# Long Distance Links

Training materials for wireless trainers

The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

This 45 minute talk covers the technical aspects of planning and building wireless networks that stretch further than a few kilometers.

Version 1.1 by Rob, @2009-11-26
Version 1.3 by Rob, @2010-02-28
Version 1.4 by Rob, @2010-03-12

# Goals

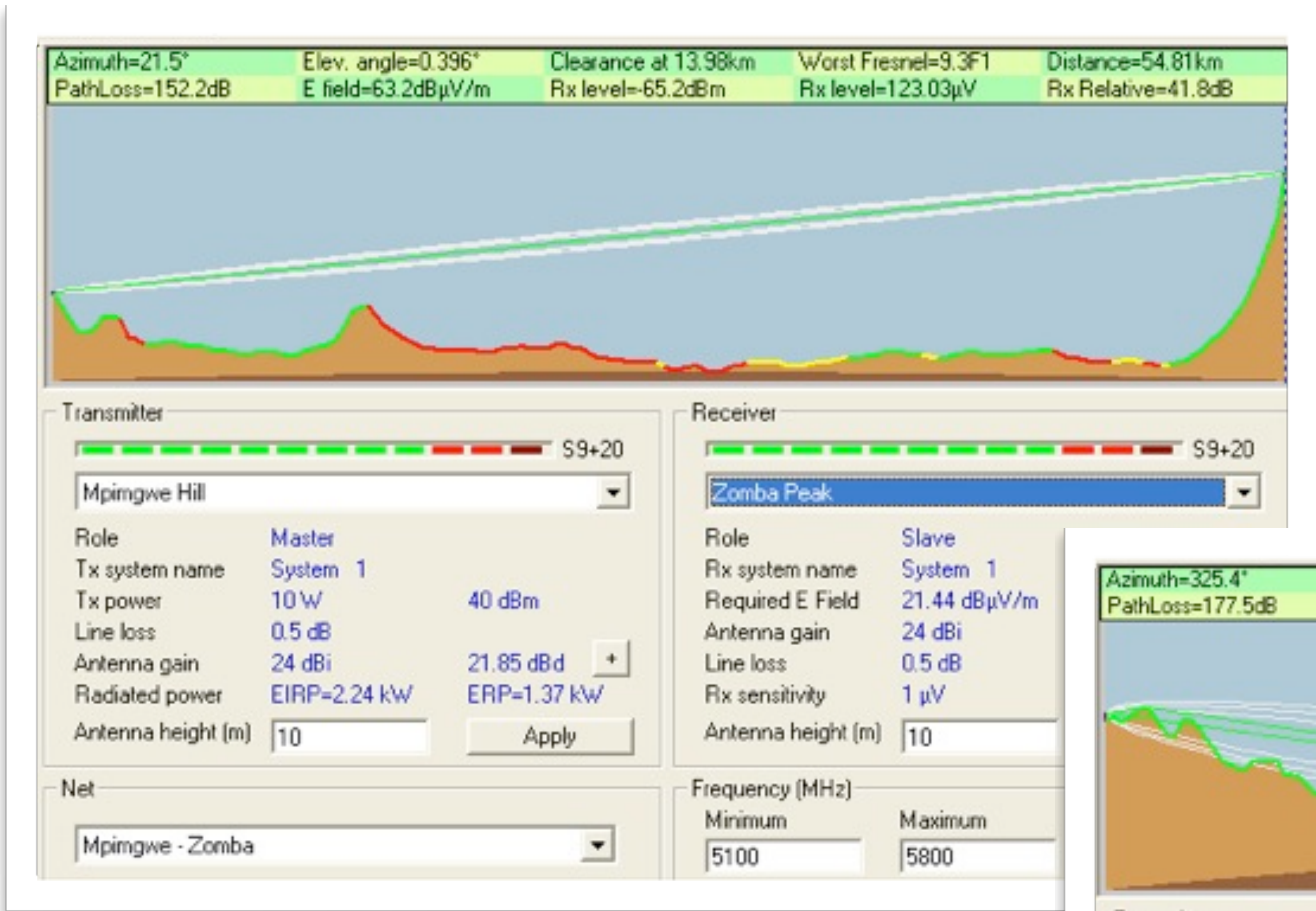
- To understand the engineering challenges of building long distance links
- To realize the limitations of long distance wireless
- To learn a methodology for aligning antennas at a distance
- To see some real world examples of extremely long distance wireless networks

