IEEE 802.11 Long Reach Link.

Goal: Explore the limits of 802.11 technology by building a link longer than those made in other places of the world.
The success of this project proves that WI-FI networks still have a lot to contribute as an access solution both in urban and rural areas.

Abstract
Pico del Águila- El Baúl Link.

Central frequency: 2412 MHz
IEE 802.11 (Wi-Fi), channel 1, 22 MHz. bandwidth
Wireless routers: Linksys WRT54G, OPEN-WRT firmware at el Águila and DD-WRT firmware at El Baúl.
Length: 279 km.
Parabolic dish antennas were used at both ends, recycled from satellite service.
At El Aguila site an aluminum mesh reflector 2,74 m diameter, center fed, at el Baúl a fiberglass solid reflector, offset fed, 2,4 x 2,74 m. At both ends the feeds were 12 dBi Yagis.
Linksys WRT54g routers fed the e antennas with short LMR400 cables, so the effective gain of the complete antenna is estimated at about 30 dBi.
As far as we know, this is the longest range attained with this technology, improving on a previous US record of 125 miles achieved last year in U.S. The Swedish space agency attained 310 km but using 6 watt amplifiers to reach an overhead stratospheric balloon

Background

Thanks to a favorable topography, Venezuela has already somel long range links, like the 70 km long operated by Fundacite Merida between Pico Espejo and Canagua and a trial 100 km link between Maracaibo and Machiques in Zulia State.
The Swedish space agency achieved a 310 km link with a stratospheric balloon, but they did not have to deal with ground clearance and were aided by 6 watt amplifiers.
In 2005 a group of American radio amateurs achieved a 125 miles link over ground. We aim to improve on this record.

While looking at the terrain in Venezuela in search of a stretch with high elevation at the ends and low ground in between, we first focused in the Guayana region. Although plenty of high grounds are to be found, in particular the famous “tepuys” (tall mesas with steep walls), there were always obstacles in the middle ground.

We therefore turned our attention to the Andes, whose steep slopes rising abruptly from the plains proved adequate to the task. We first examined links between Pico Espejo at

4765 m above sea level and several sites in the Amazonas State, but there were again obstacles in the path. So we looked towards the town of El Baul, in Cojedes State, and using the free software *Radio Mobile*, available at www.cplus.org/rmw/english1.html, we found that there was no obstruction of the firs Fresnel zone between Pico Espejo and El Baul, along the whole 300 km link. We also tried the path between Pico del Aguila and El Baul, and it also proved feasible, with a 283 km span.

Action Plan

Once satisfied with the existence of a suitable trajectory, we looked at the equipment needed to achieve the goal. We have been using Orinoco cards for a number of years. They are robust and trustworthy sporting an output power of 15 dBm and receive threshold of -84 dBm. The free space loss at 282 km is 149 dB, so we would need 30 dBi antennas at both ends and even that would leave very little margin for other losses.

On the other hand, the popular Linksys WRT54G wireless router runs Linux and the Open Source community has written several firmware versions that allow for a complete customization of every transmission parameter. In particular, OpenWRT firmware allows for the adjustment of the acknowledgment time of the MAC layer, as well as the output power. Another firmware, DD-WRT has a GUI interface and a very convenient site survey utility. Furthermore, the Linksys can be located closer to the antenna than a laptop, so we decided to go with a pair of these boxes, one as an AP (access point) and the other as a client. The WRT54G can operate at 100 mW output power with good linearity, and can even be pushed up to 200 mW, but at this value non linearity are very severe and spurious signals are generated, so we discourage this practice. Although these are consumer grade equipment and quite inexpensive, after years of using them we felt confident that they could serve our purpose, provided we kept a spare set handy.
By setting the output power at 100 mW (20 dBm), we still had 5dB advantage compared with the Orinoco card. We therefore settled for a pair of WRT54Gs.

Pico del Águila site survey.

This site was chosen instead of Pico Espejo because there is a road leading to it, whereas Pico Espejo can only be reached by cable car.
On January 15 we went to Pico del Águila to check the site that Radio Mobile had reported as suitable. The Azimuth towards El Baul is 86 degrees, but since the magnetic declination is 8° 16', our antenna should be pointed to a magnetic bearing of 94°.

