Create a Long-Distance Wi-Fi Link

chapter 13

in this chapter

☑ Selecting a site

☑ Choosing an antenna

☑ Determining the Fresnel zone

☑ Planning the link

☑ Testing your connection

There will come a time when you are ready to span a great divide using wireless. It's obvious that free space radio signals can travel great distances. Previous chapters spoke at length about high-gain antennas, picking up signals while wardriving, and even broadcasting a signal to the neighbors.

But what about beaming a signal 5, 10, 20 miles, or more? Wireless is a natural replacement for land lines, T1s, DSL, and other high-speed data when needed in a remote location. Or even a location that's not so remote, but where DSL or cable Internet may not be available. Figure 13-1 shows a prime example. A long-distance Wi-Fi link creates a high-bandwidth connection to the mountain operating at the speed of light.

Creating a long-distance link gathers many of the essentials of wireless and adds a healthy dose of physics to overcome the obstacles of a long-distance, free space link.

This chapter is a compilation of practical guidelines designed to enable you to establish a long-distance Wi-Fi link of your own . For your convenience, we've condensed the most essential aspects of strategy, design, and experimental deployment for you here. We'll start with site selection, then take on design considerations including antenna location considerations, and work our way through important hindrances—such as Fresnel zones, path loss, and the Earth's curvature—many of which can be mathematically determined. We'll move on with a discussion on link planning and actual deployment strategies, and conclude the chapter with tips and recommendations for creating a successful link.

A typical long-distance Wi-Fi link will require:

- Two wireless access points or wireless bridges
- Two high-gain, directional antennas
- Two people
- Spotting scope or binoculars (optional)
- Topographic software (optional)
- Handheld radio system/cellular phone
- GPS

FIGURE 13-1: Experimental link to a mountaintop eight miles away.

Selecting a Site

One of the most important fundamental aspects of setting up a long-distance wireless link lies in the matter of site selection. Choosing the proper location of your links can mean the difference between a quick and easy setup and a long day of problems when it finally comes time to establish the link.

The time you spend on initial site selection can be drastically reduced by using topographical mapping software. This easy-to-use software can show the terrain profile of a line drawn between two or more points (see Figure 13-2). From that line, you can quickly gauge whether or not line-of-sight is possible given the terrain.

In the case of large obstructions blocking your path, you'll need to seek an alternative. One alternative is to employ a repeater, as was described in Chapter 9 (see Figure 13-3). Other solutions are to shift the site requirements slightly. You can run Ethernet cabling up to 100 meters from network equipment, and fiber cable can be run for several kilometers. The possibility of stretching the wired portion of the link horizontally or vertically to a suitable transmission point is apparent.

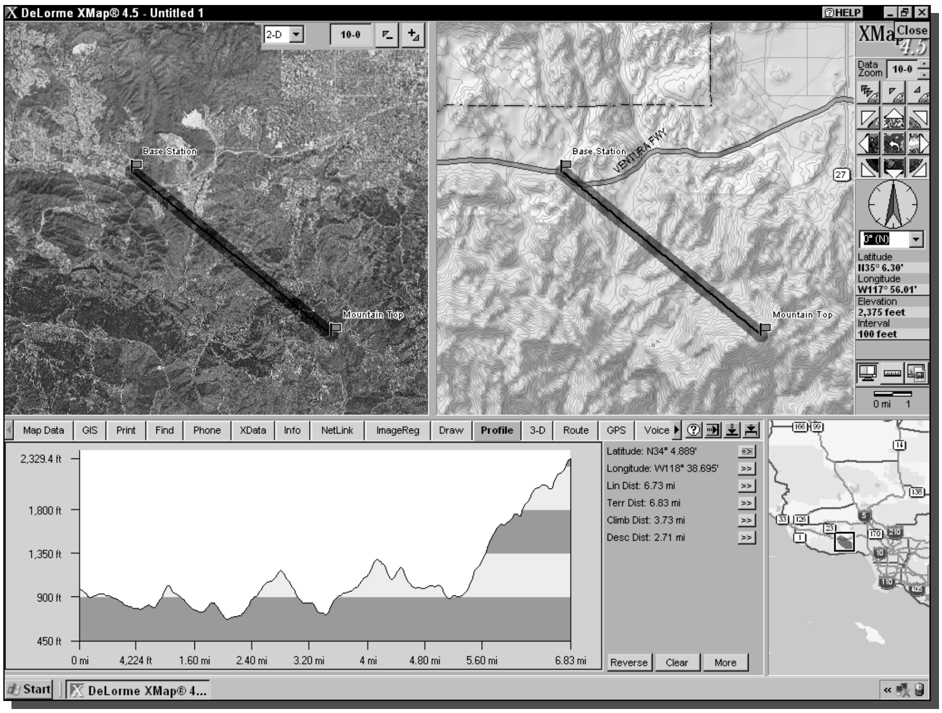

FIGURE 13-2: Forgiving terrain for a mountain-to-valley link.

Software is only the first step. You'll need to make an actual site visit to determine if foliage, buildings, or other obstructions will interfere with the link path. One of the best tools for this is a spotting scope (see Figure 13-4). Binoculars will also help, but the magnification level is not as high as a spotting scope.

Tip

As magnification increases, things like field of view, image brightness, image steadiness, and even sharpness decrease. Also, higher magnifications are much more sensitive to atmospheric turbulence and pollution. Be sure to use the magnification to just cover the distance between your antennas.

