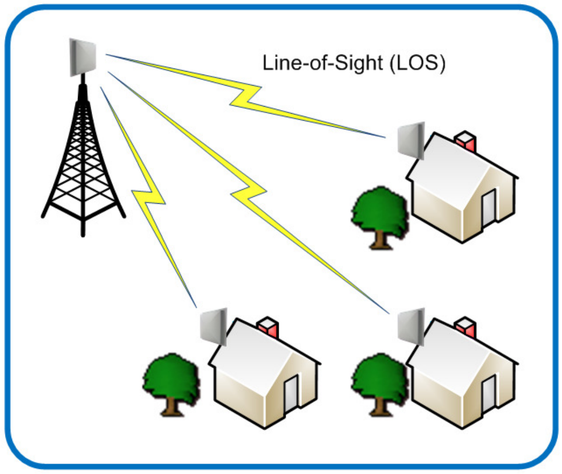
Wireless Link Budget Analysis

How to Calculate Link Budget for Your Wireless Network

Whitepaper

Radio Systems

How far can it go and what will the throughput be? These are the two common questions that come up when designing a high speed wireless data link. There are several factors that may impact the performance of a radio system. Available and permitted output power, available bandwidth, receiver sensitivity, antenna gains, radio technology, and environmental conditions are some of the major factors that may impact system performance. For large scale network deployments, a detailed site survey and network design are highly recommended. This paper will attempt to provide the reader with an overview on how a link budget is calculated.



Line-of-Sight (LOS) Link Budget

To limit the scope of this paper, only line-of-sight links with sufficient Fresnel Zone clearance will be considered. The following equation shows the basic elements that need to considered when calculating a link budget:

Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) − Losses (dB)

If the estimated received power is sufficiently large (typically relative to the receiver sensitivity), the **link budget** is said to be sufficient for sending data under perfect conditions. The amount by which the received power exceeds receiver sensitivity is called the **link margin**.

Free-Space Path Loss

In a line-of-sight radio system, losses are mainly due to free-space path loss (**FSPL**). FSPL is proportional to the square of the distance between the transmitter and receiver as well as the square of the frequency of the radio signal. In other words, free-space path loss increases significantly over distance and frequency.

$$FSPL(dB) = 10\log_{10}\left(\frac{4\pi d f}{c}\right)^2$$

Other losses in a radio system to consider are due to antenna cabling and connectors, which are already accounted for in Tranzeo's all-in-one units with integrated antennas. However, for units with external antenna, 0.25dB loss per connector and 0.25dB loss for every 3-ft of antenna cable should be included in the link budget calculations. For a radio system with a 3-ft LMR400 cable and 2 connectors, 0.75dB loss should be included .

	FSPL (dB)		
Distance	**900MHz**	**2.4GHz**	**5.8GHz**
1km	91.53	100.05	107.72
2km	97.56	106.07	113.74
3km	101.08	109.60	117.26
4km	103.58	112.10	119.76
5km	105.51	114.03	121.70
10km	111.53	120.05	127.72
20km	117.56	126.07	133.74
30km	121.08	129.60	137.26
40km	123.58	132.10	139.76
50km	125.51	134.03	141.70

Table 1: Free-Space Path Loss (FSPL)

The FSPL equation can be further simplified as follow:

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right)$$
$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) - 147.55$$

where:
f is signal frequency in **Hz**
d is distance in meters (**m**)
c is the speed of light in a vacuum (**3 x 10^8 m/s**)

Normally, distance is measured in **km** or **miles** and frequency in **MHz**, in this case the above equation becomes:

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) + 32.45$$

where **d** is in **km** and **f** in **MHz**

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) + 36.58$$

where **d** is in **miles** and **f** in **MHz**

Table 1 shows some calculated FSPL values for 900MHz, 2.4GHz, and 5.8GHz links.

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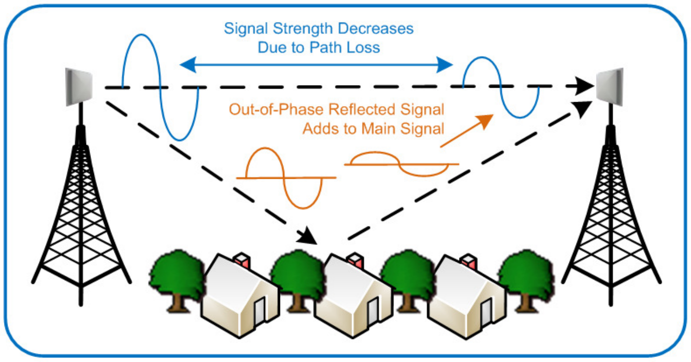
Multipath and Fade Margin

Multipath occurs when waves travel along different paths and cause unwanted interference with the waves travelling on the direct line-of-sight path. This is normally referred to as fading. A rare worst case occurs when waves travelling along different paths end up completely out of phase and cancel each other. One way to overcome this problem is to transmit more power, or have enough link margin. In some cases, relocating or repositioning the antennas slightly may reduce the impact of multipath.

$$Link\ Margin = Received\ Power\ -Receive\ Sensitivity$$

Fading due to multipath can result in a signal reduction of more than 30dB, and it's highly recommended that adequate link margin is factored into the link budget to overcome this loss when designing a wireless system.



The amount of extra RF power radiated to overcome this phenomenon is also referred to as fade margin. The exact amount of fade margin required depends on the desired reliability of the link, but a good rule-of-thumb is to maintain 20dB to 30dB of fade margin at all times.

Table 3 shows the Rayleigh Fading Model, which highlights the relationship between the amount of available link margin and link availability as a percentage of time.