The Merida radio amateurs association has built a shelter as shown in figure 1

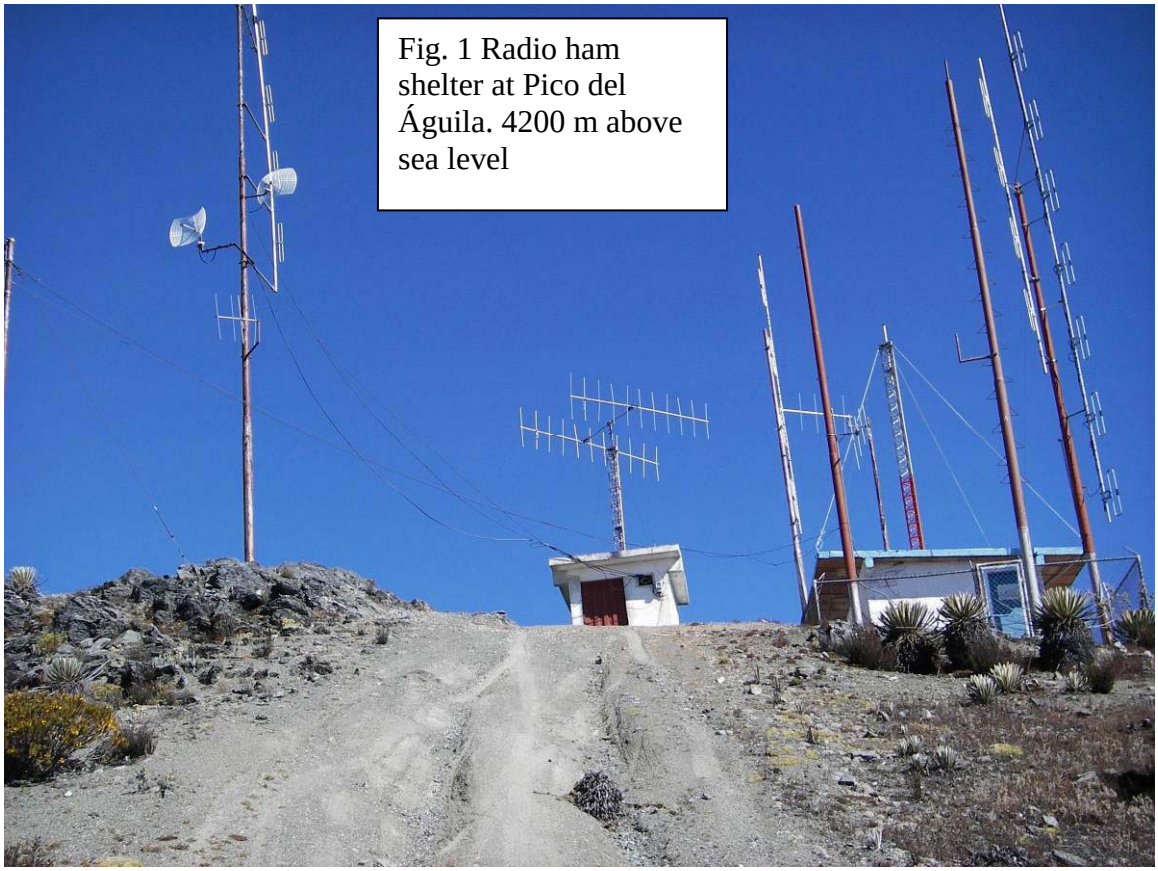

Fig. 1 Radio ham shelter at Pico del Aguila, 4200 m above sea level

Unfortunately, when we looked towards 94° we found the line of sight obstructed, as can be seen in fig. 2:

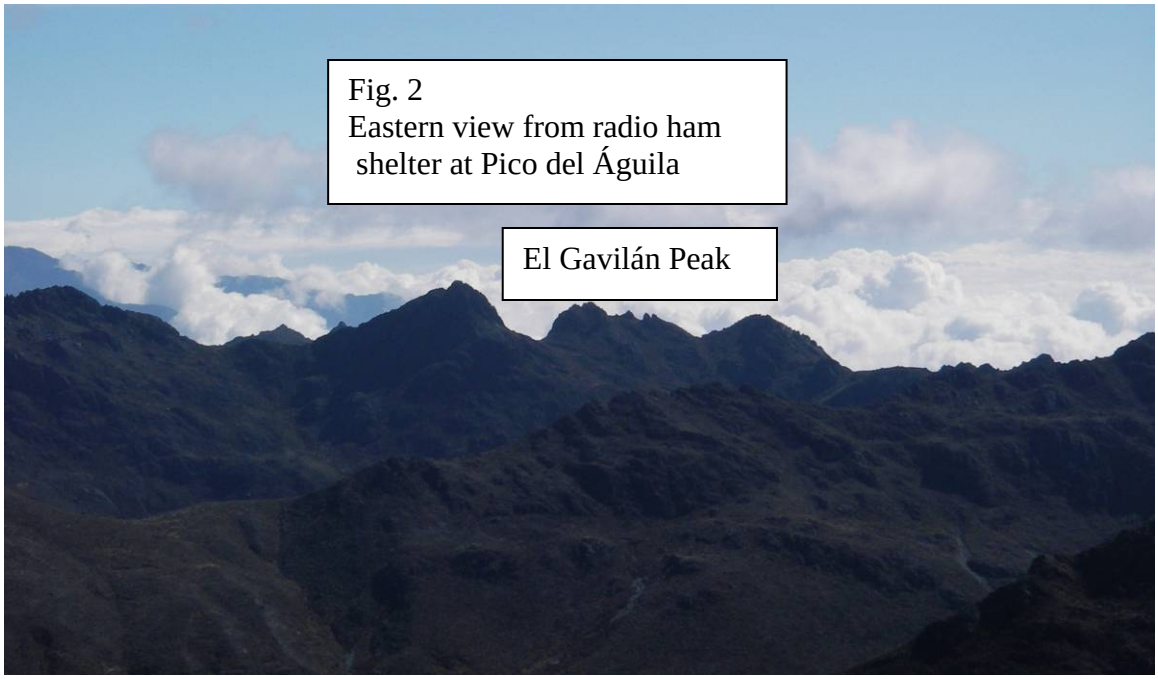

Fig.2 View towards El Baúl from Pico del Aguila

We therefore examined the landscape from every one of the dozen towers in the area and found the view due East obstructed from all of them, as can be seen fro the aerial photograph in fig.3.

