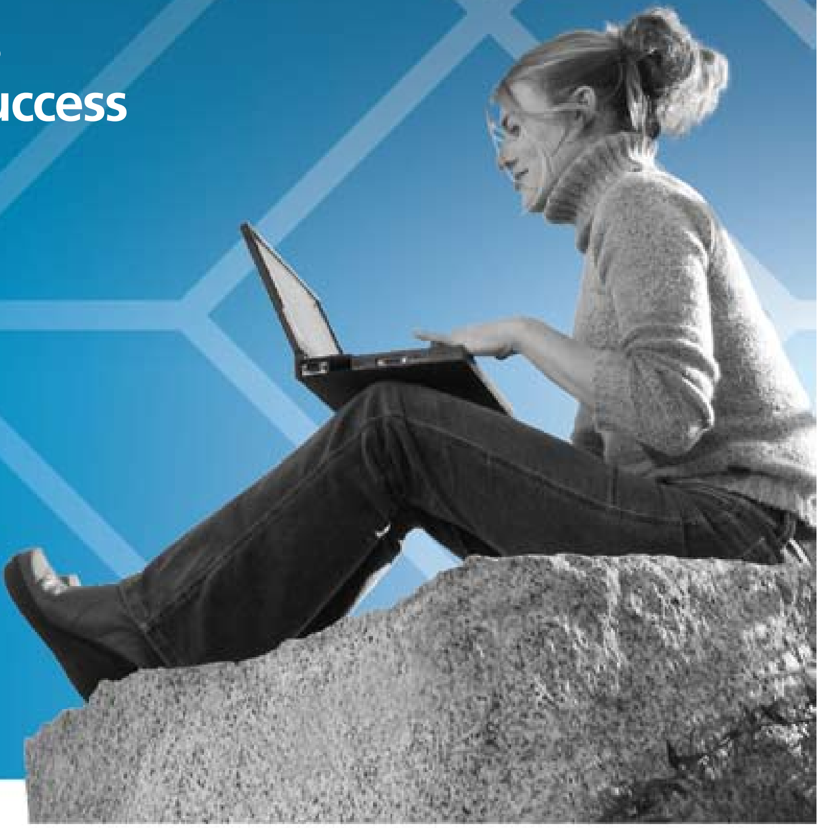
BLACK BOX
NETWORK SERVICES

The Ten Commandments of Wireless Communications

Take These Ten Steps to Ensure Wireless Success



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You’ll be live with one of our technical experts in less than 20 seconds.

1. Thou shalt know thy dBm and recall thy high-school logarithms.

The power of a wireless signal is measured in dBm—decibels referenced to a value of 1 milliwatt of power. It's worth knowing how to calculate dBm from milliwatts (mW) and how dBm relates to radio power. Radio Frequency (RF) power is measured in mW or, more usefully, in a logarithmic scale of decibels (dB), or decibels referenced to 1 mW of power (dBm). Because RF power attenuates as a logarithmic function, dBm is measured on a logarithmic scale. Roughly speaking, every 3 dBm is a doubling/halving of power, and every 10 dBm is an order of magnitude difference: 2 mW in power yields 3 dBm of signal, 10 mW of power yields 10 dBm of signal, and 100 mW of power yields 20 dBm of signal.

1 mW	=	0 dBm
2 mW	=	3 dBm
4 mW	=	6 dBm
10 mW	=	10 dBm
100 mW	=	20 dBm
1 W	=	30 dBm

You can use any scientific calculator to calculate the relationship between mW and dBm:

dBm = 10 * log(mW)

mW = 10 ^ (dBm/10)

A related measure you'll encounter is dBi (decibels relative to an isotropic radiator). This is a measure of the gain of a wireless antenna and is also measured in a logarithmic scale, so every three dBi doubles the power of a wireless signal.

2. Covet not high frequencies, as the lower the frequency, the more forgiving the laws of physics and propagation.

Wireless applications typically operate in "license free" frequency bands, also referred to as ISM (Industrial, Scientific, and Medical). The frequencies and power of these bands varies from country to country. The most common frequencies are:

- 2.4 GHz band: nearly worldwide
- 915 MHz band: North America, South America, and some other countries
- 868 MHz band: Europe

As frequency rises, available bandwidth typically rises, but distance and ability to overcome obstacles is reduced. For any given distance, a 2.4-GHz installation has roughly 8.5 dB of additional path loss when compared to 900 MHz. However, lower frequencies require larger antennas to achieve the same gain.

