13. OUTDOOR INSTALL

Although WiFi technology was designed for local area networks, its impact in developing countries is more dramatic in long-distance applications.

In developed countries, fibre optic cables offering large bandwidths have been installed satisfying the communication needs of most cities. The penetration of optical fibre in the developing world is not nearly as great and nowhere near enough to cover the needs. And the cost of its expansion often does not meet the ROI (Return on Investment) goals of telcos within a reasonable period of time. Wireless technologies, on the other hand, have been much more successful in developing countries and the potential for increasing the penetration using wireless networks is enormous.

Telcos have installed traditional microwave radio links in most countries. This is a mature technology that offers high reliability and availability reaching 99.999%. However, these systems cost many thousands of dollars and require specially trained personnel for installation.

Satellite systems have proved well suited for broadcast traffic like TV and certain other applications. However, satellite solutions are still expensive for bidirectional traffic, while WiFi is quite cost effective in outdoor point to point networks as well as in typical access networks where a Base Station (BS) is serving many Clients/CPEs (point to multipoint). In this chapter we will be concentrating on the outdoor long- distance point to point links.

Two significant hurdles had to be overcome before applying WiFi to long distance: Power budget limitations and timing limitations. The remaining limitations for using WiFi over long distances are the requirement for the existence of radio line of sight between the endpoints and the vulnerability to interference in the unlicensed band. The first limitation can often be addressed by taking advantage of the terrain elevations, or by using towers to overcome obstacles such as the curvature of the earth and

to provide Fresnel zone clearance.
For indoor applications, line of sight is not required since the stations are very close together and most obstacles can be cleared by reflections on walls, ceiling, etc. But for long distance applications, line of sight is absolutely critical. The second limitation is less pronounced in rural areas and can be alleviated by migrating to the less crowded 5 GHz band.
The power budget issue can be handled by using high gain antennas and powerful and highly sensitive radios attached directly to the antenna to avoid RF cable loss. The timing limitation has to do with the media access techniques. WiFi uses a random access method to share the communications medium. This makes it subject to collisions, which cannot be detected over the air, therefore the transmitter relies on receiving an acknowledgment for every successfully received frame.
If, after a specified amount of time, called the "*ACKtimeout*", the acknowledge frame is not received, the transmitter will resend the frame.
Since the transmitter will not send a new frame until the ACK for the previous one has been received, the *ACKtimeout* must be kept short.
This works well in the original scenario intended for WiFi (indoor networks), in which the propagation time of 33.3 microseconds per kilometre is negligible, but breaks down for links over a few kilometres.

Although many WiFi devices do not have provisions for modifying the *ACKtimeout*, newer equipment meant for outdoor applications (or third party firmware like Open WRT) will give you this possibility, often by means of a *distance* field in the GUI (Graphical User Interface).
Changing this parameter will allow for a reasonable throughput, which will anyway decrease proportionally to the distance. The contention window slot-time also needs to be increased to adapt to longer distances.
Other manufacturers have chosen to move from random access to ***Time Division Multiple Access*** (***TDMA***) instead. TDMA divides access to a given channel into multiple time slots, and assigns these slots to each node on the network. Each node transmits only in its assigned slot, thereby avoiding collisions. In a point to point link this provides a great advantage since ACKs are not needed because each station takes turns at transmitting and receiving.
While this method is much more efficient, it is not compliant with the WiFi standard, so several manufacturers offer it as an optional proprietary protocol, alongside the standard WiFi. WiMAX and proprietary protocols (such as Mikrotik Nstreme, or Ubiquiti Networks AirMAX) use TDMA

to avoid these ACK timing issues.
The 802.11 standard defines the receiver sensitivity as the received signal level required to guarantee a BER (Bit Error Rate) below 10^{-5}.
This determines the amount of energy per bit required to overcome the ambient noise plus the noise generated by the receiver itself. As the number of bits/second transmitted increases, more receiver power will be needed to provide the same energy per bit. Therefore the receiver sensitivity decreases as the transmitter rate increases, so to maintain the same signal/noise ratio as the distance increases the throughput diminishes, or, alternatively, for longer distances one should choose lower data rates to compensate for the reduction of the signal strength with distance.

1. What is needed for a long distance link?

There are four aspects that need to be considered to adapt WiFi devices to long distance: increase the radio dynamic range; increase the antenna gain; decrease the antenna cable loss; and make provisions for the the signal propagation time.