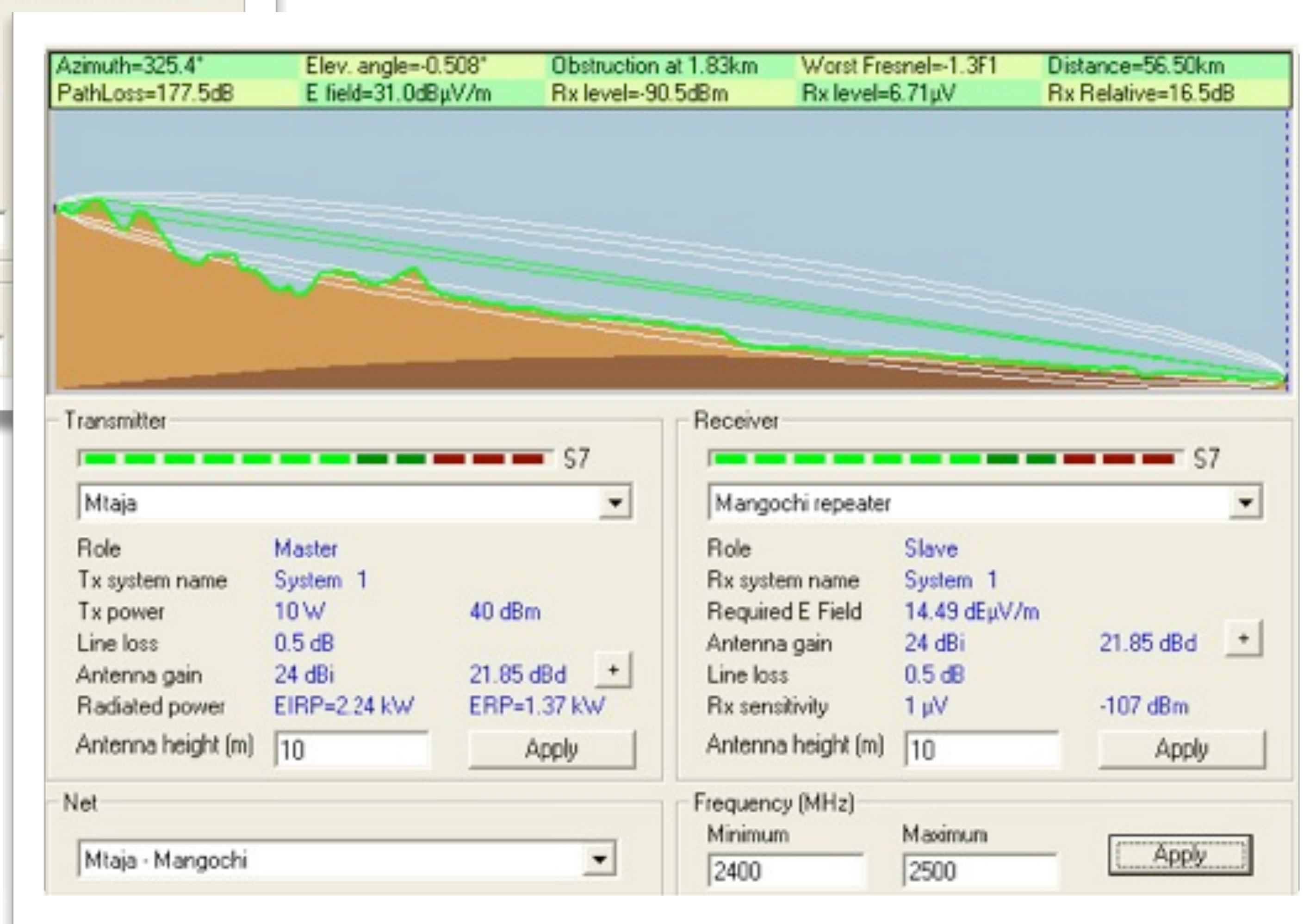
# Long Distance Link Requirements

For a successful long distance link one must:

- Simulate the link and perform a site survey.
- Use suitable structures to hang antennas so that the Fresnel Zone and earth curvature can be cleared.
- Choose special purpose equipment, or modify short distance equipment, to allow for long distances.
- Use proper antenna alignment techniques.

# Step 1: Simulate the link!






Simulating the link in Radio Mobile is absolutely required for very long distance links, to first verify that the link is even possible. A few hours of simulation time can save many days of effort.

See the talk “Site Survey” for more information.

# Step 2: Perform a site survey



Once you have located possible link locations, perform a physical site survey. Is there power at the site? How difficult is it to access? Can you obtain permission to install your equipment there?

Again, see the talk on Site Surveys for more detailed information.

# Step 3: Where to mount your gear?

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Are appropriate mounting structures (buildings, towers) available? If so, what is the height of the structure you may be permitted to use? Will this height clear any obstacles and allow for a clear Fresnel Zone?

# Step 4: Selecting and preparing long-range equipment

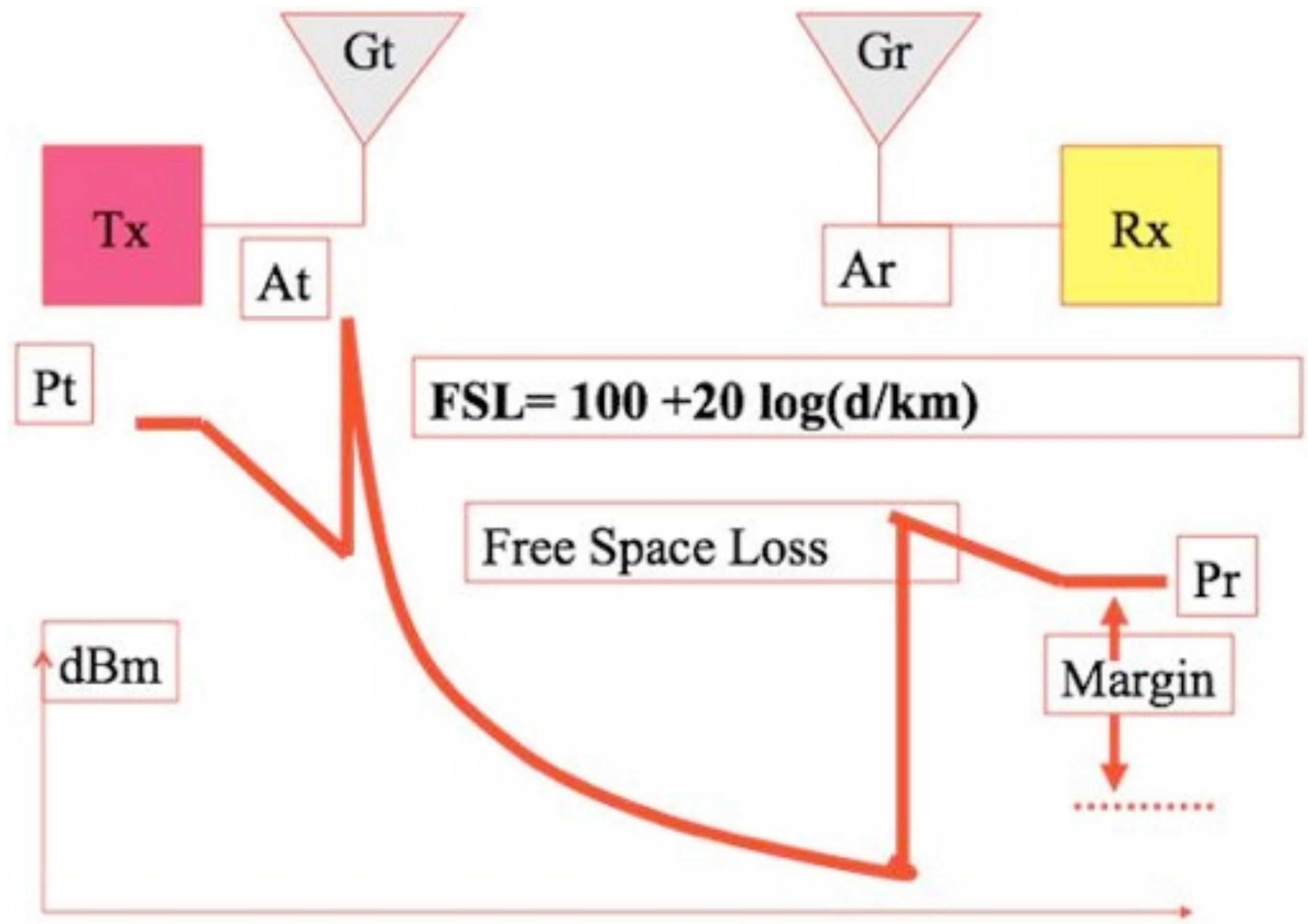
- Equipment should be chosen that maximizes the available signal level at both ends of the link.
- External antennas are **required** for long links.
- In addition to link budget considerations, ***protocol issues*** (such as acknowledgment timing, hidden node, and other media access problems) become a factor.



