High Capacity long distance wireless link

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Abstract—

An experiment to assess the throughput attainable over a 304 km microwave overseas link showed a maximum throughput of 176 Mbps in one direction and 179 Mbps in the other direction using COT equipment.

Keywords- Long wireless links, microwaves, RF propagation.

I. INTRODUCTION

Marconi experiment of 1901 demonstrated the feasibility of radio communications across the Atlantic Ocean, showing that communication was not prevented by the earth curvature. This was possible thanks to reflections in ionized layers of the ionosphere. These layers can only reflect long waves, at frequencies below 30 MHz, and are therefore quite limited in the amount of information that they can carry, which is proportional to the carrier frequency.

Several experiments were later performed to assess the maximum range of the so called quasi-optical waves, later known as microwaves. These could carry vast amount of information, but could not be reflected by the ionosphere and were therefore limited by the line of sight range. In 1930 Marconi [1] installed the first microwave radio telephone system and then set about to probe the maximum range attainable with microwave communications. He was able to transmit from Rocca di Papa, near Rome, to Capo Figari, in Sardinia over a distance of 270 km, despite the blockage introduced by the earth curvature. Fig. 1 shows the plate at Capo Figari commemorating the event.


Marina Militare

ITALIAN NAVY RADIO STATION

The radio station, built at the end of the 1800s, is of great historical importance, as it is here that Guglielmo Marconi carried out his scientific discoveries on radio communications. In April 1930, somewhere along the Lazio coast, a group of experts led by Guglielmo Marconi, prepared a 10 m wavelength radio electric directional beam, oriented on Golfo Aranci. On 23 May 1930, the ship Electra stopped at Golfo Aranci and for many days, Marconi's collaborator, the engineer Monachesi and his assistants, engaged in preparing the equipment necessary to complete the planned experiments. The results were exciting, but nevertheless, the scientific discoveries were questioned by an American scientist, jealous of the Italian genius. To eliminate all doubt, Marconi boarded the Electra on 6 August with a government commission, composed of eminent radio technicians, to Golfo Aranci. The equipment was transported the next morning and installed on the terrace of the radio station at 342 m above sea level. The signals arrived almost immediately. A very proud Marconi said of his achievement: "You see, once again the so-called theorists were wrong, and I, without a lot of calculations, without a lot of theories, I have shown that the micro-waves propagation is different from that of the light waves."

Fig. 1 Plate at Capo Figari in Sardinia commemorating the early microwave experiments conducted by Marconi

In April 2006 a team from EsLaRed (Escuela Latinoamericana de Redes, www.eslared.net) and ICTP (International Centre for Theoretical Physics, www.ictp.it) showed the feasibility of WiFi transmission at over a 280 km in Venezuela, and in April of 2007 we were able to increase the distance to 382 km. Over this longer path we used Linksys WR54G wireless routers with 1.5 m parabolic antennas that provided a very limited throughput at 2.4 GHz. Substituting the Linksys with TDMA routers the throughput increased to 3 Mbps in each direction for a total of 6 Mbps [2].

The profile in Fig. 2 shows that that the first Fresnel zone could be cleared despite the curvature of the earth when the earth radius is modified by the K=4/3 factor.

Fig. 2 Profile of the 382 km path between Pico del Aguila and Platillon in Venezuela

In June 2007 italian radio ham members of C.I.S.A.R. set up a link between Mount Amiata in Tuscany and Mount Limbara in Sardinia, on a 304 km path. Using 1.2 m parabolic reflectors with home made feedhorns to obtain antennas with an estimated gain of 35 dBi, connected to MikroTik routerboards fitted with UBNT 5 GHz radio cards, they were able to receive about 5 Mbps on a 5 MHz channel. The latency was between 8 and 20 ms [3], [4], [5].

Fig.3 shows the profile between Amiata in Tuscany and Limbara in Sardinia, most of the path is over water which facilitates clearing the first Fresnel Zone.

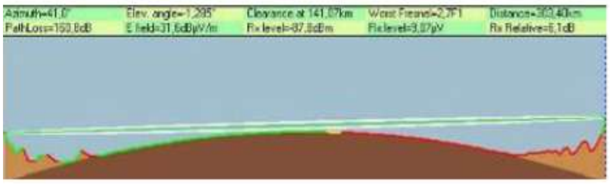

Fig. 3 Profile of the Limbara-Amiata 304 km link showing 2.7 clearance of the firs Fresnel Zone with K=4/3

II. FASTFORWARD

In 2015 we were approached by Alex Pavlos with the proposition of testing some new firmware that was supposed to provide a significant improvement in throughput of the Ubiquiti Networks AF5X radios over very long distances. Since we are keen on keeping abreast with technology advances, we started immediately searching for a suitable testbed. After looking at some very promising sites, which offered unencumbered line of sight over distances in the 300 km range, we focused on the Amiata-Limbara path for the following reasons:

