Go the Distance

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How Far and How Fast

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The first question asked by the novice to microwave networking is always: "How fast does it go?" followed immediately by "What distance does it cover?" The answers are not always simple, because you can gain extra distance by giving up speed, and vice versa. In addition, the performance of the system depends heavily on the choice of antennas. Finally, the local environment (topography, vegetation, weather) will influence your network performance.

This article is an attempt to explain the relationships between these parameters, in order to enable you to properly compare different equipment.

How Far?

The quality of a radio-frequency communication link is a function of five parameters:

- The receiver sensitivity (what is the minimum amount of signal voltage that must reach the receiver in order to decode the transmission)
- The background noise level in the band (what is the minimum signal-to-noise ratio that will allow the receiver to extract a usable signal amidst the competing signals within the frequency band occupied by the desired signal).
- The transmitted signal power level (how many milliwatts did the transmitter deliver to its antenna)
- How the transmitting and receiving antenna systems shape the signal in 3-dimensional space
- The dissipation of the signal as it travels through the atmosphere (or open space) from the transmitter to the receiver

Traditionally, all of these factors are expressed in decibels, allowing for simple, practical calculations of performance. Decibels (abbreviated **dB**) are a logarithmic scale, expressing relative signal strengths. 10 dB (or 1 Bel) is a relative factor of 10 and 3 dB is a relative factor of 2.

Power and Sensitivity

Transmit power and receiver sensitivity are expressed relative to a reference level of 1 milli-Watt (mW) and abbreviated **dBm**. In the unlicensed ISM bands, the maximum power we are allowed to feed the antenna in the USA is 1 W or 30 dBm. In Europe, it is 250 mW or 24 dBm. The sensitivity of a good ISM band receiver ranges from -75 dBm to -90 dBm. (-90 dBm means the receiver can decode a signal at 1 nanoWatt !)

Transmit power is limited by the regulatory authority. Under the US rules (FCC) you can feed up to 27 dBm of power into a 9 dBi omnidirectional antenna (4 W EIRP or 36 dBm), or 24 dBm of power into a 24 dBi directional antenna for point-to-point links (48 dBm or 16W EIRP). Under the European rules (ETSI) the maximum effective radiated power (transmit power plus antenna gain) is 100 mW EIRP (20 dBm).

Receiver sensitivity is generally measured by reducing the input power until the error level exceeds a defined threshold. It is common to indicate the sensitivity as the level when the error rate has increased to 10E-6 (one bit error per 1 million bits of data). With a lower data rate, the connection will be more robust. Typically, the sensitivity decreases by 3dB when the data rate is doubled.

Antenna Systems

The ability of the antenna to shape the signal and focus it in a particular direction is called "antenna gain" and is expressed in terms of how much stronger the signal in the desired direction is, compared to an "isotropic radiator" which is an hypotetical antenna that distributes the signal evenly in all directions. To express the relationship to the isotropic reference, this is abbreviated **dBi**. The typical omni-directional "stick" antenna is rated at 6-8 dBi, indicating that by redirecting the signal that would have gone straight up or down to the horizontal level, 4 times as much signal is available horizontally. A parabolic reflector design can easily achieve 24 dBi.

For more information, read our Antenna Selection Guide.

Under the antenna system, we also need to account for losses in the cables between the radio and the antenna. Count on 0.25 dB of loss for each connector and the following losses per 100 feet of feed cable (the figure in parenthesis is how many feet of cable it takes to lose 10 dB):

Cable Type	325MHz	900 MHz	2.4GHz
RG-58/U	8.2dB (122 ft)	20dB (n/a)	n/a (n/a)
LMR-195	6 dB (160 ft)	11.1dB (75 ft)	19dB (n/a)
Belden 9913	2.3dB (434 ft)	4.2dB (238 ft)	8.0dB (125 ft)
LMR-400	2.2dB (450 ft)	3.9dB (250 ft)	6.8dB (147 ft)

Free-Space Loss

As the radio signal travels through space, it deteriorates for two reasons:

- The signal spreads out in space, proportional to the square of the distance.
- Some of the signal is absorbed by the atmosphere (especially on a rainy day; the microwaves will heat up the raindrops, and that energy comes right out of your signal!) The higher the frequency, the greater the attenuation.