Design Considerations

When you set up your long-distance Wi-Fi link, there are several factors to consider, including background research and testing. Through the course of this section, we'll work our way through the most commonly used types of antennas, followed by antenna location, and finally review potential obstacles and impedance problems and how to deal with them accordingly.

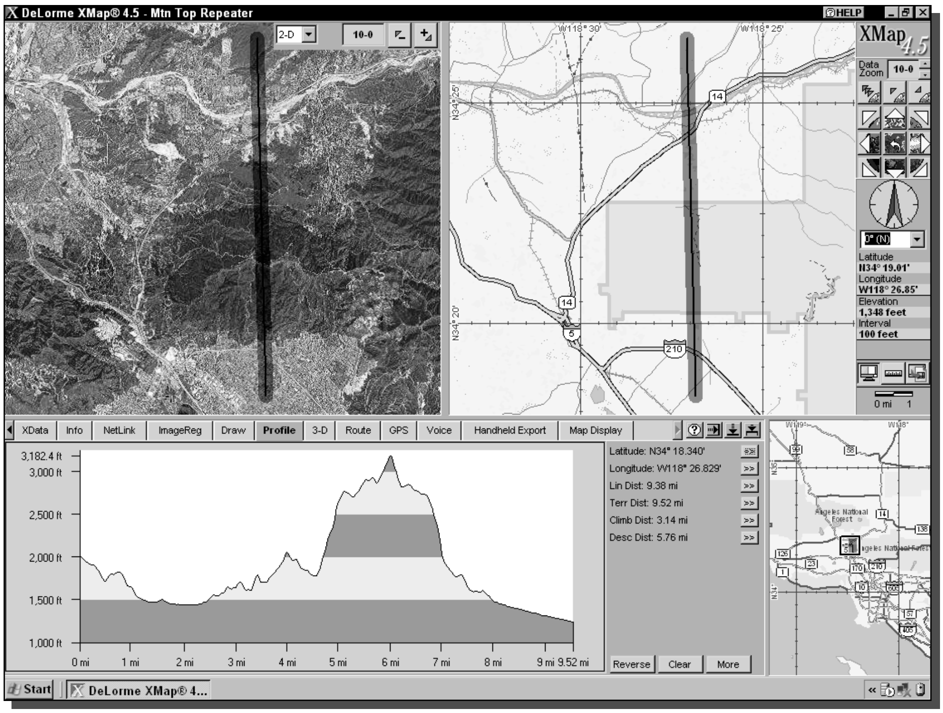

FIGURE 13-3: A mountaintop repeater may be necessary to establish this link.


FIGURE 13-4: Spotting scope used to determine direction and angle.

Antenna Types

There are several types of antennas and characteristics to consider for deployment in a distanced WLAN. This section is a synopsis of the most common types you should be aware of. First, let's review some important general definitions.

- Isotropic antenna. A hypothetical, loss-less antenna that has an equal radiation intensity in all directions. Used as a zero dB gain reference in directivity calculation (gain).
- Antenna gain. Basically a measure of directivity, it is defined as the ratio of the radiation intensity in a given direction that would be obtained if the power accepted by the antenna was radiated equally in all directions. (Antenna gain is expressed in dBi.)
- Radiation pattern. A graphical representation in either polar or rectangular coordinates of the spatial energy distribution of an antenna.
- Side lobes. The radiation lobes in any direction other than the main lobe.
- Omnidirectional antenna. Radiates and receives equally in all directions in azimuth.
- Directional antenna. Radiates and receives most of the signal power in one direction.
- Antenna bandwidth. The directiveness of a directional antenna is defined as the angle between two half-power (−3 dB) points on either side of the main lobe of radiation.

We'll only focus on three types of antennas you could deploy in your outdoor WLAN as a link between two points or point-to-multipoint: the dipole antenna, coaxial antenna, and the dish antenna. Albeit interrelated, each type has its own design strengths.

A *dipole antenna* is a straight electrical conductor measuring half a wavelength from end-to-end and connected at the center to a radio frequency. This antenna, also called a doublet, is one of the simplest types of antennas, and constitutes the main RF radiating and receiving element in various sophisticated types of antennas. The dipole is inherently a balanced antenna, because it is bilaterally symmetrical. For best performance, a dipole antenna should be more than half a wavelength above the ground, the surface of a body of water, or other horizontal, conducting medium such as sheet metal roofing. The element should also be at least several wavelengths away from electrically conducting obstructions such as supporting towers, utility wires, guy wires, and other antennas.

A *coaxial antenna* is a variant of the dipole antenna, designed for use with an unbalanced feed line. One side of the antenna element consists of a hollow conducting tube through which a coaxial cable passes. The shield of the cable is connected to the end of the tube at the center of the radiating element. The center conductor of the cable is connected to the other half of the radiating element. The element can be oriented in any fashion, although it is usually vertical.

A *dish antenna* (also known simply as a dish, see Figure 13-5) is common in microwave systems. This type of antenna consists of an active, or driven, element and a passive parabolic or spherical reflector. The driven element can be a dipole antenna or a horn antenna. The reflector has a diameter of at least several wavelengths. As the wavelength increases (and the frequency decreases), the minimum required dish diameter becomes larger. When the dipole or horn is properly positioned and aimed, incoming electromagnetic fields bounce off the reflector, and

FIGURE 13-5: A parabolic dish antenna.

the energy converges on the driven element. If the horn or dipole is connected to a transmitter, the element emits electromagnetic waves that bounce off the reflector and propagate outward in a narrow beam.