Although standard based equipment is normally preferable, for long distance links "modified" standard equipment or even proprietary solutions might be the best choice in a given application. Bear in mind the local conditions, availability of support, spares and so on when choosing the equipment.

# Maximizing the power budget

- Increase the antenna gain on one or both ends of the link.
- Increase the transmitting power on **both** ends of the link.
- Use more sensitive radios (lower minimum received signal level) on both ends of the link.
- Reduce transmission line loss by using shorter or better quality radio cables, or eliminate them entirely.






This graph 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. The antenna then focuses the power, providing a gain. At this point, the power is at the maximum possible value for the link.

Then 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, then the link is possible.

# Practical link budget considerations

- Legal regulations on maximum EIRP
- High power and very sensitive radios are often (but not always) more expensive.
- Amplifiers are very expensive and are almost never a good idea.
- High gain antennas (parabolic dishes) tend to be larger, more expensive, and difficult to transport.
- High gain antennas are difficult to align at long distance and have greater wind loads.



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, 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 general, it is better to use high gain antennas than high power output. A greater antenna gain will help both in transmission and reception making a greater impact in the link budget.

# Timing issues

Due to the very fast timing of 802.11 frames, the speed of light becomes an issue at long distances. At approximately 15 km, standard timings are too short for ACKs to be received. It takes 1 ms for radio waves to travel 300 km!

Some cards and drivers (such as Atheros) allow timings to be adjusted, permitting very long distance communications.

Proprietary protocols (such as WiMAX, Mikrotik Nstreme, or Ubiquiti AirMAX) use TDMA to avoid these ACK timing issues.



There is very little time for nodes to acknowledge that 802.11 frames have been accurately received. Standard acknowledgement (ACK) timings assume that the furthest client on a network is at most a few hundred meters away. If acknowledgements are not received before the ACK time has expired, the frames are retransmitted.

Given the constant speed of light, this limits the effective range of a network for a given ACK time. Longer distance networks are possible, but they will inefficiently retransmit frames, reducing overall throughput. By changing the ACK time, you can tune your WiFi network to allow for much greater distances but there will be a throughput penalty.

By using a protocol that doesn't rely on ACK timings (such as Mikrotik Nstreme, Ubiquiti AirMAX) you can avoid this problem altogether-- but note that these devices, while using WiFi hardware, no longer adhere to any 802.11 standard.

# CSMA vs. TDMA

802.11 WiFi uses ***Carrier Sense Multiple Access*** (***CSMA***) to avoid transmission collisions. Before a node may transmit, it must first listen for transmissions from other radios. The node may only transmit when the channel becomes idle.

Other technologies (such as WiMAX, Nstreme, and AirMAX) use ***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.

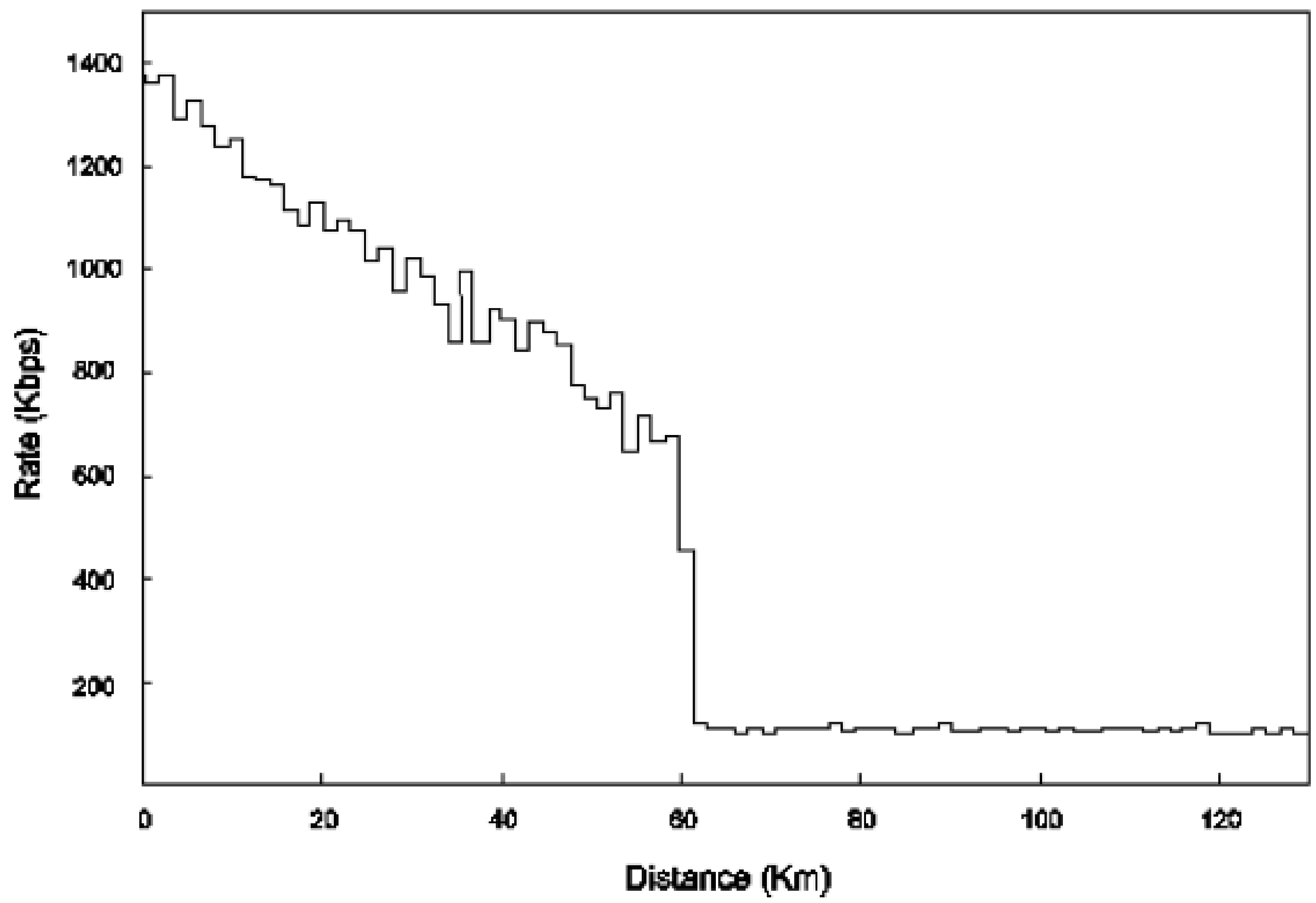


CSMA and TDMA are completely different media access methods. Technologies such as AirMAX or Nstreme may use 802.11 WiFi hardware, but the protocol is **not** compatible with standard WiFi!
TDMA is particularly well suited for point to point links, where there are no wasted time slots. In point to multipoint applications at short distances CSMA is more efficient.