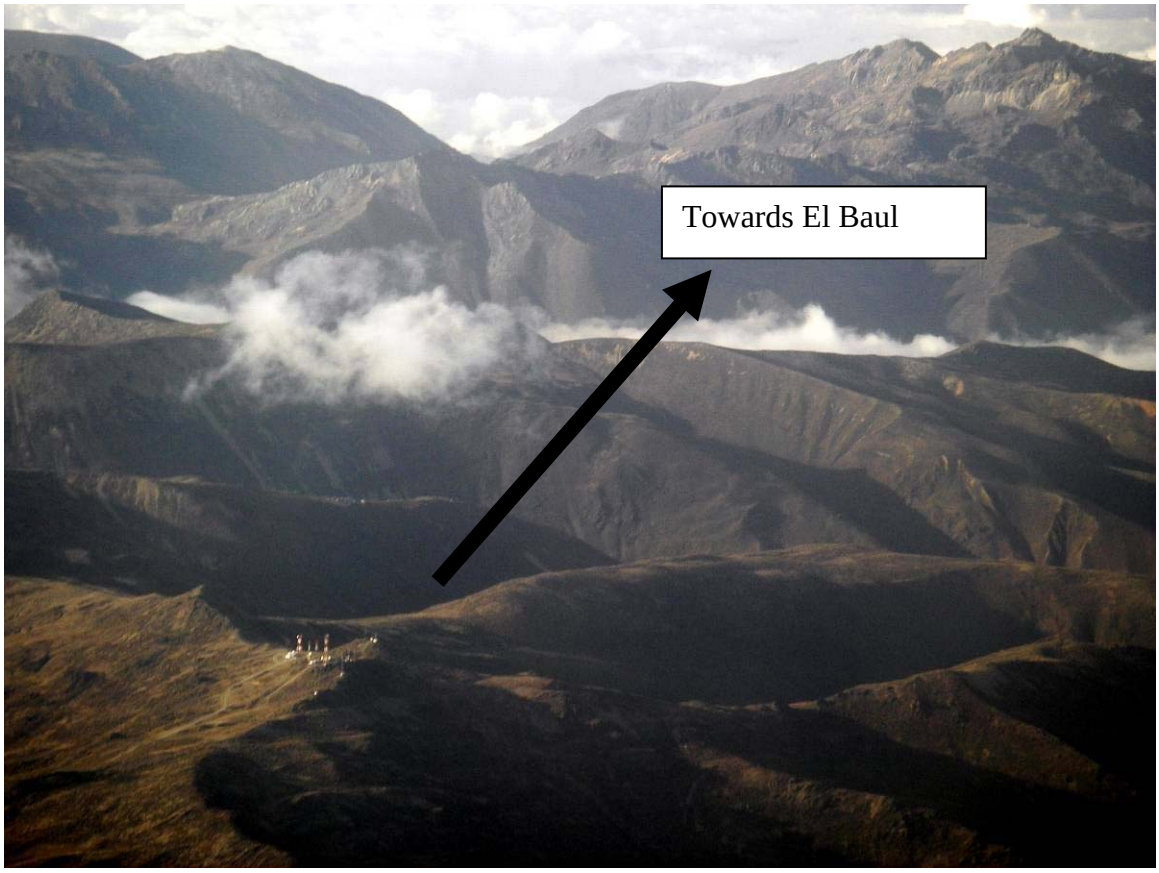

Fig. 3. Aerial photograph of the Pico del Aguila region

It can be seen that at the right of the Gavilan peak the mountain slopes down. This leds us to look into other sites, south of the Trasandina road that presumably could have unobstructed view, as can be appreciated in the following site photograph:

Fig. 4
El Gavilán Peak

Indeed, we were able to locate several possible sites before the fog prevented the visibility.
Some of the sites that seemed feasible are:

Site 204: 8° 50’ 8,4” N, 70° 49’33.9” W, h = 4100 m, Magnetic Azimuth towards El Baúl 95°, d= 282 km

Site 205: 8° 50” 0,5” N, 70° 49’ 47” W, h = 4098 m. Vehicle accesibility closer than the former.

Site 207: 8° 49’ 56” N, 70° 49’ 45,3 E, h= 4100. This site is at the edge of a ravine, which allows for the placing of the antenna at ground level and yet permits clearing of the first Fresnel Zone. The road is a little farther than from the previous site, but the ground is relatively flat.

Fig. 5. Site 207

Fig. 7. The dirt road that reaches the sites mentioned.

Site 208: 8° 49’ 54,3’ N, 70° 49’ 43,6” W, h=4090 m. This site is reachable directly by vehicle, and there is a quick drop of the terrain in the eastern direction, as can be seen by the following picture.

Fig. 8. View of site 207 from north. The fog prevented further explorations for the day.