Antenna Location

A long-distance Wi-Fi link is not an easy accomplishment. There are many factors working against successful communications such as distance, open space, interference, obstructions, and inherent equipment limitations. To start building a strategy, you should consider location very carefully. Your radio signal path must have a clear, line-of-sight path—end-to-end—and a clear Fresnel zone (covered in more detail later on). Be sure to use GPS and a spotting scope to visually map and sight your path over long distances. Incidentally, Fresnel zone losses of up to 6 dB can be avoided by ensuring that there are no objects large enough to act as diffracting edges within the first 0.6 Fresnel zone. If a large, rounded object is in your path, losses may exceed 20 dB through several Fresnel zones. This will force you to mount your antennas on towers or buildings at a significant height. Unfortunately, microwave frequencies can also be affected by too much antenna height, and the signal can be degraded due to ground reflections canceling out the signal. Signals will propagate through a few obstructions such as trees or small buildings, and the radio signal will slightly extend over the line-of-sight horizon, but you shouldn't always count on it.

Table 13-1 Microwave Attenuation

Frequency (MHz)	Approximate Attenuation (dB/meter)
432	0.10–0.30
1296	0.15–0.40
2304	0.25–0.50
3300	0.40–0.60
5600	0.50–1.50
10000	1.00–2.00

For all practical purposes, it's safe to assume that if light can't penetrate a stand of trees, microwave losses will be unacceptable. Consider Table 13-1.

Potential Obstacles and Impedance

Although typically microwaves are not affected by the ionized layers in our atmosphere because these layers are higher than the normal line-of-sight transmission of the signals, temperature inversions can still prove to be a problem. This is because as the hot air rises, moisture rising within the air causes attenuation of the signal. One might assume that lower microwave frequencies are affected by water vapor and oxygen, but this is not the case.

Also consider the temperature effects on paths such as: reflections, refractions, diffractions, transmission "ducts" and even tropospheric reflections and scattering. These atmospheric conditions can cause a link to fail even though you have visual line-of-sight. A basic understanding of these conditions may help you when troubleshooting a long-distance link.

Other sources of performance degradation in frequency hopping systems are spectrum background noise, received signal fading, interference from other services in that frequency range, random FM components in the signal, "click" noise resulting from the phase discontinuities between frequency hops, errors in receiver synchronization, or even the wind moving your antennas.

Polarization

The antennas will also have to have the same RF signal polarization. The polarization of the signal will depend on the direction the actual antenna is positioned. If it's up/down, the polarization is vertical; if the antenna is left/right, the polarization is horizontal. If the antenna is diagonal (45 degrees usually), you'll have diagonal polarization. By not having the same polarization on your network's antennas, you can receive a 20 dB loss of signal strength. This is an enormous loss, but can also be very useful. By changing antenna polarization, you can help eliminate certain types of radio interference, or allow many antennas in one location. Horizontal antenna polarization at microwave frequencies will generally provide less multipath and may also provide lower path loss in non line-of-sight situations, but you should always experiment with different polarizations.

Tip

Try to avoid installing your antenna in areas that are located near *multipoint microwave distribution system* (MMDS) or *instructional television fixed service* (ITFS) transmitter sites. You can query FCC or PerCon frequency databases for the coordinates to transmitter locations in your area. You can then look up the sites via these coordinates at the Tiger map server here: `http://tiger.census.gov/cgi-bin/mapbrowse-tbl`. You should also note that MMDS uses horizontal antenna polarization, so if you need to locate your antenna site near one, use vertical polarization. Other things to look out for at your antenna site are high-power PCS wireless cell phone transmissions in the 1.8–1.9 GHz band, broadband noise from high-power colocated transmitters, harmonics from mobile radio and paging transmitters, and other nearby microwave links.

Grounding

The proper Earth grounding of your antenna tower is essential for lightning protection and static discharge. Many towers are inadequately grounded by using only a few grounding rounds and large gauge round copper cables. This is not correct. The small number of grounding rods are inadequate, and round copper cable has a relatively high impedance to an instantaneous rise in electric current (lightning hit). Extremely high voltages will develop across these cables and instead of going to ground, these charges will go directly into your building equipment. A minimum of four ground rods per tower leg with some sort of chemical grounding material should be used. The chemical grounding material will help to lower the ground rod resistance. Copper straps should be used to connect the ground rods to the tower due to their low inductance. In areas with sandy soil or excessive wind-generated static, it's advisable to use a more elaborate grounding method. Most likely a radial grounding system like that found in AM radio.

You should also try to have all your transmission line runs inside the tower column. This will help shield them from lightning if it hits the tower. You should also securely bond the lines to the tower every 15 meters or so. Use the recommended bonding kits that your tower manufacture approves of.

Beam Tilt

Antennas mounted on very high towers may need to take into account beam tilt. Beam tilt is needed when a radiating signal's vertical beam width is narrowed (by using high-gain antennas), and the areas near the tower location lose service because most of the signal is wasted by broadcasting into open air. The beam must be tilted either mechanically or electrically to steer the signal back into its proper location.

Mechanical beam tilting is relatively easy. The antenna can be mounted slightly less than 90 degrees from the horizontal plane so the tilted beam illuminates the desired service area. However, in the opposite direction, the signal will be pointed toward the sky, reducing the effective service area in that direction of the antenna.

If the signal needs to be "bent" downward in all directions around the antenna site, an electrical tilting method must be used. This is commonly referred to as "null fill". Electrical tilting is produced by controlling the current phase in the antenna itself. Thus, it must be done during the antenna's design stages by an engineer with expensive equipment.