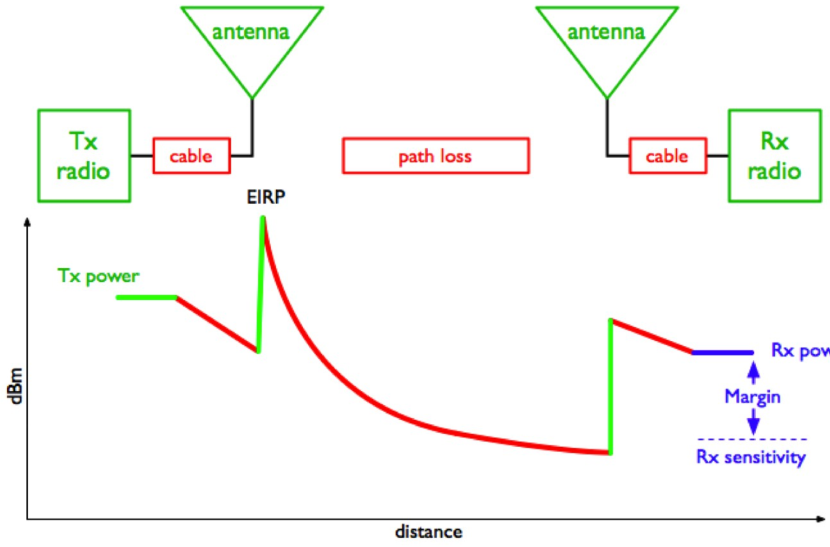


Figure OI 1: Power in dBm vs distance in a radio link (Power budget).

The graph above shows the power level at each point in a wireless link.

The transmitter provides some amount of power.
A small amount is lost in attenuation between the transmitter and the antenna in the RF cable or waveguide. The antenna then focuses the power, providing a gain. At this point, the power is at the maximum possible value for the link. This value is called the EIRP (Equivalent Isotropic Radiated Power) since it corresponds to the power that a transmitter would have to emit if the antenna had no gain.

Between the transmitting and receiving antennas there are free space and environmental losses, which increase with the distance between the link endpoints. The receiving antenna provides some additional gain. Then there is a small amount of loss between the receiving antenna and the receiving radio.

If the received amount of energy at the far end is greater than the receive sensitivity of the radio, the link is possible. Increasing the transmission power can lead to violations of the regulatory framework of the country.
Increasing the antenna gain is by far the most effective way to improve range. Make sure that the radio to be employed has connectors for an external antenna (some devices have an embedded or otherwise non removable antenna).

Decreasing loss in antenna cables is still an important issue, and the most radical way to attain it is to place the radio outside, directly attached to the antenna, employing a weatherproof box. Often this lends to powering the radio using PoE (Power over Ethernet).

Improving the receiver sensitivity implies choosing a model with better performance, or settle for lower transmission speeds where sensitivity is higher.

Although high gain antennas can be expensive, in many countries one can find satellite antennas that are no longer being used and can be modified for the WiFi bands.

In a perfect world, we would use the highest gain antennas with the loudest and most sensitive radios possible. But a number of practical considerations make this impossible. Amplifiers introduce an additional point of failure, in addition they might violate maximum power permitted by local regulations and add noise in reception, so they should be avoided. High power transmitters are available from many manufacturers that offer up to 1 W of output power which could be used instead of amplifiers in those countries where this is legal.

In general, it is better to use high gain antennas than high transmitter power. Greater antenna gain will help both in transmission and reception making a double impact in the link budget. It will also cause less interference to other users and receive less interference from other users and limit multipath effects But a high antenna gain implies a very narrow beamwidth, which means that special alignment techniques are required.

2. Antenna alignment

For short distances, when the corresponding antenna is visible, the antenna alignment procedure reduces to pointing the antenna in the direction of the correspondent, both in the horizontal plane (azimuth) and in the vertical plane (elevation). This should suffice to establish the connection. Once the connection is attained a fine adjustment can be made by reading the RSSL (Receiver Signal Strength Level) in the local radio. This value is provided by the user interface, and can also be obtained from programs like *netstumbler*. The procedure consists of moving the antenna in the horizontal plane in small steps while reading the RSSL. Do not touch the antenna when reading, since your body will affect the measurement. Once satisfied that a maximum value is obtained, the procedure is repeated in the vertical plane, moving the antenna first up and then down until a maximum value of received power is obtained, at which point the bolts that secure the antenna are tightened. This is all that is needed to aim a client device at an Access Point or Base Station. If you have a point to point link, the same procedure should be repeated at the other end of the link.

For long distances and when the other end of the link is not visible, some extra steps are required. First, the horizontal direction (bearing) to aim the antenna must be obtained from the coordinates of the end points. Then a compass is used to determine the direction in which the antenna should be aimed.
Keep in mind that in general there is a difference between the *magnetic* bearing measured by the compass and the *geographical* bearing obtained

from the coordinates of the end points or from a map.
This difference is called the *magnetic declination*, it can be very significant in some places and must be accounted for to properly aim the antenna. Fig. OI 2 shows the 10° difference between the magnetic north shown by the compass and the geographical or true north indicated by the brass plate.