Later, we checked the existence of line of sight using Radio Mobile and all the aforementioned sites were feasible.
The following picture shows the location of the sites in relation with Pico del Aguila storage facilities and telecommunications towers:

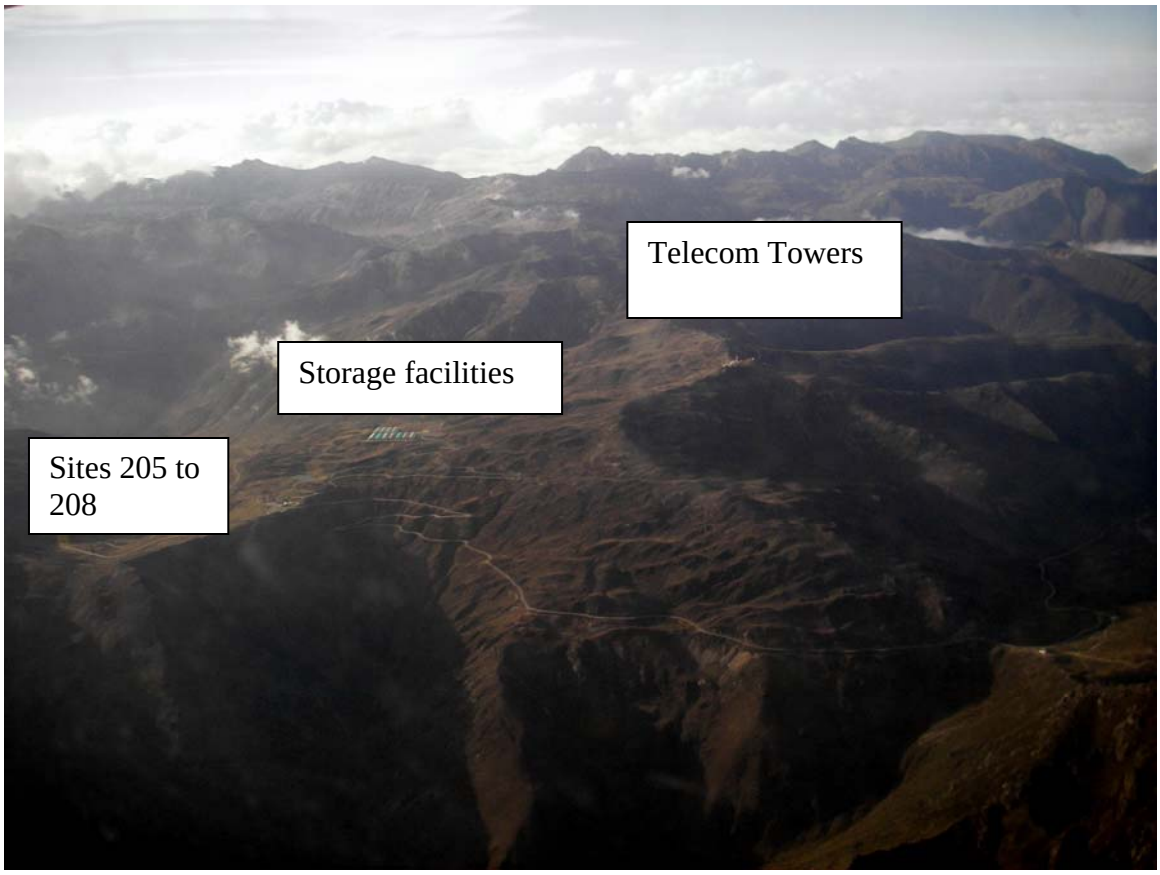

Fig.9. Aerial photograph of the Trasandina Road and the sites. Next pictures is a more detailed view.

Fig. 10.Close up of the previous .

By means of Google Earth, we could also corroborate the feasibility of the link towards EL Baul:

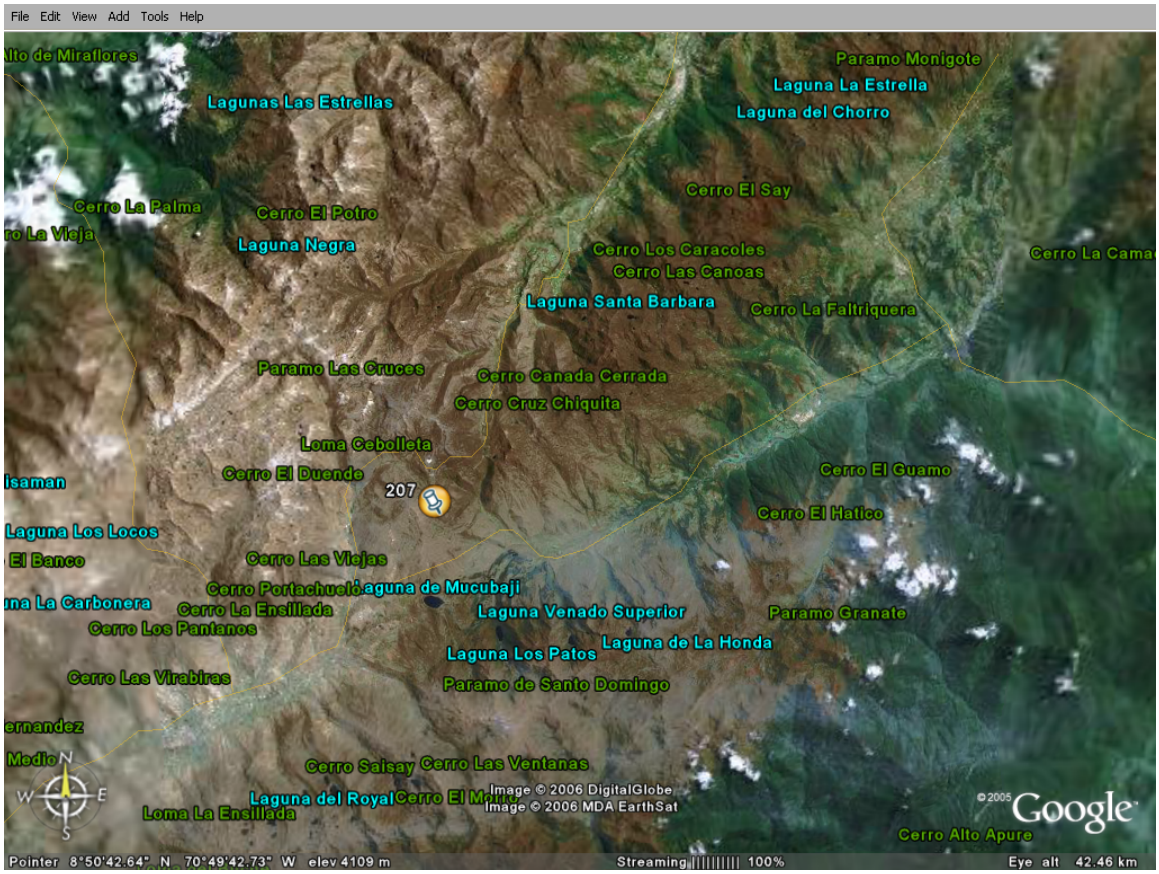

Fig.11. Location of site 207 between to mountain ranges. El Baul is due East.

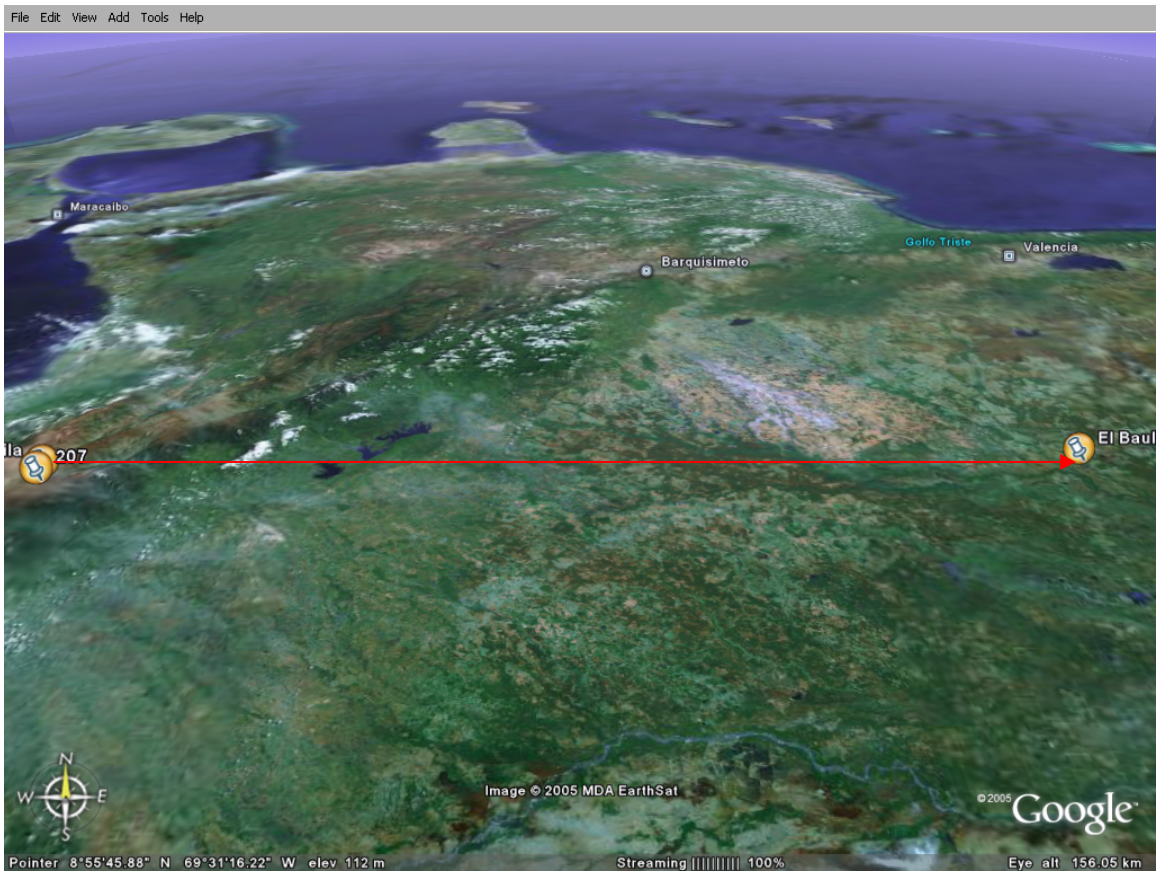

Fig. 12. View of the 282 km link, to the left Maracaibo's Lake, to the North, the Peninsula of Paraguaná

Antennas

The easiest solution is to purchase 30 dBi gain commercial antennas like the one sold by Hyperlink Technologies. These are fairly portable, and with a 5, 6 degree beamwidth, relatively easy to point, and weighing in at 16 kg easy to carry. They sell for about $400 in Florida but the transportation and importation costs are significant.

We decided instead to recycle parabolic reflectors formerly used for satellite service, replacing the feed with a 2,4 GHz. We proved the concept with an 80 cm dish, but the gain was way too low, so we next tried an offset fed 2,4 m reflector which offered ample gain, albeit with some difficulties in the aiming of the 3,5 degrees beam. The 22,5 degree offset meant that the dish appeared to be pointing downwards when it was horizontally aligned.
Several test were performed with cantennas as feed and also using a 12 dBi Yagi. We pointed at a base station of the university wireless network located 11 km away on a

3500m mountain. The test site sits at 2000m and therefore the elevation angle is 8 degrees. Because of the offset fed, we pointed the dish 14 degrees downward as can be seen in the following picture:

Fig. 13. 2,4 m offset fed Reflector with a 12 dBi antenna at its focus, looking 14 degrees down. The actual elevation is 8 degrees up.

