Link Budget Estimation and Implementation on Power Private Wireless Data Network

Haiyang Wang¹*, Yong Zhang² and Haipeng Sun³

¹,³Shandong Electric Power Engineering Consulting Institute Ltd, Jinan, China
²State Grid Shandong Electric Power Company, Jinan, China

*Corresponding author

Abstract. A link budget estimated scheme on wireless data network is introduced in this paper. The wireless propagation model for 230MHz frequency band and 1800MHz frequency band was analysed. Through Matlab GUI, a visual link budget estimated software was implemented. Results show that the estimation data coincides with the actual measured results. The link budget method and the estimated software could be employed in planning the wide coverage and large connection wireless network and 5G new radio network in the future.

Keywords: Link budget; LTE-230; Propagation model.

1. Introduction

In October 2019, State Grid Corporation of China (SGCC) released a white paper of building ubiquitous power Internet of Things (IoT) [1]. Back to 2018, Ministry of industry and information technology of China had assigned 7MHz wireless frequency bands, from 223MHz to 235MHz, to the SGCC for their private wireless data network. At first, LTE-230 and IoT-230, which introduced carrier aggregation and dynamic spectrum sharing techniques, became the candidate techniques and were experimented in several cities. However, with the development of the 5G new radio (NR) network [2, 3, 4], SGCC realized that 5G NR network could effectively achieve the massive access of ubiquitous power IoT.

No matter what kind of wireless network access technology is adopted in the power IoT, large-scale network construction and network planning are of great significance, while accurate network planning largely depends on the wireless link budget scheme. Since 230MHz frequency band belongs to private wireless data network, research on its channel character is relatively less in China.

Based on literature search and measured data analysis [5, 6], Okumura-Hata channel model was introduced for the link budget of 230MHz frequency band in this paper. According to the wireless link budget scheme, a general software for wireless link budget is developed. By changing the propagation model and some simulating interpreting data in the software algorithm, the preliminary wireless link budget could be implemented for different transmission technologies and frequency bands, such as LTE-230M, IoT-230M, LTE 1.8GHz and 5G NR 2.6GHz.

2. Link Budget Scheme

Link budget refers to the estimation of the maximum allowable path loss (MAPL) in space propagation based on different application scenarios and various parameters between the transmitter and receiver, on the premise of meeting the quality of service requirements - cell coverage requirements. Furthermore, under the appropriate propagation model, the cell radius and coverage of a single base station could be estimated. In wireless data networks, link budget is divided into uplink budget and downlink budget, while the principle of which is basically identical.
2.1. Cell Coverage Requirements
Instead of the continual frequency band, the power private wireless frequency band, by which the National Radio Commission of China assigned, is discrete. The bandwidth of each spectrum is 25 kHz, which implies that every carrier could only contain one OFDM resource block when LTE or 5G new radio technique is employed [7]. Even if 64QAM modulation signal is adopt, the peak rate could only reach to 35 kbps/25kHz under a 30dBm transmission power. Since the edge of the cell is far away from the base station, due to the influence of path loss and fading, QPSK/BPSK modulation can only be employed, which result in that it is difficult to reach the peak rate at the edge of the cell. Therefore, in the development of this budget plan, in order to ensure the service quality of the edge users, we selected two edge rates: 16kbps/25kHz and 24kbps/25kHz, respectively, which could fulfill the access requirements of "three-remotes" and precise load control under the condition of a single carrier [8].

