10 to 12.

6. Conclusions
To achieve the project goal, it is better to use at least 2 gateways to provide bigger data rate reserve and also to increase amount of packets that require ACK. It should be noticed, that calculated network coverage for several gateways does not consider spatial division of channels, that is pessimistic case of configuration.

It is extremely complicated to build a channel model for LoRaWAN with ACK since collisions act unpredictably and have snowballing effect because of re-transmissions. But it is possible to check up the data transfer quality and incrementally increase packets with ACK upon the deployed network. 16 frequency channels might be used by the gateway within managing of these channels between nodes that work on 8 frequency channels, by standard.

As it is shown in the research, the LoRa technology is well fit for the project goals. The data collection and management network is able to serve ranging information between tags and UWB base stations, delivering safety and management efficiency on a dedicated industrial area with harsh and lossy environment. So the UWB base stations of the positioning systems could be deployed in a short time within autonomous supply. This combining of UWB and LoRa data transmission technology allows building the integrated ranging and management system of large scale.

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