Weather

Finally, consider potential weather problems. Ice buildup on antenna elements will result in an increased SWR (impedance mismatch, standing wave ratio) that will de-tune a transmitter system, significantly reducing its output power. Ice can also cause severe transmission line damage, and falling icicles can kill. The easiest way to prevent ice buildup is with special antenna heaters or by covering the antenna system with a fiberglass radome. Radomes will increase the wind load on the tower and antenna heaters can be expensive. For more information, visit the Web at: www.teletronics.com/tii/documents/Antennas/2.4%20GHz/Antennas_Omni.pdf.

There's a great guidebook to building your own custom WLAN antenna on the Web at www.saunalahti.fi/elepal/antennie.html.

Determining the Fresnel Zone

In radio communications—especially given a point-to-point signal between two antennas—the Fresnel zone is part of the concentric ellipsoids of revolution of a circular aperture. In other words Fresnel zones are caused by diffraction by a circular aperture; it's an elliptical region surrounding the line-of-sight path between the transmitting and receiving antennas. To further explain, imagine line-of-sight between two antennas with a signal that spreads out in an elliptical path between the ends (shown in Figure 13-6). The path is divided into different zones that accommodate radio waves that are traveling at different velocities. The Fresnel zone's radius at the point where the ends of the ellipse peak out (known as the midpoint) should be free and clear to provide adequate signal strength. In a good long-distance Wi-Fi design, you should calculate the elliptical shape to determine height and placement of your antennas. In this section we will examine Fresnel zone calculations in detail, but first we'll review some of the obstacles to take into consideration.

Path Loss and Earth Curvature

Path loss between two antennas in a long-distance Wi-Fi link can be caused by a number of objects, including buildings, trees, and landscape features such as protruding hills (see Figure 13-7), and even open air (which we'll talk more about later). However, although many times it is insignificant, one entity to also consider is the curvature of the Earth given by the distance between the two endpoints. Typically this can be an issue when the distance between endpoints is over 10 miles.

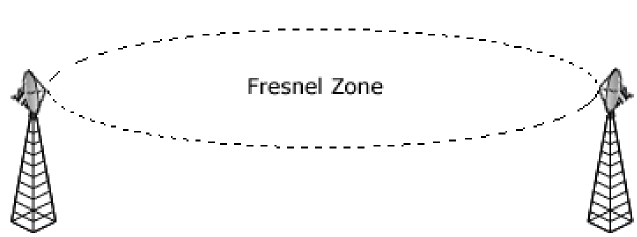

FIGURE 13-6: Fresnel zone. Notice the elliptical path between endpoints.

FIGURE 13-7: Path loss. The elliptical path between endpoints should be clear from obstruction.

For all practical purposes, let's assume that the earth is a sphere with a radius of 3,958 miles. If you are at some point on the Earth and move tangent to the surface for a distance of 1 mile, then you can form a right-angled triangle as shown in the diagram in Figure 13-8. Next, using the theorem of Pythagoras, $a^2 = 3958^2 + 1^2 = 15665765$. Therefore, $a = 3958.000126$ miles.

As a result of this calculation, your position is $3958.000126 - 3958 = 0.000126$ miles above the Earth's surface. Furthermore, 0.000126 miles $= 12 \times 5280 \times 0.000126 = 7.98$ inches. For this reason, we can speculate that the Earth's surface curves approximately 8 inches given the particulars in the scenario. Eight inches isn't very much, and a mile isn't all that far either. But this "dropoff" of the horizon adds up over distance. If your long-distance link goes much farther than a few miles, you will need to raise antenna elevation to compensate for the curvature of the Earth.

As shown in Figure 13-8, we're assuming the Earth has a radius of 3,958 miles and you are at some point on the surface moving in tangent for 1 mile.

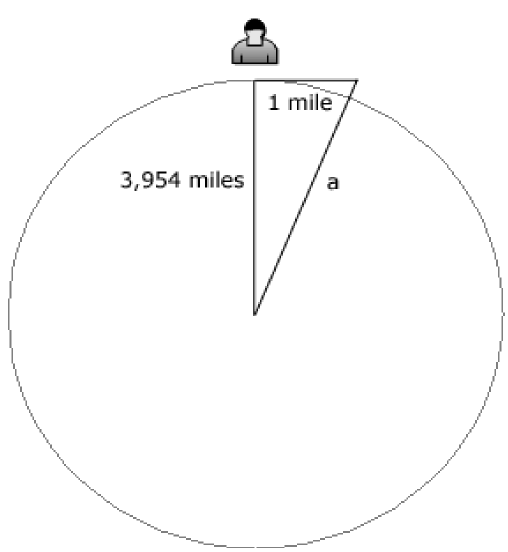

FIGURE 13-8: Calculating the Earth's curvature.

Note

The Theorem of Pythagoras states that if a triangle has sides of length *a*,*b*,*c*, with sides *a*,*b* enclosing an angle of 90 degrees ("right angle"), then $a^2 + b^2 = c^2$. By the way, a right angle can be defined here as the angle formed when two straight lines cross each other in such a way that all four angles produced are equal.

Fresnel Zone Calculations

As mentioned earlier in this chapter, the Fresnel zone's radius at the point where the ends of the ellipse peak out, or the midpoint, should be free and clear to provide adequate signal strength. A rule of thumb is to keep blockage under 40 percent, but transmission loss is imminent if there's any obstruction of the Fresnel zone.