The free space loss can be calculated according to the formula

$$-L = C + 20 * \log(D) + 20 * \log(F)$$

where D is the distance, and F is the frequency in MHz. The constant C is 36.6 if D is measured in miles, and 32.5 if D is in kilometers. The following are some examples of free space losses:

Distance		Loss at F=		
in miles	in km	900 MHz	2.4GHz	5.8GHz
1.6 mi	2.5 km	99 dB	108 dB	116 dB
3.1 mi	5 km	106 dB	114 dB	122 dB
5 mi	8 km	110 dB	118 dB	126 dB
6.2 mi	10 km	112 dB	120 dB	128 dB
10 mi	16 km	116 dB	124 dB	132 dB

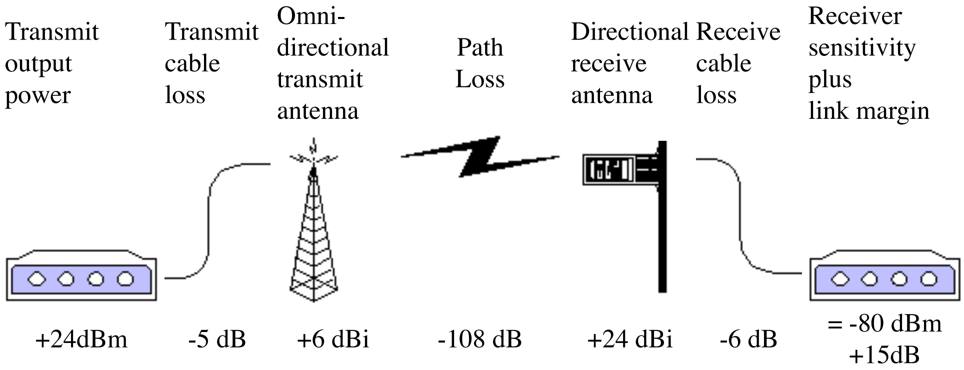
These figures do not take into account deterioration due to weather. Typically, we recommend allowing 15 dB of "fade margin" to accommodate for weather, antenna alignment, and other miscellaneous losses.

Putting it Together

Assume that you have a 2.4GHz multipoint radio system consisting of

- a transmitter at 24 dBm (250 mW)
- with a 6 dBi omni antenna,
- 5 dB of cabling loss on the antenna tower (2 connectors and 75 feet of LMR-400)
- sending to a receiver with a 24 dBi directional antenna
- 6 dB of cabling loss (2 connector and 30 feet of LMR-195) and
- a receiver sensitivity of -80 dBm.

The maximum allowable loss would be 123 dB. If we want a 15 dB link margin to protect against weather, then we are at 108 dB allowance for distance, which would be 1.6 miles.



If the radio system allows you to improve the sensitivity by dropping the link speed, you can typically gain 3dB of sensitivity by dropping to half speed. This would allow you to increase the distance to 2.3 miles.

If this system is used in point-to-point mode, the 6 dB omni antenna can be replaced with a 24dBi directional antenna, which would allow you to run 12.4 miles at full speed.

If your radio had a sensitivity of -90 dB instead of -80 dB, your multipoint system can serve an area out to 5 miles instead of 1.6 miles at full speed.

The RF Link Budget Calculator which is very helpful in making these calculations.

Evaluating AFAR Radios

The above discussion is strictly factual and generic, and should be of interest for anyone contemplating installation of a wireless system. In the following, we apply these principles to a specific radio, namely the PulsAR-24027 Wireless Ethernet Bridge from AFAR Communications.

At its full link speed of 2.75Mbps, the receiver sensitivity is -90 dBm. In a typical point-to-point configuration, with 24dBi antennas, the link budget looks like this:

Item	FCC Rules	ETSI Rules
Transmit Power	23 dBm	0 dBm
Transmit Antenna Gain	24 dBi	21 dBi

Cable and Connector Losses (Rx+Tx)	-2 dB	-2 dB
Receive Antenna Gain	24 dBi	21 dBi
Receiver Sensitivity	-90 dBm	-90 dBm
Fade Margin Allowance	15 dBm	10 dBm
Allowable Free Space Loss	144 dB	120 dB
Achievable Distance	153 km (95 miles)	9.7 km (6.0 miles)

As you can see, the European rules are much less favorable for outdoor deployment of unlicensed wireless equipment. The reports one reads on the Internet about very successful installations would lead a knowledgeable observer to conclude that many people are cheating on the power limits and getting away with it. Still, the numbers are not as bad as you would have expected from comparing the EIRP limit (16 W versus 100 mW) because you can back off a bit on the fade margin with the shorter distances: The amount of rain drops in the path will be less.

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