1) *With the collaboration of C.I.S.A.R. radio amateurs who can provide access to both ends of the path the logistics will be greatly simplified.*
2) *This collaboration will also allow conducting long term measurements over the proposed path with different kind of equipment.*
3) *There is convergence of interest of the three satkeholders; ICTP for the scientific aspects, C.I.S.A.R for exploring the bleeding edge of technology and Ubiquiti to get real world data on the performance of their radios.*
4) *Long distance wireless links are particularly useful to provide connectivity to islands, so the test bed chosen can provide useful insights into the planning for some of the projects we are currently contemplating.*

Consequently, we held several teleconferences to discuss the details and finally set the dates for the installation at May 7 and 8, 2016. The radios and antennas will be shipped from U.S.A. It was agreed to use 1.2 m parabolic reflector, dual polarization antennas that should provide strong enough signals to support the maximum throughput over the envisioned path.

The team at Amiata in Tuscany was composed by Giuseppe Misuri IW5CGM, Mauro Calderini IK0YUK, Renzo Rossi IW0SAB, Marco Brunozzi IW0RED and Giorgio Chiuppesi IZ5OCH from C.I.S.A.R, Marco Zennaro from ICTP and Bill Parise from UBNT.

Fig.5. The Amiata team inside the shelter

The team at Limbara in Sardinia was composed by Natale Sardo IWOUIF, Gianni Schintu ISOXDA, Gianluigi Corona IWOUUE, Paolo Piredda ISOFXH, Mario Mellis IWOUQF e Giampiero Usai ISODKG from C.I.S.A.R, Ermanno Pietrosemoli from ICTP and Alex Pavlos from UBNT.

Unfortunately, there were delays in the custom clearing for the big dishes, and in fact the one for Sardinia was delivered at the very last moment, Friday May 6 at 16:17, in Oristano, so next morning the Sardinia team had to start very early to take the antenna to Mount Limbara, while in Tuscany the installation work had already began taking advantage of the favorable weather in the early morning, as shown in Fig. 4.

Fig.4 View from Mount Amiata, 1739 m altitude, towards Mount Limbara, 1362 m, 304 km away in Sardinia

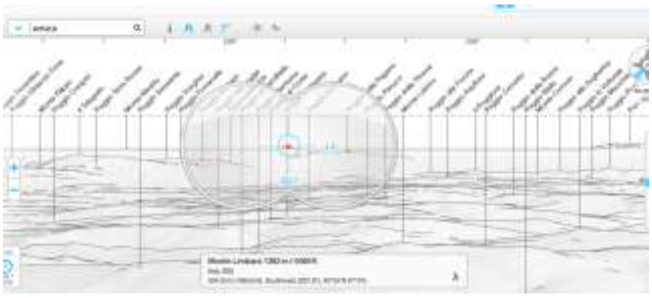

Fig. 5. Augmented Reality view from Mount Amiata towards Mount Limbara, using Peak Finder

Fig. 5 Shows the view towards Mount Limbara provided by the Peak Finder tool (http://www.peakfinder.org), showing the azimuth and corroborating that there is a non obstructed view to the remote site

Fig. 6 Hoisting the antenna in Amiata.

The installation of the 1.8 m dish in Amiata was accomplished by Giuseppe and his colleague as shown in Fig. 6.

Meanwhile, the weather was very foggy at Limbara when we were assembling the antenna shown in Fig. 7. Despite the fog and drizzle we succeeded installing the antenna in the tower, pictured in Fig. 8. The temperature was 6 degrees Celsius, the same as at the other end of the link, and the wind was blowing so we had to take turns to perform the installation and the antenna pointing in both azimuth and elevation. It took a while before we could see the glow of the LEDs in the AF5X that confirmed the alignment, and then we proceeded at the fine tuning using the reading of received signal strength provided by the radio web interface inside the shelter. The values were relayed to the team up the tower over hand held radios. The alignment task was complicated by the fact that the received signal presented significant fluctuations, we observed variations of the value of a few dBs even when the antennas were stationary at both ends.

Fig. 7. Assembling the antenna in Limbara

We first used slanted 45º polarizations at both ends and then switched to vertical and horizontal polarizations, taking advantage of the fact that the polarization changes only required rotating the feedhorn, without disturbing the parabolic reflector alignment. We did not observed any significant difference between the two arrangements, so we decided to stabilize into the 45º slanted polarization and leave further measurements for the next day. To complicate things, we had decided to use shielded Ethernet cables since there is quite a lot of RF at the top of both sites, but because of a mistake, the cables supplied where not shielded. Fortunately, Natale had some shielded cable and RJ45 connectors so we could limit the interefence on the line. In an effort to address the received signal fluctuations, Giuseppe Misuri, honoring his last name, proposed to use an RF signal generator to feed a single frequency power stable source at the Amiata antenna, so that we could improve the alignment at both ends using the spectrum analyzer tool provided by the AF5X web interface.