In your long distance Wi-Fi design you should calculate the Fresnel zone to determine height and placement of your antennas to ensure there will be no hindrance. It's also important to consider physical obstacles and their relation to the time of year. For example, during the warm seasons leaves will sprout again and over time young trees could grow into the zone as well.

For purposes of performing Fresnel zone calculations let's look at a real world example and factor in the potential obstacles. The formula we will use to calculate the Fresnel zone radius is shown in Figure 13-9, where *f* is frequency in GHz, *d*1 (distance from transmitting antenna to mid-point) and *d*2 (distance from receiving antenna to mid-point) represent the statute miles, and *h* is the radius in feet.

Caution

For best transmission results you should keep the link path of the Fresnel zone at least 60 percent free from obstruction.

For an example scenario, we surveyed the following specifications:

- The distance between endpoint antennas is 9.5 miles.
- The curvature of Earth is $y = L^2 / 8R$ or $y = 9.5^2 / 8(3958)$ or $y = 90.25 / 31664$ miles; therefore $y = 15$ feet.
- The highest mid-point obstacle is a one-story building at 22 feet.
- The frequency in GHz is 2.4.

$$h = 72.1\sqrt{\frac{d_1 d_2}{f(d_1 + d_2)}}$$

FIGURE 13-9: Fresnel zone formula, where f is the frequency in GHz, d1 and d2 represent the statute miles, and h is the radius in feet.

Using the Fresnel zone formula, we simply follow these steps to calculate the radius of the mid-point ellipse:

1. Divide 9.5 by 2 to get the $d1$ and $d2$ values: 9.2 / 2 = 4.6.
2. Multiply $d1 \times d2 = 4.6(4.6) = 21.16$.
3. Multiply the total distance by frequency or $f(d1 + d2) = 2.4(9.5) = 22.8$.
4. Divide the value from Step 2 by the value from Step 3 or $(d1 \times d2)$ / $f(d1 + d2) = 21.16 / 22.8 = 0.928$.
5. Take the square root of the value in Step 4 (as 0.928) = 0.963.
6. Multiply the value from Step 5 by 72.1 to get $h = 72.1(.963) = 69.4$ feet, which is the radius of the mid-point Fresnel zone ellipse.

That's it! Simply factor in the height of the obstacles and you have the antenna height for this long-distance Wi-Fi link in feet: 69.4 + (15 + 22) = 106.4. However, remember the 40 percent blockage rule from earlier in this section? If necessary, you could reduce the height of the antennas by further multiplying by 0.6, which accommodates 60 percent signal transmission strength (with 40 percent blockage). By doing so, the final antenna height would decrease to 106.4(0.6) = 63.8 feet.

Following are some popular ways you can improve the line-of-sight between end point antennas:

- Raise the antenna mounting point on the existing structure.
- Build a new structure, that is, a radio tower, that is tall enough to mount the antenna.
- Increase the height of an existing tower.
- Locate a different mounting point, such as another building or tower, for the antenna.
- Cut down problem trees.

Budgeting Your Wireless Link

Now that you've made calculations to work around obstacles and accommodate Fresnel zone radius requirements, it's time to calculate whether or not the signal strength for your equipment will meet the receiver's signal threshold. This process is called *link planning* or *link budgeting* and involves several variables, all of which we'll cover in this section.

We'll break a WLAN link into the following elements:

- *Effective transmitting power*: transmitter power (dBm) − cable and connector loss (dB) + antenna gain (dBi)
- *Propagation loss [dB]*: free space loss (dB)
- *Effective receiving sensibility*: antenna gain (dBi)—cable loss (dB)—receiver sensitivity (dBm)

With regard to the specific equipment you plan on or are considering using, check the specification sheets or contact the manufacturers' technicians for the values mentionedearlier. Also, for more accurate results taking into account the different transmitting and receiving properties at both ends of the link, link budgeting should be performed in both directions. Moving forward let's break down each element and detail its individual components.

Caution

The link budget formula is actually not too difficult. Basically, to pre-suppose a positive connection, the transmitting power + propagation loss + receiving sensibility must be greater than zero. A strong link, on the other hand, should have a 20 dB margin.

Effective Transmitting Power

The effective transmitting power consists of the transmitter power, cable, and connector loss, and antenna gain. For simplicity, let's look at each individual component:

The transmitter power (in watts or milliwatts) can be expressed on a logarithmic scale relative to 1 milliwatt in dBm (deci-Bell relative to one milliwatt). Therefore, the output is compared to one milliwatt: (1 dBm = 10 × log10(*P* / 0.001)); (*P* in watts).

- To convert watts to dBm: 10 log (watts × 1000) = dBm
- To convert dBm to watts: $10^{(dBm / 10)}$ / 1000 = watts. (Note: 10 to the (dBm / 10) power is the inverse log of (dBm / 10))

For cable and connector loss, be sure to account for the cable length when calculating cable loss and don't forget to add the (negative) value for the connector. Cable manufacturers will supply the cable and connector loss you can expect for a given frequency. A very nice cable loss calculator is available at the Times Microwave Web site: `www.timesmicrowave.com/cgi-bin/calculate.pl`.

Antenna gain is important as it defines the antenna pattern with regard to where the far field is strongest and weakest and in the middle, and by how much. Antenna gain is normally given in decibels over an isotropic antenna (dBi). It's the power gain in comparison to a hypothetical isotropic (all directions equal) antenna. If your antenna specifications express gain in dBd, you should add 2.14 to obtain the corresponding gain in dBi, since it's compared to a dipole antenna. We specify maximum antenna gain in terms of dBi.