Figure OI 2: Difference between Magnetic and Geographical North at El Baul, Venezuela in 2006.

Keep in mind that iron and other magnetic metals will affect the reading of the compass, so stay away from those when making the measurement. If the antenna is to be mounted in an steel tower, it might be impossible to get an accurate reading near it. Instead, one must walk away a certain distance, use the compass to determine the direction the antenna must be aimed and then try to locate some easily recognisable object that can be used as a reference for pointing the antenna at later. Since the beamwidth of a highly directive antenna might be just a few degrees, after pointing with the compass we need to do some fine adjustment for the proper aiming of the antenna by measuring the strength of the received signal.
Unfortunately the RSSL indicated by the radio software will only work after a proper packet has been satisfactorily received and decoded, and this will only happen when the antenna is well aimed.
So we need an instrument that can reveal the strength of the received

signal independently from the modulation that it might have.
The instrument needed for this task is the Spectrum Analyser.
There are a great variety of spectrum analysers on the market, some of them costing thousands of dollars, but if we are only interested in the WiFi bands we can make do with some inexpensive solutions like the following:

"RF Explorer" offers inexpensive devices for several frequency bands.
The "RF Explorer model 2.4G" costs 120$ from
http://www.seeedstudio.com/depot/-p-924.html?cPath=174
and is a stand alone unit that can measure signals from 2.4 to 2.485 GHz, with a sensitivity of -105 dBm. It has an SMA connector for the antenna and therefore is well suited for antenna alignment.

"WiSpy" is a spectrum analyser in a USB dongle that attaches to a laptop. You will need the models with SMA RP connector, there is one for 2.4 GHz moderately priced and another one that covers both the 2.4 and the 5 GHz bands sold for 600$ at www.metageek.net.

"Ubiquiti Networks" , www.ubnt.com, used to sell USB dongle spectrum analysers for 2.4 GHz at 70$.

Unfortunately they seem to have discontinued this product after incorporating the spectrum analyser capability in their M series radios.
So when using these radios you can take advantage of their "airView" alignment tool. In principle one of these inexpensive radios like the "Bullet M" which comes with a N Male connector can also be used to align antennas for other radios in both the 2.4 and 5 GHz bands.
Unfortunately the digitally modulated signal transmitted by WiFi radios is not well suited for antenna alignment, since its power is spread over the 20 MHz bandwidth. For antenna alignment a single frequency with a stable output power is required.
This type of signal is produced by a microwave signal generator, but they are quite expensive.
The "RF Explorer model 2.4G" incorporates a 2.4 GHz signal generator, but the maximum output power of 1 dBm is not well suited for long distance antenna pointing.Instead, we have repurposed devices called "video senders", meant for transmitting video signals, which act as powerful microwave single frequency signal sources when no modulation is

applied.
They are available for both the 2.4 GHz and the 5 GHz bands with output power up to 33 dBm. For our purposes it is necessary to buy a model with an antenna connector, so that we can attach our own antenna. There are many vendors to choose from, see for instance:
http://www.lightinthebox.com/Popular/Wifi_Video_Transmitter.html

As an example of long distance link using modified WiFi devices, we can mention an experiment performed in April 2005 in Venezuela between Pico del Aguila (8.83274638° N, 70.83074570°W,4100 m elevation) and El Baul (8.957667° N, 68.297528° W, 155 m elevation).

Using the Radio Mobile software, we find that the distance to El Baul is 280 km, the azimuth is 97°, the antenna elevation angle is -2.0°, and the place at which the beam is closest to the ground happens at 246 km, where it clears 1.7 times the first Fresnel zone at the 2.412 GHz frequency.

Fig. OI 3 shows the output of the program:

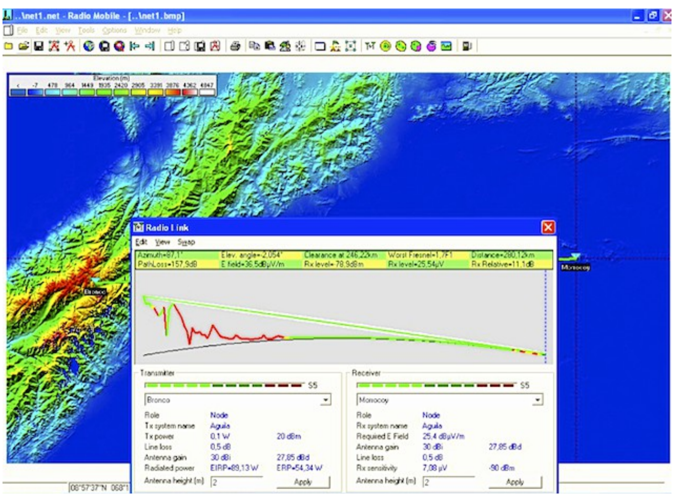


Figure OI 3: Profile of a 280 km path over which standard WiFi gear with OpenWRT firmware which allows for the ACKtimeout increase was used to transfer files at about 65 kb/s in April 2006 between Pico del Aguila and El Baul in Venezuela.