3. Honor thy receive sensitivity, as long-range performance is not a function of transmit power alone.

The more sensitive the radio, the lower the power signal it can successfully receive, stretching right down to the noise floor. There is so much variety in "specsmanship" for radio sensitivity, that it is difficult to make a meaningful comparison between products. The most meaningful specification is expressed at a particular bit error rate and will be given for an ideal environment shielded from external noise. Unless you're in a high RF noise environment (typically resulting from numerous similar-frequency radio transmitters located nearby), the odds are good that the noise floor will be well below the receive sensitivity, so the manufacturer's rated receive sensitivity will be a key factor in your wireless system and range estimates.

You can often improve your receive sensitivity, and therefore your range, by reducing data rates over the air. Receive sensitivity is a function of the transmission baud rate so, as baud rate goes down, the receive sensitivity goes up. Many radios give the user the ability to reduce the baud rate to maximize range.

The receive sensitivity of a radio also improves at lower frequencies, providing another significant range advantage of 900 MHz vs. 2.4 GHz—as much as six to twelve dB!

4. Thou shalt be wary of radio noise and recognize situations where radio noise may hamper thine installation.

RF background noise comes from many sources such as solar activity, high-frequency digital products, and radio communications. This kind of background noise establishes a noise floor, which is the point where the desired signals are lost in the background ruckus. The noise floor will vary by frequency.

Typically the noise floor will be lower than the receive sensitivity of your radio, so it will not be a factor in your system design. If, however, you're in an environment where high degrees of RF noise may exist in your frequency band, then use the noise floor figures instead of radio receive sensitivity in your calculations. If you suspect this is the case, a simple site survey to determine the noise floor value can be a high payoff investment.

When in doubt, look about. Antennas are everywhere nowadays—on the sides of buildings, water towers, billboards, chimneys, even disguised as trees. Many sources of interference may not be obvious.

5. Thou shalt always know thy fade margin, lest ye have a wireless link that worketh not in rain, snow, nor the presence of interference.

Fade margin is a term critical to wireless success. Fade margin describes how many dB a received signal may be reduced by without causing system performance to fall below an acceptable value. Walking away from a newly commissioned wireless installation without understanding how much fade margin exists is the number one cause of wireless woes.

Establishing a fade margin of no less than 10 dB in good weather conditions provides a high degree of assurance that the system will continue to operate effectively in a variety of weather, solar, and RF interference conditions.

There are a number of creative ways to estimate the fade margin of a system without investing in specialty gear. Pick one or more of the following and use it to ensure you've got a robust installation:

a. Some radios have programmable output power. Reduce the power until performance degrades, then dial the power back up a minimum of 10 dB. Remember that doubling output power yields 3 dB, and an increase of 10 dB requires a tenfold increase in transmit power.

b. Invest in a small 10 dB attenuator (pick the correct one for your radio frequency). If you lose communications when you install the attenuator in-line with one of your antennas, you don't have enough fade margin.

c. Antenna cable tends to lose signal, more so at higher frequencies. Specifications vary by type and manufacturer, but generally, at 900 MHz, a coil of RG-58 cable in the range of 50 to 100 feet (15 to 30 m) will be 10 dB. At 2.4 GHz, a cable length of 20 to 40 feet (6 to 12 m) will yield 10 dB. If your system still operates reliably with the test length of cable installed, you've got at least 10 dB of fade margin.

6. Thou shalt use thy given powers of mathematics and logic when specifying wireless equipment.

Contrary to popular opinion, no magic is required to make a reasonable prediction of the range of a given radio signal. Several simple concepts must be understood first, and then we can apply some simple rules of thumb.

The equation for successful radio reception is:

TX power + TX antenna gain – Path loss – Cabling loss + RX antenna gain – 10 dB fade margin > RX radio sensitivity or (less commonly) RF noise floor

Note that most of the equation's parameters are easily gleaned from the manufacturer's data. That leaves only path loss and, in cases of heavy RF interference, RF noise floor as the two parameters that you must establish for your particular installation.

In a perfect world, you will measure your path loss and your RF noise conditions. But for the majority of us who don't, there are rules of thumb to follow to help ensure a reliable radio connection.

7. Thou shalt not allow leafy greens nor mounds of earth between thine antennas; and thou shalt elevate thine antennas towards the heavens; and thou shalt never, ever attempt a system at the manufacturer's maximum advertised distance.

In a clear path through the air, radio signals attenuate with the square of distance. Doubling range requires a four-fold increase in power, therefore:

- Halving the distance decreases path loss by 6 dB.
- Doubling the distance increases path loss by 6 dB.

When indoors, paths tend to be more complex, so use a more aggressive rule of thumb, as follows:

- Halving the distance decreases path loss by 9 dB.
- Doubling the distance increases path loss by 9 dB.