Note

There's an excellent discussion about antenna gain on the Web at this address: `www.marcspages.co.uk/tech/antgain.htm`.

Propagation Loss

Propagation loss (PL) can be simply defined as loss of a wave in free space. Technically it is defined as the signal attenuation between transmit (TX) and receive (RX) antennas due to the

$$PL_{FS}(d) = 10n \log_{10}\left(\frac{4\pi l}{\lambda}\right)\Bigg|_{n=2}$$

FIGURE 13-10: Path loss in an ideal free-space path.

TX to RX separation and multipath (scattering). Basic transmission loss is given by the following formula: PL(dB) = P_t(dB) − P_r(dB) + G_t(dB) + G_r(dB), where P_t is the transmitted power, P_r is the received power, G_t is the transmit antenna gain, and G_r is the receive antenna gain. An ideal free space (FS) path (no ground reflection, no multipath) has a path loss which is proportional to the square ($n = 2$) of the separation d, where l is the wavelength, as shown in Figure 13-10.

This typically represents the minimum path loss and serves as a lower limit. Values of n on the order of 4 are more representative of realistic, cluttered environments.

Note

For more information on path loss, visit the following Web page: `www.wireless.per.nl:202/multimed/cdrom97/pathloss.htm`.

Effective Receiving Sensibility

The first two components of effective receiving sensibility, antenna gain (in dBi) and cable loss (in dB), were covered previously. Therefore, we'll only touch upon the third component, namely receiver sensitivity (in dBm).

Receiver sensitivity is one of the vital specifications of any receiver. Whether measured as a signal to noise ratio, SINAD, or noise figure it is essential that any receiver has a sufficient level of sensitivity. In other words to achieve a required bit rate, the receiver power threshold on the card connector must be up to par. Otherwise, there will be a noticeable decrease in performance. This specification is provided by the manufacturer; however, some of the most common values are indicated in Table 13-2.

Table 13-2 Common Client Adapter Receive Sensitivity

Client Adapter	dBm at 11 Mbps	dBm at 5.5 Mbps	dBm at 2 Mbps	dBm at 1 Mbps
Orinoco PC-Card	−82	−87	−91	−94
Cisco Aironet 350 PC-Card	−85	−89	−91	−94
Edimax USB Client	−81	n/a	n/a	n/a
Belkin Router/ Access Point	−78	n/a	n/a	n/a

You will notice that the lower bandwidth commitment (towards the right of Table 13-2) increases receive sensitivity. For an ultra-reliable, but slightly slower link, try setting your hardware to a maximum of 1 Mbps.

Putting It All Together

Don't be overwhelmed by the formulas and calculations required for link budgeting. If you're not comfortable with the mathematics, there's an automated online calculator at `www.olotwireless.net/castella/radio.htm`. More importantly, link planning can save your time and money when you make equipment purchasing decisions. Calculating a link budget beforehand will allow you to change components (based on their component values) to better score in a positive margin.

To recapitulate, you can assume a positive signal connection by taking the combined values from the transmitting power, propagation loss, and receiving sensibility with a final value greater than zero. A strong link, on the other hand, should have a margin of 20 dB. Therefore, referring back to our example scenario, we surveyed the following specifications:

- The distance between endpoint antennas is 9.5 miles.
- The curvature of Earth is $y-L^2/8R$ or $y-9.5^2$ / 8(3958) or $y-90.25$ / 31664 miles; therefore $y-15$ feet.
- The highest midpoint obstacle is a one-story building at 22 feet.
- The frequency in GHz is 2.4.
- Using the Fresnel zone formula, we calculated 69.4 feet; which is the radius of the midpoint Fresnel zone ellipse between antennas over our line-of-sight.
- After factoring in the height of surveyed obstacles, we found the antenna height for this long-distance Wi-Fi link should be 106.4 feet.

So based on the link budgeting factors, considering obstacles, and accommodating the Fresnel zone radius following (also depicted in Figure 13-11) is a synopsis of a realistic long-distance link experimental design:

- Antenna height on each end: 106.4 feet
- Antenna type on each end: 21 dBi Parabolic Dish Directional Antenna
- Cabling on each end: Just enough low loss cabling to ensure the greatest distance

Tip

You might assume that in order to double the distance of your long-distance Wi-Fi link, you would simply double the signal power, yet this is not the case. When dealing with long-distance Wi-Fi links you must first understand that wireless signal strength degrades as the square of the distance covered. Doubling the distance of your long-distance Wi-Fi link will require 2^2, or four times the power, which is represented by a +6 dB gain.

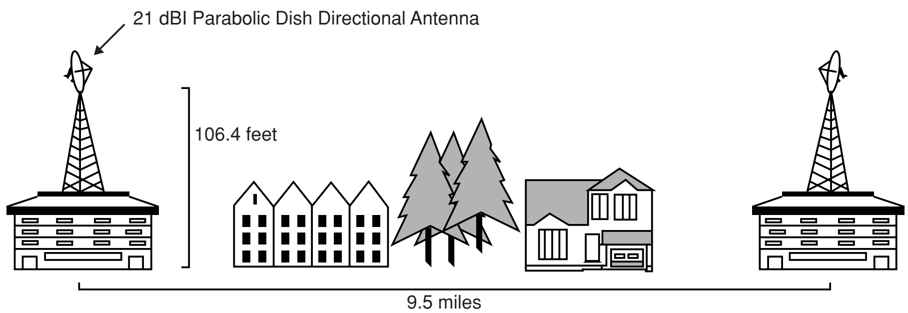

FIGURE 13-11: An experimental long-distance Wi-Fi bridge design based on our example survey results.