Notice that the earth curvature is quite apparent, and was overcome because one of the stations was at 4100 m altitude and the other at 155 m. Frequency was 2412 MHz, output power 100 mW, antenna gain around 30 dBi. Streaming video was successfully transmitted despite the limited bandwidth.

A year later the experiment was repeated with the same WiFi gear but with commercial 32 dBi antennas at both ends and similar results were obtained. Then, another type of firmware developed by the TIER group at UC Berkeley University that implements TDD (Time Division Duplexing) was tried which showed a remarkable bidirectional throughput of 6 Mbit/s with standard 802.11b hardware.
Moving the remote site to a 1400 m high hill called Platillon (9.88905350°N, 67.50552400°W), provided a 380 km testbed over which the experiment was again successfully repeated as described in the **Case Studies** section in this book.
This can be illustrated by using an on-line version of Radio Mobile, available at http://www.cplus.org/rmw/rmonline.html, which is simpler to use, although it has some limitation as compared with the downloadable version. One must register in the site, enter the coordinates of the points over which the radio link has to be established, the power values for the radios and the antennas gains and height, and the software will fetch the relevant elevation data required to perform the simulation of the link.
Keep in mind that only radio amateurs frequency are supported in the web version, so 2.3 GHz should be used instead of 2.4 GHZ, but the results are close enough and where validated by the experiment on the field.
In Figure OI 4 we show the output of the Radio Mobile on- line for this experiment that can be replicated by the reader as an exercise.

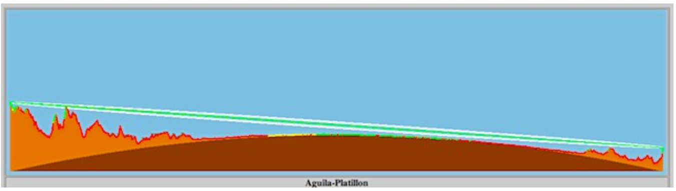
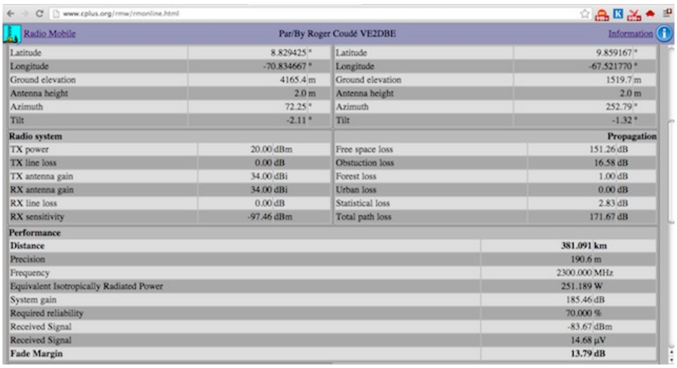


Figure OI 4: Profile of a 380 km test at 2.4 GHz performed in April and August 2007, Venezuela.

Notice that the earth curvature is even more noticeable over the 380 km path, but the height of the end points combined with flat land in between allows for ample clearance of the first Fresnel zone.

Figure OI 5 shows the numerical values of the Radio Mobile on-line simulation:



Latitude	8.829425 °	Latitude	9.859167 °
Longitude	-70.834667 °	Longitude	-67.521770 °
Ground elevation	4165.4 m	Ground elevation	1519.7 m
Antenna height	2.0 m	Antenna height	2.0 m
Azimuth	72.25 °	Azimuth	252.79 °
Tilt	-2.11 °	Tilt	-1.32 °
Radio system			**Propagation**
TX power	20.00 dBm	Free space loss	151.26 dB
TX line loss	0.00 dB	Obstuction loss	16.58 dB
TX antenna gain	34.00 dBi	Forest loss	1.00 dB
RX antenna gain	34.00 dBi	Urban loss	0.00 dB
RX line loss	0.00 dB	Statistical loss	2.83 dB
RX sensitivity	-97.46 dBm	Total path loss	171.67 dB

Performance	
Distance	**381.091 km**
Precision	190.6 m
Frequency	2300.000 MHz
Equivalent Isotropically Radiated Power	251.189 W
System gain	185.46 dB
Required reliability	70.000 %
Received Signal	-83.67 dBm
Received Signal	14.68 µV
Fade Margin	**13.79 dB**

Figure OI 5: Results of the Radio Mobile on-line simulation for the 380 km link between Aguila and Platillon.