TDMA also provides inherent Quality of Service (QoS) since the maximum time for a station to gain access to the medium is bounded.

A sort of QoS can be offered in CSMA by establishing independent queues for different type of traffic and allowing shorter interframe spacings for high priority traffic like voice, but there will be no guaranteed maximum latency.

# 802.11 rate vs. distance behavior




Rate versus distance for an FTP file transfer, simulated with NS2

From *Distance Limits in IEEE 802.11 for Rural Networks in Developing Countries* by *Javier Simo, Andres Martinez, Carlos Figuera and Joaquin Seoane.*



Without changes to the standard 802.11 protocol, throughput falls off sharply as the distance between the nodes increases.

# The "Hidden Node"

When two clients are in range of the same access point but not each other, their transmissions can interfere with each other. This condition is called a ***hidden node*** problem.

- Hidden node is alleviated somewhat by CTS/RTS (also known as channel reservation).
- CTS/RTS adds overhead, so you can specify a maximum packet size above which CTS/RTS is used.
- It is not perfect, but can help at a cost of maximum possible throughput. CTS/RTS should only be used with access points and clients, not ad-hoc networks.
- Only relevant on point-to-multipoint networks.

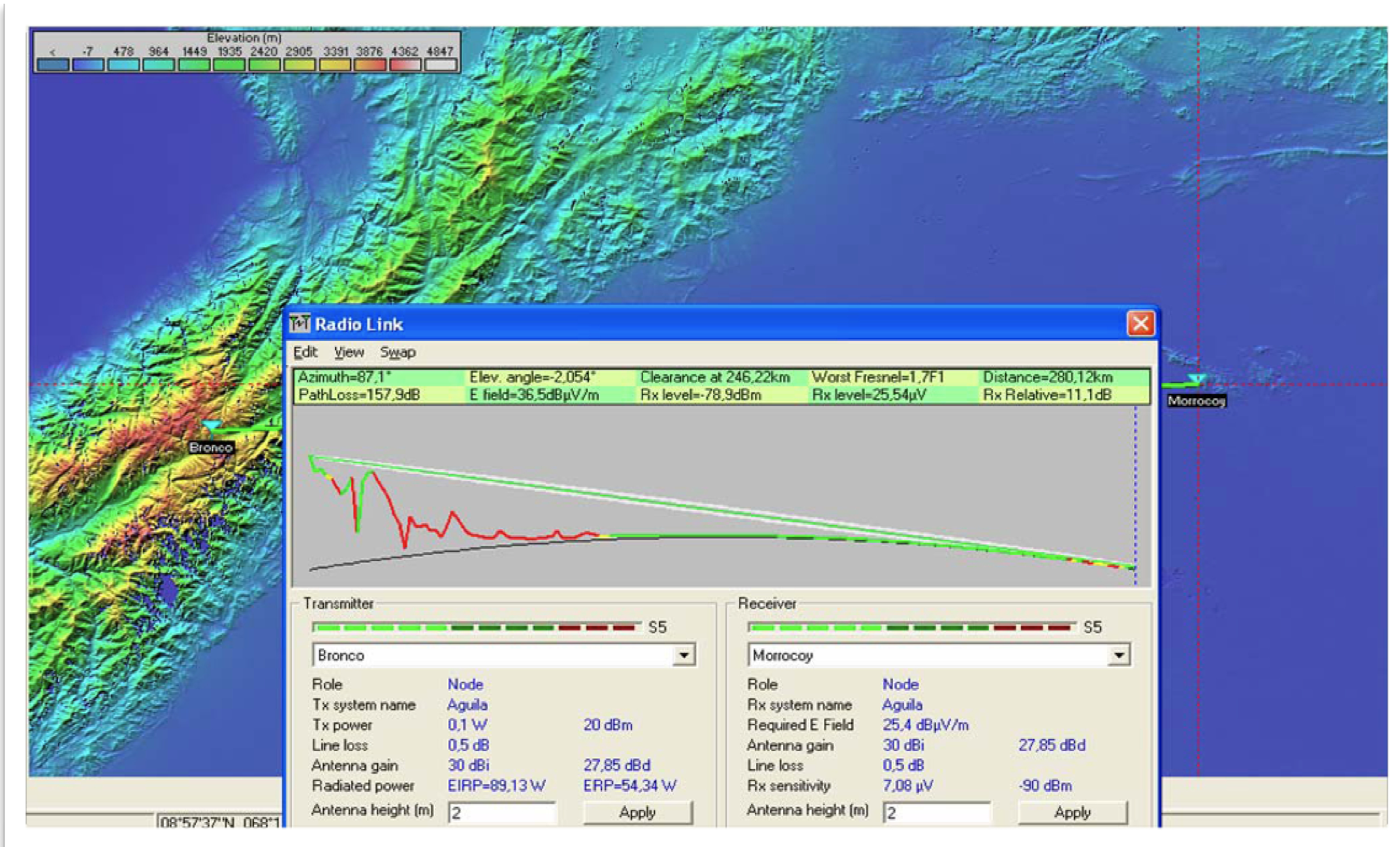


Prior to transmitting, wireless clients listen for other traffic, and will delay transmission if another device is already using the channel. But this mechanism can only work if all of the clients are in range of each other.

When clients are in range of the same AP, but cannot hear each other's transmissions, they will transmit at the same time. This causes interference for the AP. CTS/RTS can help alleviate this problem at the expense of adding more protocol overhead.

Hidden node problems only occur in shared medium networks with more than two nodes. Using a TDMA protocol, or using multiple point-to-point links can avoid hidden node problems altogether.