2.2. Maximum Allowable Path Loss
Parameters, related to the MAPL, are mostly derived from the actual measured data and network operational data.

\[
\text{MAPL} = \text{EIRP} - \text{MPR} + \text{other gain, margin or loss}
\]

Where

\[
\begin{align*}
\text{EIRP} & = \text{maximum transmitting power} + \text{antenna gain of the transmitter} - \text{transmission loss} \\
\text{MPR} & = \text{receiving sensitivity} - \text{receiving gain} + \text{receiving loss}
\end{align*}
\]

Receiving sensitivity represents the minimum receiving signal power required to meet the quality of service requirements without noise and interference. The parameter, closely related to receiving sensitivity, is the signal to interference noise ratio (SINR) at the receiving end. SINR is one of the most important empirical parameters in planning wireless network budget [9]. Its value is crucial on judging whether the receiver could demodulate the signal correctly. The choice of SINR is depended on the uplink and downlink channels, antenna configuration, modulation, coding methods and block error rate (BLER). To demodulate the higher-order modulation signal corresponds to a higher SINR. For example, in the traditional LTE network, when BLER equals 10%, the SINR of demodulating 64QAM signal should be at least 10dB, while the SINR of demodulating QPSK signal only needs to be -6dB.

Receiving loss includes feeder loss and human body loss (uplink).

\[
\begin{align*}
\text{MPR} & = \text{receiving sensitivity} - \text{receiving gain} + \text{receiving loss} \\
\text{Other gain, margin or loss} & = \text{switching gain} + \text{MIMO gain} + \text{frequency selective gain} - \text{penetration loss} - \text{slow fading margin} - \text{fast fading margin}
\end{align*}
\]

2.3. Propagation Model
Okumura-Hata model, COST231-Hata model [10], CCIR model and Young model [11] are commonly used in outdoor wireless propagation model (1km < coverage < 20km), and the applicable scope of these models is shown in Table 1.
Table 1. Outdoor wireless propagation models (Base station (BS), Mobile station (MS)).

| model       | Frequency band (f_c MHz) | Antenna height(m) | Applicable environment          |
|-------------|--------------------------|-------------------|---------------------------------|
| Okumura-Hata | 150-1500                 | BS 30-200, MS 1-10 | urban, suburban, rural area     |
| COST-231 Hata| 1500-2000                | BS 30-200, MS 1-10 | urban, suburban, rural area     |
| CCIR        | 1500-2000                | BS 30-200, MS 1-10 | urban, suburban                 |
| Young       | 150-3700                 | BS 30-200, MS 1-10 | urban                           |

Analysing the applicable frequency band and environment of these model, Okumura-Hata model is recommended for the link budget estimation of 230MHz frequency band for power private wireless data network; Cost231-Hata model is recommended for 1800MHz frequency band; and Young model is recommended for 2600MHz or 3500MHz frequency band, i.e. 5G NR frequency band.

2.4. Estimation of Cell Radius and Coverage

2.4.1. Okumura-Hata model - 230MHz band. The Okumura-Hata model has three application scenarios: urban, suburban and rural area. The path loss formula is shown in equation (5)

$$L_{\text{path}} (dB) = 69.55 + 26.16 \log f_c - 13.82 \log h_{TX} - \alpha(h_{RX}) + (44.9 - 6.55 \log(h_{RX})) \log(D) + C_{EN}$$ (5)

Where $f_c$ (MHz) is the carrier frequency, ranging from 150MHz to 1500MHz; $h_{TX}$ is effective height of transmitting antenna; $h_{RX}$ is effective height of receiving antenna; $D$ is linear distance between base station antenna and mobile antenna (cell radius); $\alpha(h_{RX})$ is correlation factor of mobile antenna whose value is shown in equation (6).

$$\alpha(h_{RX}) = \begin{cases} 
(1.11 \log f_c - 0.7)h_{RX} - (1.56 \log f_c - 0.8) & \text{medium and small cities} \\
8.29(\log 1.54 h_{RX})^2 - 1.1 & \text{urban, suburban and rural area } f_c \leq 200 MHz \\
3.2(\log 11.75 h_{RX})^2 - 4.97 & \text{urban, suburban and rural area } f_c > 200 MHz
\end{cases}$$ (6)

$C_{EN}$ is used to distinguish different application scenarios, and the value is shown in equation (7).