We were able to establish a link with the Base Station at Aguada, but our efforts to measure the gain of the setup using *Netstumbler* were not successful, there was too much fluctuation on the received power values of live traffic.

Evidently, for a meaningful measurement of the gain, we need a signal generator and spectrum analyzer. These instruments are also required for the field trip in order to align the antennas properly.

While waiting for the required equipment, we looked for an antenna to be used at the other end, as well as for a pointing system better suited to the narrow radio beam.

On February 2006 I traveled to Triest to partake in the annual wireless training event I have been attending since 1996. While there I mentioned the project to my colleague Carlo Fonda who was immediately thrilled and eager to participate.

The collaboration between the Latin American Networking School (EsLaRed) and the Abdus Salam International Centre for Theorethical Physics (ICTP) in the wireless field goes back to 1992, when the first Networking School was held in Mérida with ICTP support. Since then, several activities in which members of both institutions have participated have taken place, notably the yearly training in wireless networking at ICTP and the ones dedicated to computer networks in general organized by EsLaRed in several countries of Latin America.
Accordingly, it was not difficult to persuade Dr. Sandro Radiciella, the head of the Aeronomy and Radio Propagation Laboratory at ICTP, to support Carlo Fonda's trip in early April to Venezuela in order to participate at the experiment.

Back home I found a 2,75 m parabolic central fed mesh antenna at a neighbors house. Mr Ismael Santos graciously lent his antenna for the experiment.
Fig. 14 shows the disassembly of the mesh reflector.

Fig. 14. Carlo and Ermanno disassembling the satellite dish supplied by Mr. Ismael Santos.

We then changed the feed for a 2,4 GHz and aimed the ensemble to a signal generator located on top of a ladder some 30m away. With a spectrum analyzer we could measure the maximum of the signal and therefore locate the focus as well as pinpoint the boresight for both the central fed and the offset antennas, as shown on fig. 15:

Fig. 15. Finding the focus of the antennas with the 2,4 GHz feed

We also compared the power of the received signal with the output of a commercial 24 dBi antenna achieving an improvement of 8 dB, which led us to believe that the overall gain of our antenna is about 32 dBi. Of course, there is some uncertainty in this value, since we were receiving reflected signals as well, but the value agreed with the calculation from the antenna dimension.

El Baúl Site Survey

Once we were satisfied with the proper functioning of both antennas and their aiming, we decided to do a site survey at the other end of the link, in El Baul area. Carlo Fonda, Gaya Fior and Ermanno reached the site on April 8th and the following day we found a hill south of the town with two telecom towers from two cell phone operators and one from the mayor of El Baul. The hill of Morrocoy is some 75 m above the surrounding area, about 125 m above sea level, and provides an unobstructed view towards El Aguila as seen in fig. 16. There is a dirt road to the top, a must for our purpose, given the weight of the antenna.

Fig. 16 View from Morrocoy Hill, 8° 57’27,6 “ N, 68° 17”51,1” W , Azimuth 276° Just south of the town of El Baul

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Using again *Radio Mobile*, we found unobstructed Fresnel zone on the 279 km trajectory to Aguila and 149 dB of free space loss. The loss can be compensated with two 30 dBi antennas so we decided to go ahead with the experiment and formed two working teams, one for Aguila and the other for Baul.

Performing the experiment

On Wednesday April 12, Javier Triviño and Ermanno Pietrosemoli traveled towards Baúl with a four wheel drive truck on top of which we had loaded the offset antenna as shown on fig. 17:

Figura 17. Truck with offset antenna at El Baúl site

Thursday 13 early morning we installed the antenna and pointed it at a compass bearing of 276 degrees, given that the declination is 8 degrees and therefore the true Azimuth is 268 degrees, as seen in fig. 18.