# Real-world long distance links

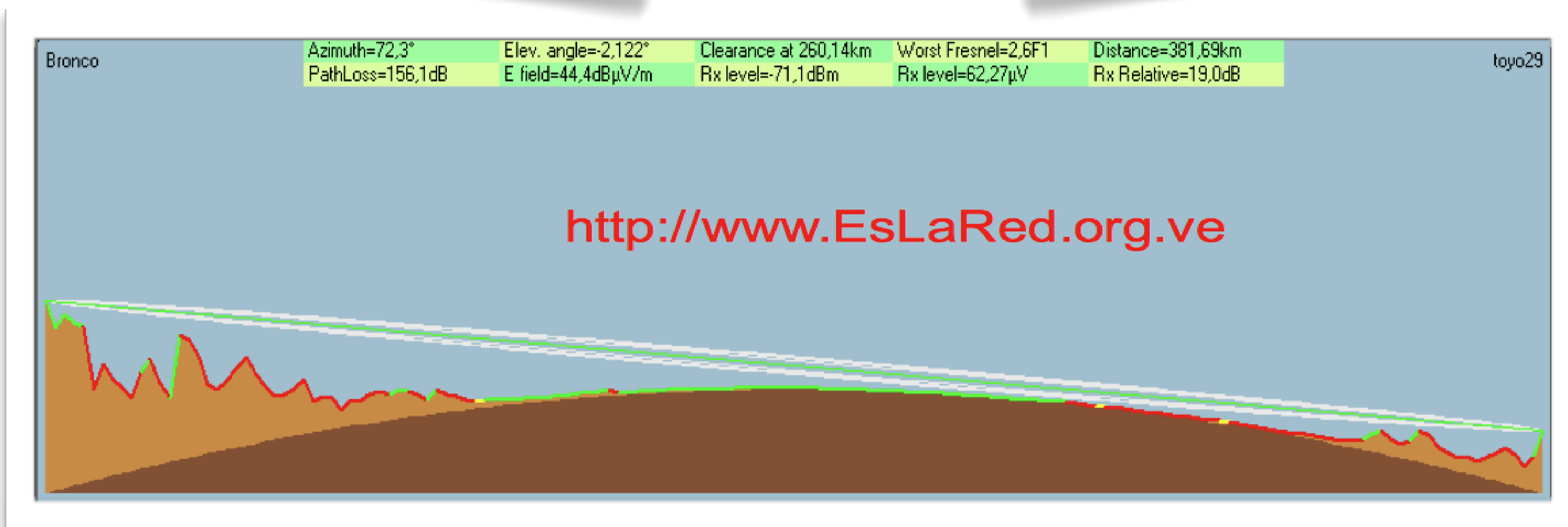



Profile of a 279 km test at 2.4 GHz performed in April 2006, Venezuela.



Using off the shelf WiFi equipment with 100 mW output power. Third party firmware allowed the increase of ACK's waiting time thus making the link viable but with a throughput of only 65 kbps.
External high gain parabolic antennas repurposed from satellite service were used.

# Real-world long distance links

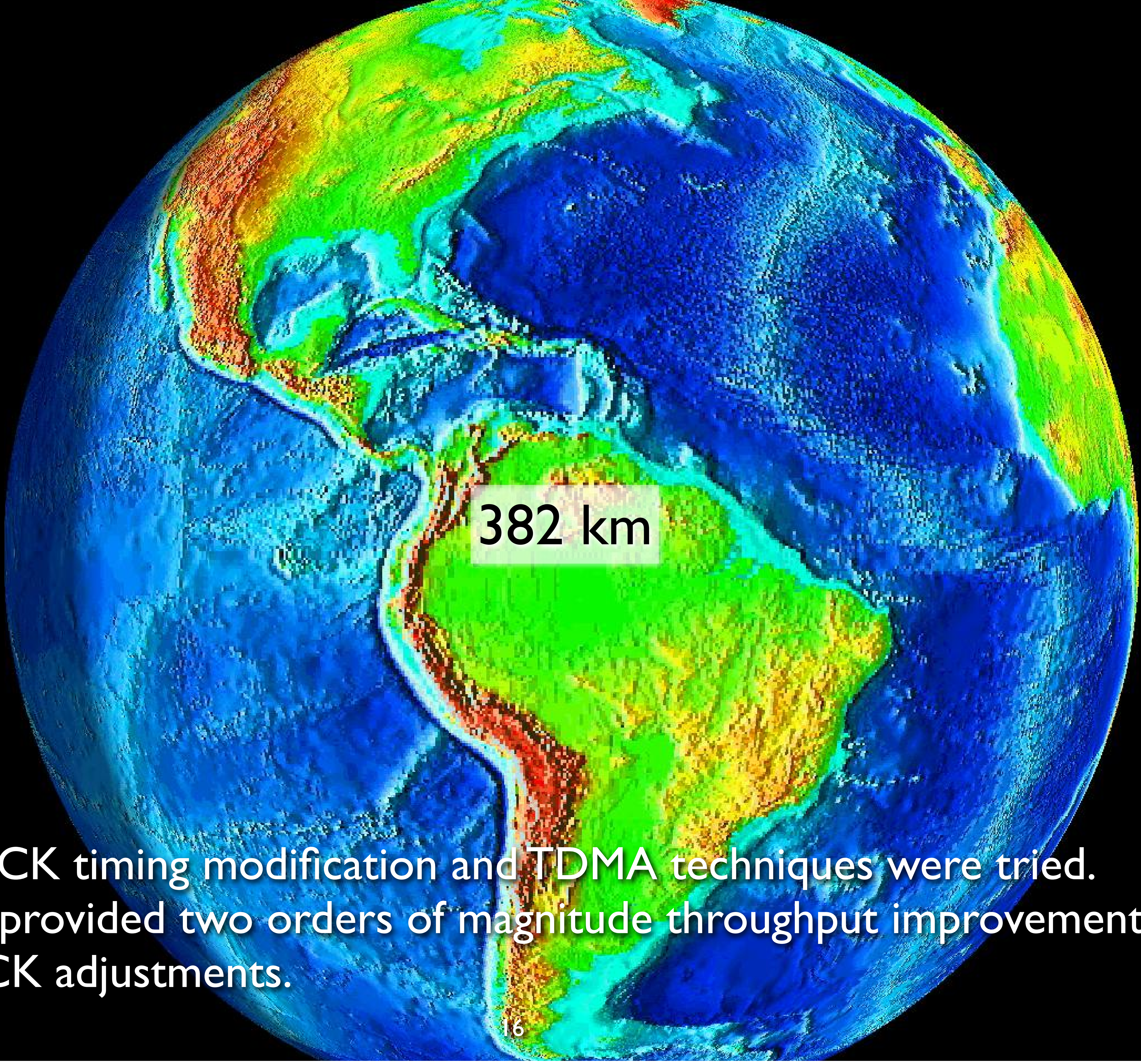



Profile of a 382 km test at 2.4 GHz performed in April and August 2007, Venezuela.