$$C_{EN} = \begin{cases} 
0 & \text{urban} \\
-4.78(\log f_c)^2 + 18.33\log f_c - 40.98 & \text{suburban} \\
-2[\log(f_c / 28)] & \text{rural area}
\end{cases}$$ (7)

Therefore, when the max path loss $L_{\text{path}}$ is known, the formula of cell radius $r$ is shown in equation (8).

$$r = 10^\mu, \mu = \frac{L_{\text{path}} - 69.55 - 26.16 \log f_c + 13.82 h_{RX} + \alpha(h_{RX}) - C_{EN}}{44.9 - 6.55 \log(h_{RX})}$$ (8)

It should be noted that, in fact, the cell radius is shown in figure 1. However, considering that the antenna height of base station is generally much higher than that of mobile station, there is very little difference between $r$ and $D$ (for example $h_{TX} = 30m$, $h_{RX} = 1.5m$, $D = 1.5km \Rightarrow r = 999.59m$).
2.4.2. Cost231 Hata model - 1800MHz frequency band. The formula of path loss is shown in equation (9)

\[ L_{\text{path}}(dB) = 46.3 + 33.9\log f_c - 13.82\log h_{TX} - \alpha(h_{RX}) + (44.9 - 6.55\log(h_{TX}))\log(D) + C_{EN} \]

Where

\[ C_{EN} = \begin{cases} 0dB & \text{suburban and rural area} \\ 3dB & \text{urban} \end{cases} \]

Thus, the cell radius could be written as

\[ r = 10^\mu, \mu = \frac{L_{\text{path}} - 46.3 - 33.9\log f_c + 13.82h_{TX} + \alpha(h_{RX}) - C_{EN}}{44.9 - 6.55\log(h_{TX})} \]

3. Link Budget Software

With reference to Okumura-Hata and Cost231 Hata models, the private wireless data network link budget software is compiled based on the Matlab graphical user interface (GUI). The input data can be read in through an Excel table. According to different parameters, the path loss for the frequency band of 230MHz and 1800MHz in different scenarios such as dense urban, suburban and rural area was calculated firstly. Then the coverage radius and area of the cell were deduced. At last, the curves of frequency, coverage radius and maximum loss were drawn.

In the link budget process, there are two kinds of input parameters.

1) Variable parameters, such as transmit power, number of transmit antennas, antenna gain, body loss, SINR, etc.
2) Parameters of different scenarios, such as standard deviation of shadow fading, penetration loss, effective height of base station antenna, effective height of mobile station antenna, etc.

All of these parameters should be written into the table shown in Table 2.