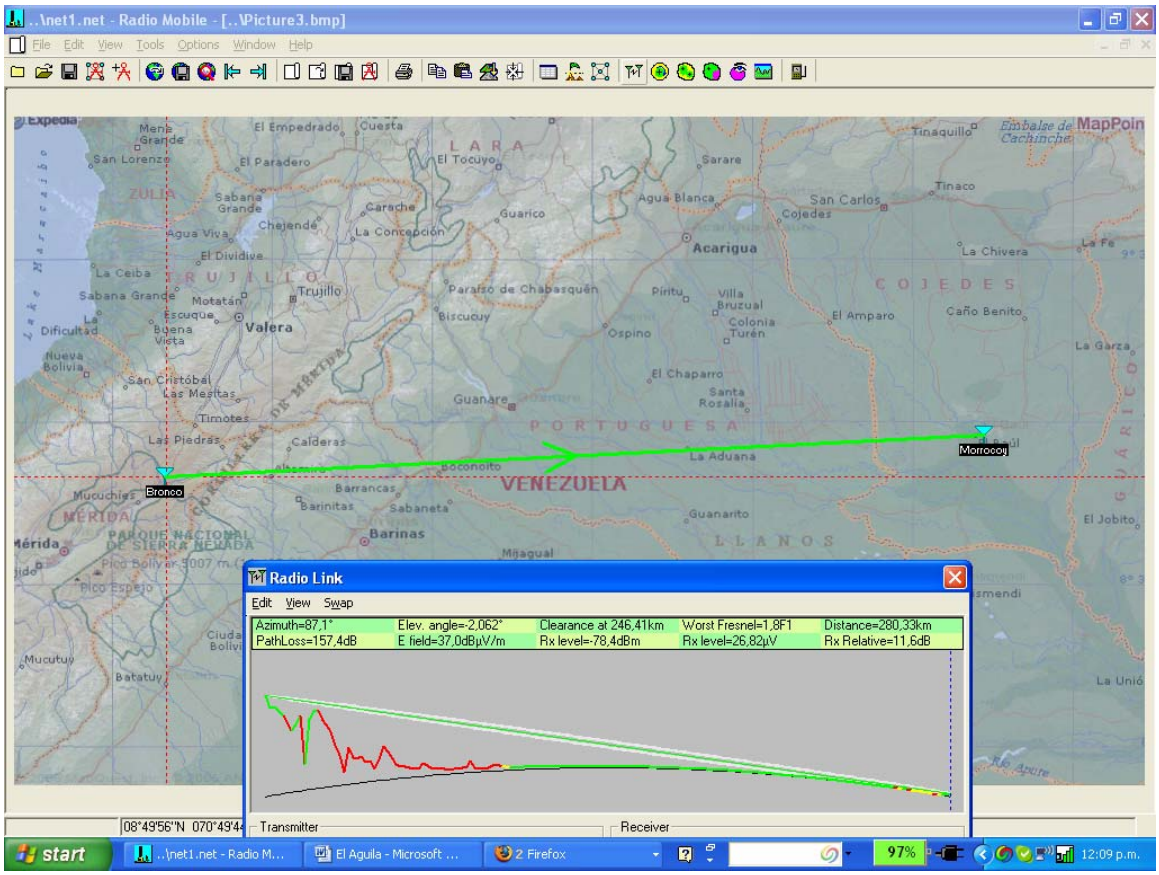

Figura 18. Map of the link and path.

Fig.19 shows values reported by *Radio Mobile*. Keep in mind that the resolution of the maps we have is 3 arc sec which corresponds to roughly 90 m, so there is a considerable degree of uncertainty in these results. The Garmin III plus GPS shows a total length of

279 km and a magnetic declination of 8 degrees.

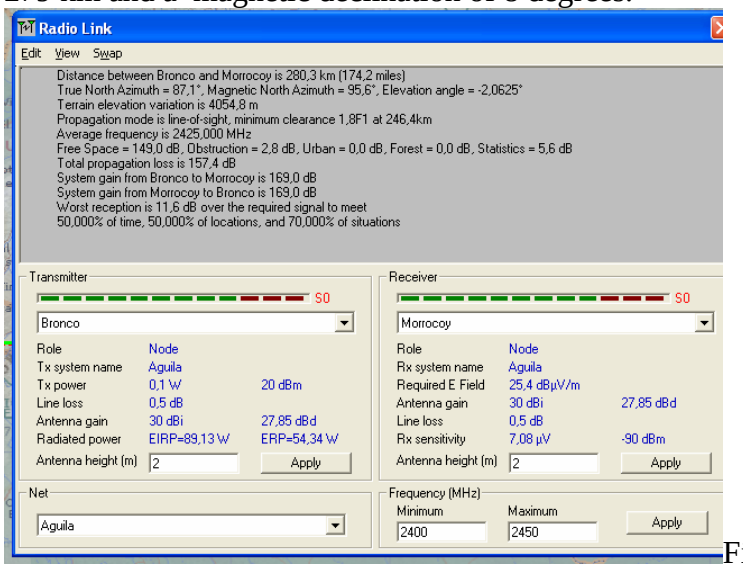

Fig. 20. Radio Link details

At the same time, the other team, composed by Carlo Fonda and Gaya Fior from ICTP, with assitance of Franco Bellarosa, Lourdes Pietrosemoli and José Triviño, rode to the previously surveyed area at Pico del Aguila in a Bronco truck carrying the 2,7 m mesh antenna, as seen in fig.21.

Figura 21. Pico del Águila and surrounds map with Bronco truck.

The Aguila team was able to install and point the mesh antenna before the fog and sleet began, as is common at this altitude of 4100 m above sea level. Fig. 22 shows the antenna and the rope used for aiming the 3 degrees radio beam.

Fig. 22. Aiming of the antenna at el Águila.

Power for the signal generator was supplied from the truck by means of a 12 V DC to 120 V AC inverter. At 11 A.M in El Baul we were able to observe a -82 dBm signal at the agreed upon 2450 MHz frequency on the spectrum analyzer. To be sure, we asked Carlo to switch off the signal and indeed the trace on the spectrum analyzer showed only noise, confirming that we were really seeing the signal originated some 280 km away.
After turning on again the signal generator we performed a fine pointing in elevation and azimuth at both ends, and when we were satisfied that had attained the maximum received signal, Carlo removed the signal generator and replaced it with a Linksys WRT54G wireless router configured as an Access Point, while Javier substituted the spectrum analyzer on our end for another WRT54G configured as a client.

At once, we started receiving “beacons” but the ping packets did not get through.