In this test, first standard IEEE802.11b gear with modified ACK timing yielding a limited throughput that nevertheless allowed video streaming was used.

Then, another type of firmware developed by the TIER group of 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.

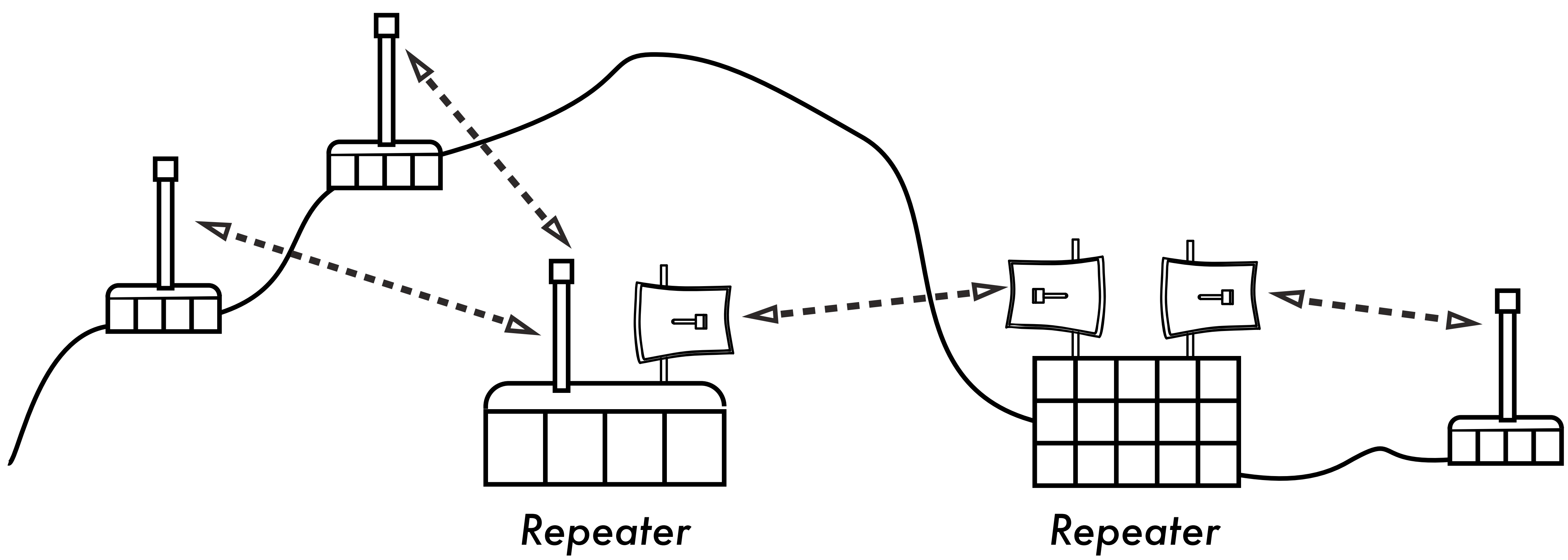



Both ACK timing modification and TDMA techniques were tried. TDMA provided two orders of magnitude throughput improvement over ACK adjustments.

# Other long distance strategies: repeaters

Rather than attempt a single long-distance link, you can often make use of ***repeaters***. Repeaters are nodes that are configured to rebroadcast traffic that is not destined for the node itself.

Adding repeaters reduces the complexity of planning a single link, but adds additional hardware and maintenance overhead to the network.






The higher in frequency, the more important line of sight becomes. With a laser or optical link, extremely high frequencies are used. Obviously, line of sight is important when using optics: if the beam is blocked, there is no link!

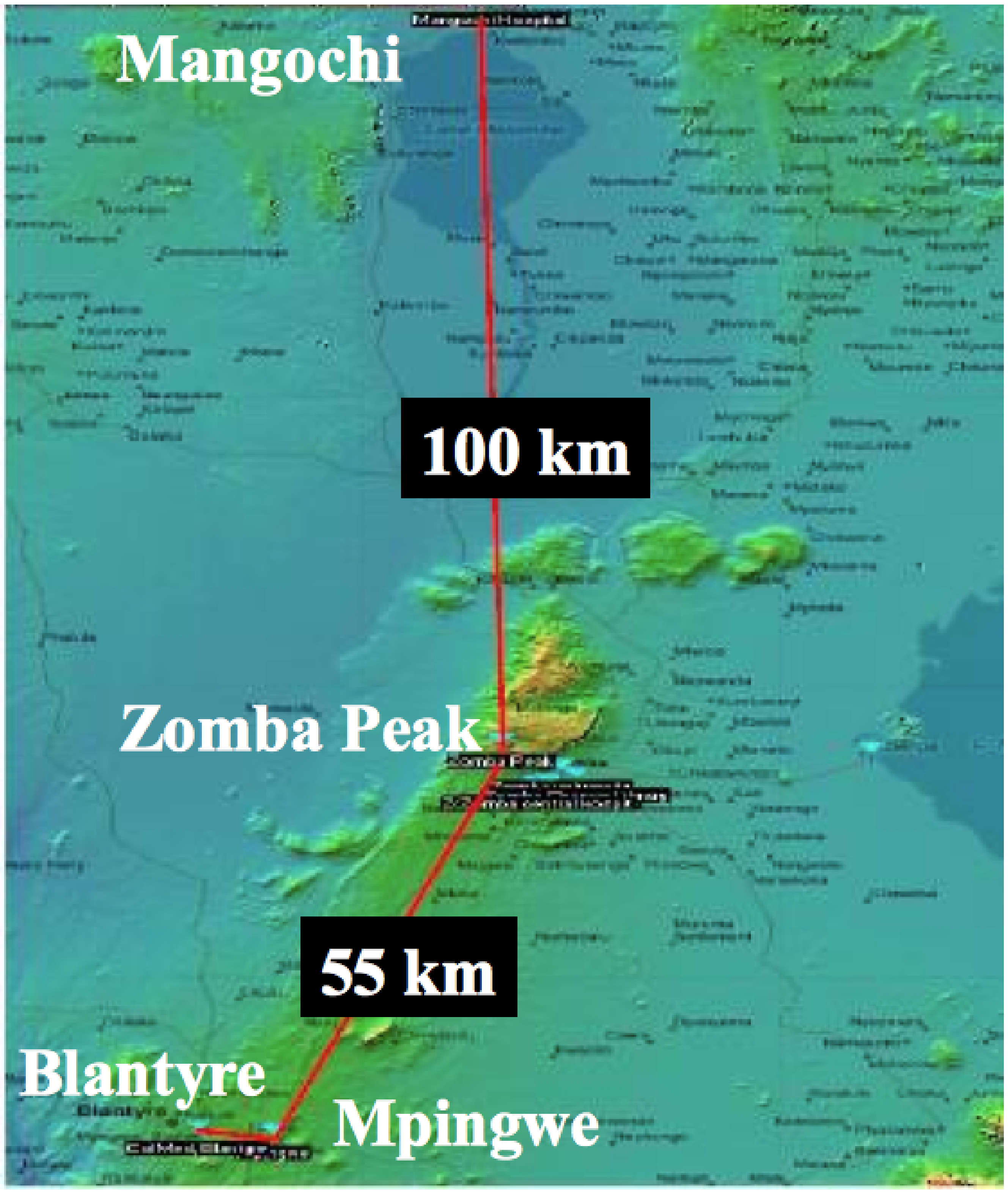
Line of sight is also important at microwave frequencies, such as 5 GHz and 2.4 GHz used by WiFi. For indoor applications, line of sight is not as important since the equipment tends to be very close together. But for long distance applications, line of sight is absolutely critical.