Time Availability (%)	Fade Margin (dB)
90	8
99	18
99.9	28
99.99	38
99.999	48

Table 3: Rayleigh Fading Model

Modulation & Encoding Scheme	Data Rate (Mbps)	SNR (dB)
BPSK 1/2	6	8
BPSK 3/4	9	9
QPSK 1/2	12	11
QPSK 3/4	18	13
16-QAM 1/2	24	16
16-QAM 3/4	36	20
64-QAM 2/3	48	24
64-QAM 3/4	54	25

Table 2: Data Rates vs. Minimum SNR

Signal-to-Noise (SNR)

Modulation techniques not only determine system bandwidth and channel capacity, they also determine system reliability. It's always a trade-off between data rates and distance. More efficient modulation techniques such as 64-QAM require greater SNR, but less efficient techniques such as BPSK require less SNR, and therefore are more resilient to channel noise.

For the purposes of link budget analysis, the most important aspect of a given modulation technique is the Signal-to-Noise Ratio (SNR) necessary for the receiver to achieve a specified level of reliability in terms of Bit Error Rate (BER).

$$SNR = Received\ Power\ -Channel\ Noise$$

Table 2 shows the minimum SNR required for the different modulation and encoding schemes. Site surveys should be conducted in all deployment locations to ensure that sufficient SNR can be achieved to meet the desired data rates.

Why Tranzeo

Tranzeo offers a complete family of 802.16d (802.16-2004) WiMAX products for 3.5GHz, 3.65GHz, and 5.8GHz spectrums including indoor and outdoor Subscriber Units and Pico Base Stations. As well, we offer a comprehensive line of 900MHz, 2.4GHz, 4.9GHz, and 5.8GHz 802.11a/b/g and 802.11n standards-based WiFi products including Routing Access Points, CPE's, Full-Duplex PtP Bridges, and advanced Mesh Routers and Access Points for complete turnkey solutions.

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Design Example

We'll use the TR-5plus-24 radio system as an example to illustrate how a link budget is calculated using the information presented in this paper.

Example:
Distance: **5 km**
Frequency: **5.8GHz**
Link Type: **Point-to-Point (PxP)**
Line-of-Sight: **Yes**
Radio Systems: **2 x TR-5plus-24**

Link Budget Analysis:
First, we need to calculate the received power. In order to do that, we need to know the transmitter power and antenna gains of the radio systems that we're using, which is normally documented in the datasheet of the radios and antennas.

Since we're using 2 x TR-5plus-24, then the link budget in both directions is expected to be symmetric. This is true because the transmit power of both radios is expected to be the same. In cases where 2 types of radio systems with different transmit power levels are used, then 2 link budgets, one for each direction, will need to be analyzed.

Consulting the TR-5plus-24 datasheet, the Tx power is +**23dBm**, and the internal antenna gain is **24dBi**. Since this product features an integrated antenna, we can assume negligible loss for cabling and connectors.

Since this is a point-to-point link with sufficient Fresnel Zone clearance, then the only losses that we need to consider when calculating the received power is the free-space-path loss (FSPL). The FSPL at 5 km is 121.70dB for 5.8GHz as per **Table 1**. The received power can then be calculated as follow:

Received Power (dBm)	= Tx Power (dBm)		+ Tx Antenna Gain (dBi)		+ Rx Antenna Gain (dBi)		–	FSPL (dB)
	=	23	+	24	+	24	–	121.70
	=	-50.70						

The required SNR to achieve 54MBps data rate is 25dB, as per **Table 3**. Now that we know what the received power and the minimum SNR, we could determine what the maximum channel noise is:

Maximum Channel Noise (dBm)	=	Received Power (dBm)	–	SNR (dB)
	=	-50.70	–	25
	=	-75.70		

Next, we need to ensure that we have enough link margin for a reliable link. The receive sensitivity of the TR-5plus-24 is -72dBm at 54Mbps, which means that we have more than 20dB of link margin:

Link Margin (dB)	=	Received Power (dBm)	-	Receive Sensitivity (dBm)
	=	-50.70	-	(-72)
	=	21.30		

At 5km, the link margin seems to be sufficient to provide 54Mbps data rate and ensure better than 99% link availability based on Rayleigh's Fading Model shown in **Table 3**.

Link Distance vs. Data Rates:

The receive sensitivity of the radio is different for the different modulation and coding rates. **Table 4** below shows what the receive sensitivity is for the TR-5plus-24 radio, and the estimated maximum distance. These calculations assume 20dB link margin, and that sufficient SNR is available for the different modulation schemes, as per Table 2.

The maximum TCP and UDP throughputs of the TR-5plus-24 were tested using 20MHz, and found to be around 22Mbps and 28Mbps, respectively.

	Data Rates							
	6 Mbps	9 Mbps	12 Mbps	18 Mbps	24 Mbps	36 Mbps	48 Mbps	54 Mbps
Receiver Sensitivity (dBm)	-90	-88	-86	-84	-82	-78	-75	-72
Minimum Received Power (dBm)	-70	-68	-66	-64	-62	-58	-55	-52
Maximum FSPL (dB)	141	139	137	135	133	129	126	123
Estimated Maximum Distance (km)	**46.14**	**36.65**	**29.11**	**23.12**	**18.37**	**11.59**	**8.20**	**5.81**

Table 4: TR-5plus-24 Data Rates vs. Link Distance

Online Resources

Tranzeo Wireless Technologies Inc. - Wireless Network Link Analysis
http://www.tranzeo.com/cgi-bin/wireless.main.cgi/

Tranzeo Wireless Technologies Inc. – Excel Link Budget Calculator
http://support.tranzeo.com/doc/Tranzeo%20WiFi%20Quick%20Calc%20Worksheet.xls

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