Radio manufacturers advertise "line of sight" range figures. Line of sight means that, from antenna A, you can see antenna B. Being able to see the building that antenna B is in doesn't count as line of sight. Decrease the "line of sight" figure specified for each obstacle in the path. The type of obstacle, the location of the obstacle, and the number of obstacles will all play a role in path loss.

To visualize the connection between antennas, picture lines radiating in an elliptical path between the antennas in the shape of a football. Directly in the center of the two antennas, the RF path is wide with many pathways. A single obstacle here will have minimal impact on path loss. As you approach each antenna, the meaningful RF field is concentrated on the antenna itself. Obstructions located close to the antennas cause dramatic path loss.

Be sure you know the distance between antennas. This is often underestimated. If it's a short-range application, pace it off; if it's a long-range application, establish the actual distance with a GPS or Google Maps™.

The most effective way to reduce path loss is to elevate the antennas. At approximately 6 feet high (2 m), line of sight is about 3 miles (5 km) because of the Earth's curvature, so anything taller than a well-manicured lawn becomes an obstacle.

Weather conditions also play a large role. Increased moisture in the air increases path loss. The higher the frequency, the higher the path loss.

Beware of leafy greens. While a few saplings mid-path are tolerable, it's very difficult for RF to penetrate significant woodlands. If you're crossing a wooded area, you must elevate your antennas over the treetops.

Industrial installations often include many reflective obstacles leading to numerous paths between the antennas. The received signal is the vector sum of each of these paths. Depending on the phase of each signal, they can be added or subtracted. In multiple path environments, simply moving the antenna slightly can significantly change the signal strength.

Some obstacles are mobile. More than one wireless application has been stymied by temporary obstacles such as a stack of containers, a parked truck, or material-handling equipment. Remember, metal is not your friend. An antenna will not receive a signal inside a metal box or through a storage tank.

Path loss rules of thumb:

- To ensure basic fade margin in a perfect line-of-sight application, never exceed 50% of the manufacturer's rated line-of-sight distance. This in itself yields a theoretical 6-dB fade margin—still short of the required 10 dB.
- Lower the distance even more if you have obstacles between the two antennas, but not near the antennas.
- Lower the distance to 10% of the manufacturer's line-of-sight ratings if you have multiple obstacles or obstacles located near the antennas, or if the antennas are located indoors.

8. Thou shalt use the correct antenna.

Antennas increase the effective power by focusing the radiated energy in the desired direction. Using the correct antenna not only focuses power into the desired area but it also reduces the amount of power broadcast into areas where it is not needed.

Wireless applications have exploded in popularity with everyone seeking out the highest convenient point to mount their antenna. It's not uncommon to arrive at a job site to find other antennas sprouting from your installation point. Assuming these systems are spread spectrum and potentially in other ISM or licensed frequency bands, you still want to maximize the distance from the antennas as much as possible. Most antennas broadcast in a horizontal pattern, so vertical separation is more meaningful than horizontal separation. Try to separate antennas with like-polarization by a minimum of two wavelengths, which is about 26 inches (0.66 m) at 900 MHz, or 10 inches (0.25 m) at 2.4 GHz.

9. Thou shalt use high-quality cables to prevent cable loss.

Those high frequencies you're piping to your antennas don't propagate particularly well through cable and connectors. Use high-quality RF cable between the antenna connector and your antenna and ensure that all connectors are also high quality and are carefully installed. Factor in a 0.2-dB loss per coaxial connector in addition to the cable attenuation itself. Typical attenuation figures for two popular cable types are listed below.

Loss per 10 feet (3 meters) of cable length

Frequency	RG-58U	LMR-400
900 MHz	1.6 dB	0.4 dB
2.4 GHz	2.8 dB	0.7 dB

Although long cable runs to an antenna create signal loss, the benefit of elevating the antenna another 25 feet (7.6 m) can more than compensate for those lost dB.

10. Thou shalt recognize the issues of latency and packetization before thou issueth purchase orders.

Before you lift a finger towards the perfect wireless installation, think about the impact of wireless communications on your application. Acceptable bit error rates are many orders of magnitude higher than with wired communications. Most radios quietly handle error detection and retries for you—at the expense of throughput and variable latencies.

Software must be well designed and communication protocols must be tolerant of variable latencies. Not every protocol can tolerate simply replacing wires with radios. Protocols sensitive to inter-byte delays may require special attention or specific protocol support from the radio. Do your homework up front to confirm that your software won't choke, that the intended radio is friendly towards your protocol, and that your application software can handle it as well.

About Black Box

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