Cabling the Antenna

Begin by measuring the distance from your computer to your outside antenna location. Be sure to choose a route that will protect your coax run and allow easy upgrading. Use a long extension cord to simulate your coax and help make the measurement more realistic. Try to keep the coax cable run as short as possible to minimize the RF power loss, and avoid sharp bends, which can damage the coax, or in some cases, change the coax's impedance. Next, choose a high quality brand of coax and cut it to that distance, plus about one meter extra, for slack. Avoid the low-quality, high-loss cable such as RG-58, CB or TV/satellite coax. The LMR series from Times Microwave is highly recommended. The coax you choose must have a 50 ohms impedance. Any other impedance, such as 75 ohms, may cause too much loss for this application.

Note

Use of the 75 ohms hard-line used in cable TV service might be possible, though some experimentation will be required. You may also be able to pick up very high-quality, hard-line coax from cellular phone or broadcast installations. They usually give the spool end runs (the last 15 meters or so) away for free or even throw it away because it's of no use to them. The connectors for commercial hard-line are very expensive and hard to make, so remember that.

Prepare the coax for installation of the two N plugs on each end. You'll need a suitable brand of N-type connectors due to the large center conductor if you use LMR-400. The RF Industries RFN-1006-PL N-Connector is a good brand. You may also need to route your coax before terminating the N-Connectors if it has to run through small diameter holes. Take your time installing the connectors. See Chapter 1 for more instructions on building your cable.

After attaching the connectors, wrap some 3 M Scotch Super 33+ electrical tape, or equivalent stretchy tape, around the bottom of the connector and a few centimeters of coax. Pull the tape as tight as possible to help make the connector waterproof. If your antenna is going to be exposed directly to heavy rain or high humidity, you may want to consider wrapping the connection with some self-fusing silicone tape (Radio Shack part number 64-2336).

Next, route your coax to your outside antenna. Secure the cable to keep it from flopping around in the wind or from people pulling on it. Leave a small loop of coax where it enters the building.

This will act as a drip loop and will keep rain from seeping into your building. You may also at this time want to install a quality brand of inline coax lightning protection. PolyPhaser is one such protector. Refer to the documentation on the proper grounding techniques that will be required for lightning protectors to work properly.

Connect the cable up to your antenna's connector jack. Wrap some Coax Seal, Mastic tape, or any other pliable waterproof tape around the connector and then also wrap all that with Super 33+ electrical tape. Secure the wrapped connector against the antenna mast.

Tip

When using rubberized Coax Seal or Mastic tape, don't apply the tape to the connector directly, you'll just end up with a mess. Instead, wrap the connection with electrical tape and then wrap the Coax Seal around the tape, sealing any small holes. This will save you a lot of hassle when you have to remove the connection.

For onsite testing, you may wish to obtain a proper pigtail to connect your computer to the N-type connector on the cable. You may also want to make some type of stress relief holder to support the weight of the coax and adapter. For more information on connectors and cabling see Chapters 1 and 2 or visit the Web at: `http://home.deds.nl/~pa0hoo/connectortypes/index.html`.

Testing and Troubleshooting

Now that your link is installed, you should give it a nice going over with some common testing tools. Also, use the network as you actually would on a regular basis. That is, download e-mails, surf the Web, transfer files, and so on.

In setting up your actual link, proper planning needs to take place beforehand because you and the person who will be helping you will be quite some ways apart and it may be difficult to communicate, not to mention exchange extra parts.

On the day of your test, you should create a "pre-link checklist" before leaving for the site. Forgetting equipment or other necesities can mean the difference between spending the day surfing the net or sitting in traffic.

A typical pre-link checklist includes the following.(Note: there should be two of everything on this list because there are two nodes required.)

- Laptop computer
- Extra laptop battery or power inverter with 12-volt adapter
- Wireless adapter
- Access point or bridge
- Directional antenna—panel, grid, Yagi, dish
- Pigtails
- Temporary mounting solution—tripod, lightstand, or something similar

- Cellular phone or handheld radio
- Spotting scope or binoculars
- GPS or a good map

Tip

Keep yourself organized and stick to the checklist, and you can leave the aspirin at home. Always remember to bring more than one pigtail per node, as their fragile end connectors are prone to breaking, and you may be many, many miles from a replacement. Extra batteries for your laptop, in addition to a power inverter, also will ensure success because a laptop on a single charge will clearly not be sufficient for a full day of testing.

Making the Link

After you reach the site, survey the initial area to find a spot with good line-of-sight to the intended direction of the link. Setting up the antenna, tripod, access point/bridge, and laptop should be a very simple and standard procedure. Connect all of the subsequent hardware and run a program that measures signal-to-noise ratio (SNR) such as NetStumbler. (See Chapter 6 for more on NetStumbler.) You will be able to detect the reception of a beacon frame, and then use the SNR measurment for link tuning. You will need to adjust and fine tune the direction of the antenna to achieve optimum signal strength. Make sure you do this in coordination with the person in control of the other end of the link to ensure precision and accuracy. Make adjustments on one side at a time.

Once you feel that you have optimized the wireless link quality to your satisfaction, confirm the success of your project by testing the network transport over the wireless link.

Set up a continuous connection to the far-side computer. Adjust the settings on both computers to enable communication between them. It will depend on your network topology, but you can often insert a laptop on either end and configure them for direct communication to each other. If your wireless radios are also routers, you will need to configure the computers to participate on each side of the network.