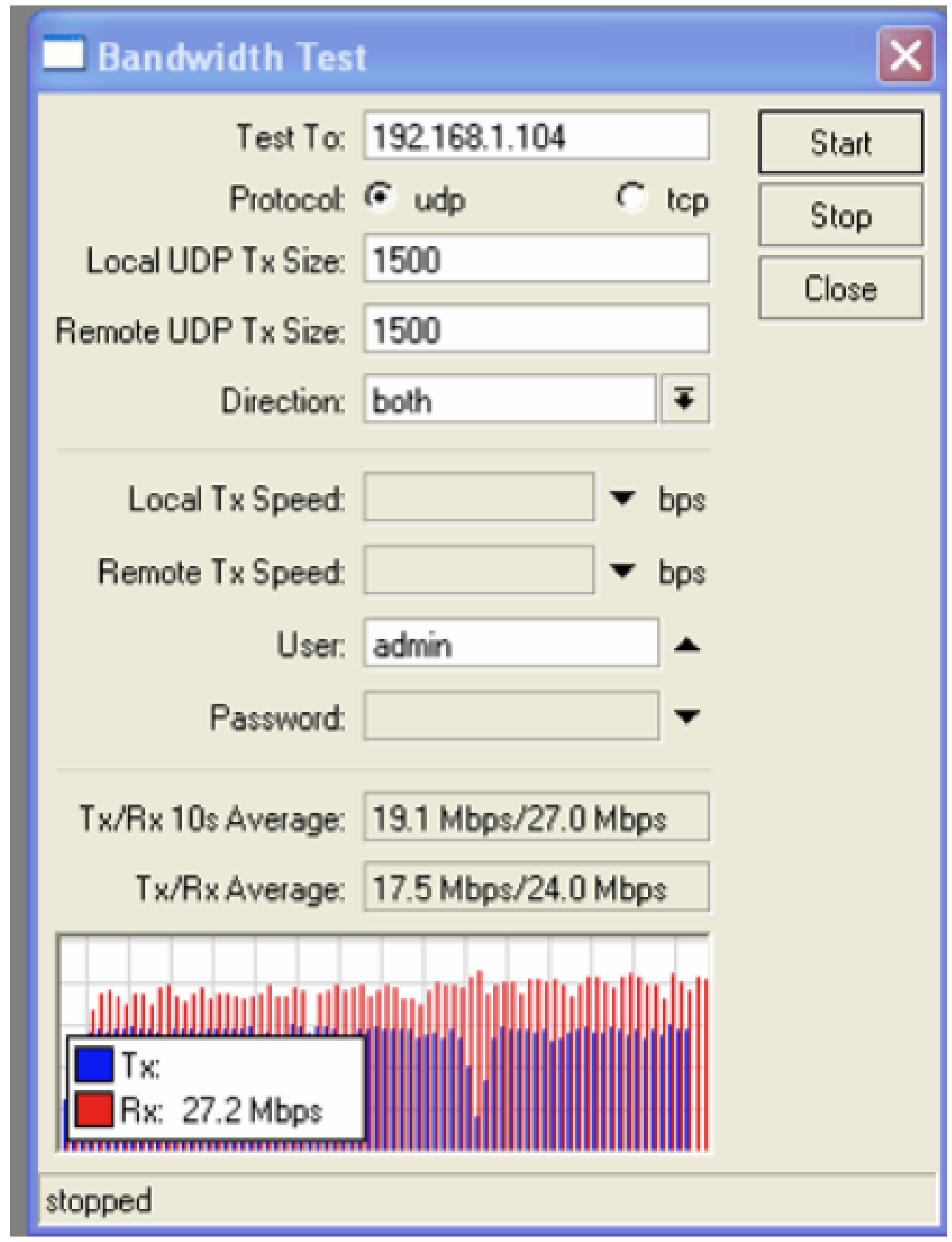
Repeaters can be used to get around obstacles that would block the path of a single long distance link. They will add latency and if a single radio is used for both directions of traffic they will essentially halve the throughput.

Making use of a repeater may imply the high cost of establishing an extra node with the corresponding site acquisition, site rental cost and powering issue, securing the equipment against theft, as well as increased maintenance costs.

Repeaters are relays that are installed solely to rebroadcast traffic for other nodes. In a mesh network, every node is a repeater.

# Blantyre-Mpingwe-Zomba-Mangochi






The Malawi network uses three repeater sites to avoid obstacles and make an extremely long distance network. It uses full duplex Mikrotik Nstreme on the backbone links.

# Step 5: Antenna alignment

To align dishes at a long distance, you must first start by aligning the antenna to the approximate bearing of the remote side.