According to Table 2, we calculated the link budget of 230MHz frequency band, and the results are shown in Table 3. Generally, the cell radius of uplink and downlink is not the same and the smaller is taken as the cell radius. As shown in Table 3, in 230MHz frequency band and general urban environment, when the cell edge rate reaches 16kbps, the cell radius is about 2.158km for single antenna and 2.626km for dual antennas respectively. While the cell edge rate approaches 24kbps, cell radius reduces to 1.894km for single antenna and 2.304 km for dual antennas, which is consistent with the measured data in reference [12] [13]. Under the same conditions (channel bandwidth of 25kHz, edge rate of 16kbps and 24kbps, respectively), we further calculated the cell radius of 1800MHz, as shown in Table 4 which is consistent with the LTE1800MHz link budget of telecom operators.
| parameter                          | TDD230 uplink 16kbps | TDD230 downlink 16kbps | TDD230 uplink 24kbps | TDD230 downlink 24kbps |
|-----------------------------------|----------------------|------------------------|----------------------|------------------------|
| Transmitting antennas             | 1                    | 1 or 2                 | 1                    | 1 or 2                 |
| Transmitting power [dBm]          | 30.0                 | 43.0                   | 30.0                 | 43.0                   |
| Antenna gain [dBi]                | 0                    | 8.5                    | 0                    | 8.5                    |
| Feeder loss [dB]                  | 0                    | 0.5                    | 0                    | 0.5                    |
| Thermal noise density [dBm/Hz]    | -174.00              | -174.00                | -174.00              | -174.00                |
| Resource blocks                   | 1.00                 | 1.00                   | 1.00                 | 2.00                   |
| Bandwidth [kHz]                   | 25                   | 25                     | 25                   | 25                     |
| MCS Index                         | 0                    | 0                      | 2                    | 2                      |
| Receive Diversity                 | 1 or 2 receive diversity | 1 or 2 Antenna dual current | 1 or 2 receive diversity | 1 or 2 Antenna dual current |
| HARQ                              | 10% BLER             | 10% BLER               | 10% BLER             | 10% BLER               |
| SINR [dB]                         | -5.00                | -5.00                  | -3.00                | -3.00                  |
| load [%]                          | 50%                  | 50%                    | 50%                  | 50%                    |
| Interference Margin [dB]          | 2.0                  | 3.0                    | 2.0                  | 3.0                    |
| Antenna gain [dBi]                | 8.5                  | 0                      | 8.5                  | 0                      |
| Feeder loss [dB]                  | 0.5                  | 0                      | 0.5                  | 0                      |
| Switch Gain [dB]                  | 2.0                  | 2.0                    | 2.0                  | 2.0                    |
| Standard deviation of shadow fading [dB] | 3.3                | 3.3                    | 3.3                  | 3.3                    |
| Slow fading [dB]                  | 2.2                  | 2.2                    | 2.2                  | 2.2                    |
| penetration loss [dB]             | 8.0                  | 8.0                    | 8.0                  | 8.0                    |
| Frequency selective gain [dB]     | 1.8                  | 1.8                    | 1.8                  | 1.8                    |
The GUI interface of the software is shown in figure 2.

![Figure 2. Link budget program interface.](image)

### Table 3. Cell radius of 230MHz band in different scenarios.

| parameter       | 16kbps | 24kbps |
|-----------------|--------|--------|
| dense urban     |        |        |
| Single antenna  | 1.762  | 1.546  |
| dual antennas   | 2.144  | 1.881  |
| urban           |        |        |
| Single antenna  | 2.158  | 1.894  |
| dual antennas   | 2.626  | 2.304  |
| suburban        |        |        |
| Single antenna  | 3.682  | 4.603  |
| dual antennas   | 6.409  | 5.614  |
| rural areas     |        |        |
| Single antenna  | 10.576 | 19.53  |
| dual antennas   | 27.291 | 23.872 |
Table 4. Cell radius of 1800MHz band in different scenarios.

| Scenario          | Parameter       | 16kbps | 24kbps |
|-------------------|-----------------|--------|--------|
| dense urban       | single antenna  | 0.829  | 0.765  |
|                   | dual antennas   | 1.061  | 0.931  |
| urban             | single antenna  | 1.301  | 1.142  |
|                   | dual antennas   | 1.583  | 1.389  |
| suburban          | single antenna  | 1.833  | 1.605  |
|                   | dual antennas   | 2.236  | 1.959  |
| rural areas       | single antenna  | 2.614  | 2.286  |
|                   | dual antennas   | 3.195  | 2.795  |

4. Conclusion
This paper discusses the link budget scheme of power private wireless data network, and implements the estimation of the coverage radius and area of a single cell by Malab programming. The estimated results are consistent with the existing measured results. Additionally, the software interface is intuitive and interactive. By changing the channel model and the corresponding input parameters, such as receiving sensitivity, penetration loss, transmission power, the link budget of different technologies and frequency bands could be realized. The budget results have important reference value on network planning. Limited by a single frequency bandwidth of only 25 kHz, the peak rate of a single carrier could only reach about 35kbps. In order to improve the data rate of a single cell, multiple frequency bands should be configured for a cell to meet the requirements of high transmission rate [14]. Since most frequency bands of the power private wireless data network are distributed discretely, the carrier aggregation technology [15] is needed for the configuration of single cell.

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