This was expected, since the propagation time of the radio wave over a 300 km link is 1ms, and therefore it takes at least 2 ms for an acknowledgment to reach the transmitter. Fortunately Open-WRT firmware allows for the tinkering with ACK timing and after Carlo adjusted for the 3 orders of magnitude increase in delay above what the standard Wi-Fi link expects we began receiving packets with delays above 5 ms.
Fig.23 shows the install at Baul.

Figura 23. El Baúl antenna install. Real elevation was 4 degrees upward.since the antenna has an offset of 22,5 degrees.

We proceeded to do several .pdf file transfers from Carlo's to Javier's laptops with the results shown on fig. 24

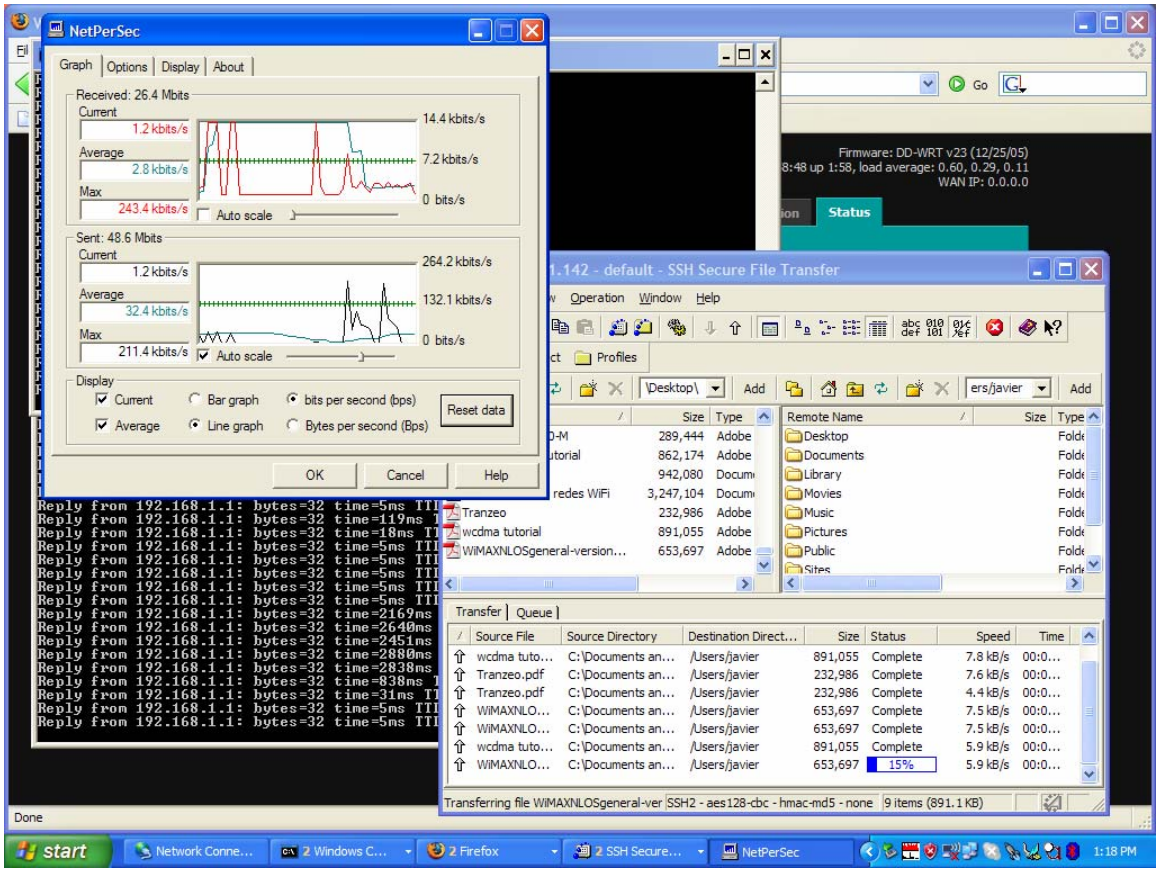

Fig.. 24. Screenshot of Javier's laptop showing details of .PDF file transfer from Carlo's laptop 279 km away, using two WRT54G wireless routers, no amplifiers.
Note the ping times as well

Fig. 25 shows the view from Baúl to Aguila

Fig. 25. View from El Baúl to El Águila.

And fro the other end:

Fig. 26. View from El Águila. Telecommunications towers can be seen in the far background

Fig. 27. Carlo Fonda, Gaya Fior and Franco Bellarosa remove the antenna at El Águila.

Fig. 28. Javier Triviño and Ermanno Pietrosemoli **beaming** from El Baúl antenna.

Acknowledgments

We wish to express our gratitude to Mr. Ismael Santos for lending the mesh antenna to be installed at El Aguila and to Eng. Andrés Pietrosemoli for supplying the special scaffolding joints used for the installation and transportation of the antennas.

To CVG Telecom for the time devoted to the preparation of this project.

To the Abdus Salam International Centre of Theoretical Physics for supporting Carlo

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Ermanno Pietrosemoli, Carlo Fonda and Javier Triviño
Eslared and ICTP

With the help of Franco Bellarosa, Lourdes Pietrosemoli and José Triviño.

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124.9 miles is the official record: http://www.wifiworldrecord.com/2005writeup.html

*Open Source firmwar*e para Linksys: http://openwrt.org/

Fundacite Mérida: www.funmrd.gov.ve

CVG Telecom: cvgtelecom.com.ve

Mérida, Venezuela, 17 April 2006.