Once your network settings are configured as needed, a good first test is to ping the remote computer over the wireless link. (Your pal on the other end should also do this and other steps with your computer.) Run the Command Prompt and enter `ping -t ip_address`. The `-t` option tells ping to keep going forever. If the link doesn't work at this point, jump to the Troubleshooting section below. Ping should resolve the address and start replying once a second. This will help show you the link quality but it won't measure throughput or continuous connectivity.

Tip

Sometimes a stray DHCP server may give you the wrong address and send your traffic over an Internet connection away from the wireless link. If this happens, you will be able to surf the Web, but you will not be able to connect to the computer on the other end of the wireless link. Perform a `tracert ip_address` command to the far-side computer. Tracert will report on which devices are routing your network traffic.

Next, use the link as it will actually be used on a daily basis. If you will be surfing the Web and checking e-mail, do that. If it will be used for videoconfereincing or voice-over-IP (VoIP), try that, too. Watch streaming videos, copy files back and forth to each other, and so on. You could also try using Microsoft NetMeeting to send video or transfer files acrosss the link. Basically, you want to exercise the link in any way you can.

While doing these link excercises, insert some attentuation into the system to simulate a low signal condition. The "Go/NoGo Tester" from Wireless Info Net (`www.ask-wi.com`) is a neat, simple way to test how your link will perform on a bad day. Just plug this loss-inducing barrel connector into your cabling and see if the link stays up. If the link dies, you need to carefully reconsider the components comprising the network. Check antenna selection, cable lengths, connector quality, radio sensitivity, and of course antenna direction and physical aim.

Once you have accomplished these tasks and kept the link up and running, you have successfully designed and deployed your own long-distance Wi-Fi link.

Troubleshooting

Even when you've planned carefully, there can still be troubleshooting issues that may arise when establishing a wireless connection of this type. The most common troubleshooting problems are something that most wireless users will experience at some time or another.

Broadly, problems arise in one of two areas: the wireless connection and network settings.

If you don't have any experience setting up a TCP/IP network, try to have a good friend that knows the stuff onsite, or at least on the other end of a cell phone. Dozens of things can go wrong in configuring a basic network connection on a regular wired Ethernet link. By adding wireless to the mix, you could be in for a long day without proper support.

We are here to help. Try some of these basic solutions to common link problems:

- *Antenna alignment*: Often, if the antenna mount is not secure, the alignment may skew from its original position, causing a link disruption. Make sure that everything is mounted securely, and that the antennas have been properly aligned. Double-check the link after tightening down mounting bolts. Contents may have shifted during tightening.
- *Bad cables*: Any pigtail cables in use as the connection between your laptop and the antenna will likely have very fragile end connectors and often will break easily if not handled properly. Ensure these cable ends are not damaged and are seated properly.
- *Network configuration*: TCP/IP settings must be properly configured or you will not be able to establish your network link. If you can detect the presence of the network from the laptop, the link is probably fine. Ensure that all network settings are configured for access across the wireless link, and make sure that both computers are fully configured to receive traffic. Disable any firewalls.
- *Ping problems*: Immediately check your wireless components and TCP/IP settings. These settings can vary wildly based on your actual deployment. On a basic level, ensure that the two computers are on the same IP subnet or can route to each other, and make sure your gateway is set to the correct router device, if applicable.
- *Fresnel zone obstructions*: Trees, buildings, and other obstructions in the Fresnel zone will degrade your link quality severely, and appropriate actions must be taken to ensure a

clear Fresnel path. You may need to move the link, or raise the antennas above the obstruction.

- *Intermittent signal*: This toughest of all problems to troubleshoot can be caused by a number of things. Check for some of these: bad wireless devices or poor configuration, damaged antennas or connectors, bent or cut cables, too many connectors, RF design errors, RF interference, other Wi-Fi radios, and possibly vehicular traffic, birds, or other intermittent antenna obstruction. Also, check for water damage or any sign of seepage into your electronics or antenna components. And finally, make sure you removed the Go/NoGo tester.

With all of these tips, you should have little trouble in making your link a success. Enjoy your new-found freedom!

Summary

A long-distance wireless link bridges two remote locations and allows data to travel where it has never traveled before. A high-speed Wi-Fi link can bring another building online, light up a remote outpost, or establish a temporary uplink to the Internet. Beaming wireless signals across long distances makes just about any personal, research, or business task much easier. The technology has enabled researchers to keep in constant contact with each other and their test subjects, businesses to save money by connecting multiple offices, and sharing of Internet access to friends or relatives. Entirely new business models and research methods are being revealed through long-distance wireless connectivity.

Creating a successful long-distance Wi-Fi link is certainly not unproblematic. Yet, as this chapter has shown, a good design begins with an accurate survey, Fresnel zone and path loss calculations, followed by level-headed link planning. If you're not up to the task mathematically, use the online link budget calculator at `www.olotwireless.net/castella/radio.htm`. Also, remember that most, if not all, of the specifications required for the calculations in this chapter are available in your hardware manuals, on the manufacturer Web sites, or through quick customer support phone calls. The task is not without challenges. The reward is limitless.

Now we'll lighten the subject a bit. Read on to Chapter 14, where we employ some unusual wireless link tactics to create a car-to-car videoconferencing session. Prepare for a road trip with a 1970s-style convoy, this time with Wi-Fi video instead of CB radio! 10-4 good buddy. I mean, "lights, camera, action!"