A string a few meters long can help estimate the direction at which a large antenna is pointing.

It also helps to separate your compass from the influence of ferrous objects in the antenna mounting structure.


Once you have a rough idea of the bearing, other instruments are needed to properly align the antennas.

# Aligning antennas

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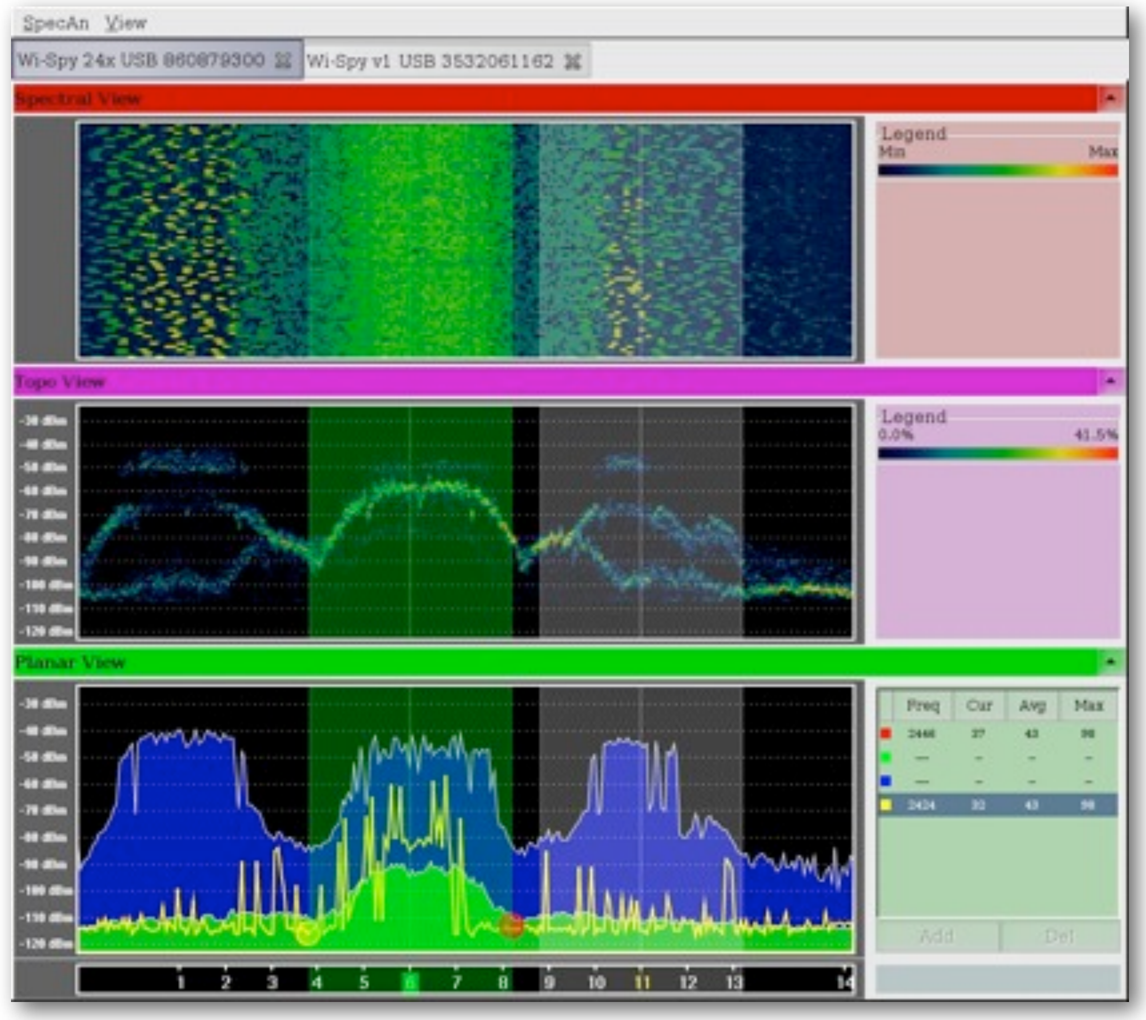


The ideal antenna alignment toolkit consists of a ***signal generator*** and a ***spectrum analyzer***, preferably one of each at both ends of the link.

By attaching a signal generator to one end of the link and a spectrum analyzer to the other, you can observe the received power and watch the effect of moving the antenna to various positions in real time.



A spectrum analyzer shows you how changes in the antenna position affect the received signal level. Connect the spectrum analyzer to the antenna at one end of the link, and a signal generator (such as a TV transmitter) to the other. Find the maximum received signal level while making small adjustments to the antenna position, and when the maximum is found, tighten down all antenna connections. Then replace the measurement equipment with your communications gear.

A USB spectrum analyzer and signal generator are included in the kit. Use them to perform experiments with antenna alignment.

# Antenna alignment tips

Aligning antennas at very great distances is something of an art. These tips may help reduce the time you will spend getting your antenna alignment "just right".

- Test all equipment ahead of time
- Bring backup voice communications (FRS or ham radio in addition to mobile phones)
- Test the signal in both directions, but only one side at a time
- Don't touch the antenna when taking a reading
- Don't be afraid to push past the best received signal when adjusting the antenna
- The antenna angle may look completely wrong
- Double-check polarization on both ends



Determine the bearing at which each antenna must be pointed. Use a compass in the field for a rough alignment when the remote end is not visible. Make corrections for the magnetic declination of your site.

Perform a calculation of the expected received signal power prior to the antenna alignment so you know what value of received power readings are to be expected. This can be done with Radio Mobile or just calculating the received power in terms of the transmitted power (the video sender output power), antenna gains and free space loss.

Make a large sweep of the antenna position to be certain that you are indeed looking at the main lobe of the antenna pattern and not one of the sidelobes,

# Conclusions

- By modifying consumer grade WiFi equipment and fitting it with external antennas, very cost effective long distance and high throughput links can be built in the non-licensed frequency bands.
- These techniques have been demonstrated in deployments in several countries.
- They are particularly useful in sparsely populated areas where interference from other users of the same spectrum is less likely.
    - Low cost commercial equipment that implements TDMA is available from Mikrotik and Ubiquiti.

# Thank you for your attention

For more details about the topics presented in this lecture, please see the book ***Wireless Networking in the Developing World***, available as a free download in many languages:

*http://wndw.net/*


For more information, see Chapter 8 of the book.