Fig. 8 Antenna at the tower in Mount Limbara

This would be available the next day, therefore, each group descended to their respective hotels to celebrate the success of the mission.

III. MEASUREMENTS

On Sunday May 8, the weather was also quite unstable, nevertheless both teams focused on improving the alignment; Giuseppe attached his generator to the Amiata feedhorn, injecting a 21.8 dBm tone at 5761 MHz and Alex read the received signal power on the screen of his laptop (Fig. 9), while we swept the Limbara dish first horizontally and then vertically until we found the peak of the signal, then we fixed the antenna in Limbara while the Amiata team repeated the procedure at their end.

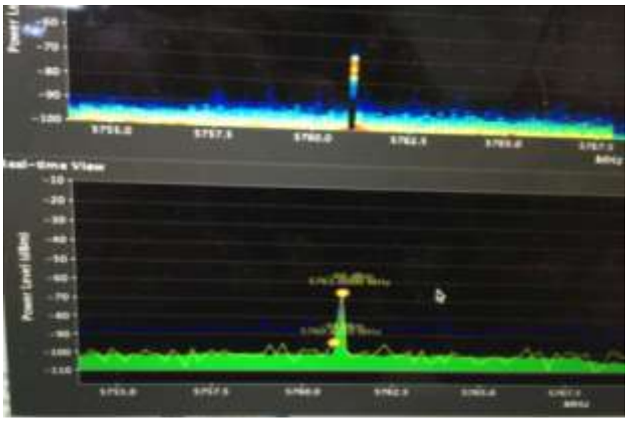

Fig. 9. Screenshot of the signal generator tone received after traversing 304 km.

We were then satisfied that the antenna alignment was optimum, but there were still fluctuations on the value of the signal that could be attributed to multipath, or to variations of the refraction index of the troposphere along the 304 km path, from the cold top of the mountains to the warm sea in between. Other factors, like the changing weather, could also intervene. At any rate, to address the multipath issue, Giuseppe connected one chain of the AF5X radio in Amiata to the 1.2 m dish and the other chain, through a 5 m RF jumper, to a smaller antenna in the same tower, while we were measuring the signal in Limbara. There were still signal fluctuations so we decided to move to the next phase of the experiment; replacing the the signal generator by the AF5X radio in Amiata and start measuring the throughput at different channel widths, one representative screenshot is Fig.10.

Fig. 10. Screenshot of the AF5X performance for a 10 MHz wide channel on a 304 km path with 1.2 m dishes.

We kept doing measurements over the following days, and the peak performance observed was 176 Mbps in one direction and 179 Mbps in the other direction by reducing 1 dB in the conducted power, on a 50 MHz wide channel as shown in Fig. 11. Using a 50 MHz wide channel was allowed by a temporary permit from Italy's Ministero dello Sviluppo Economico, to whom we express our gratitude. The received signal power still presents deep fading and we will conduct further measurements to investigate this aspect.

Fig. 11. Screenshot of the 304 km link on a 50 MHz channel showing a total throughput of 356 Mbps using 64 QAM MIMO with 1.2 m parabolic dishes.

There are still severe fluctuations of the received signal that can be attributed to multipath and also to variations of the tropospheric refraction index that modify the K factor.

Giorgio Chiuppesi performed simulations of the propagation profile for K= 4/3, the standard atmosphere, showing that the minimum clearance is 34 m, as shown in Fig. 12.

However, for K= 1.298, Fig. 13 shows that the path is now grazing and for lower values it becomes non line of sight for the radio signal. For optical signals the path is obstructed even at K=4/3. The layout of the link is shown in Fig. 14.

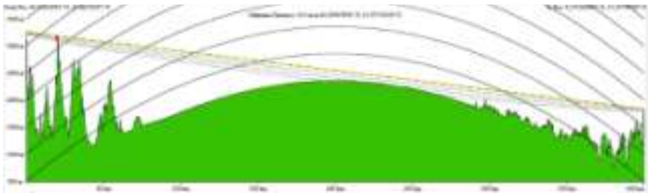

Fig. 12 Radio path for K=4/3 showing 34 m of clearance of the first Fresnel zone.

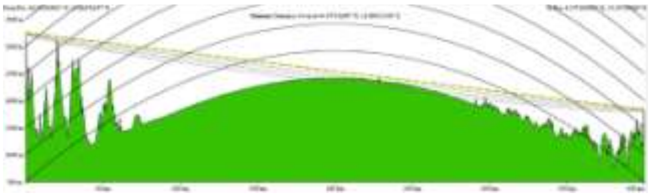

Fig. 13 Radio path for K=1.298 showing 0.4 m of clearance of the first Fresnel zone, that is a grazing path. For this value the received signal is attenuated several dBs and for lower values of K the radio path is obstructed.

Fig. 14. Layout of the link.

Fig. 15 Giuseppe Misuri delivering CISAR recognition to Bill Parisi and Marco Zennaro

IV. CONCLUSIONS

By the joint efforts of three parties, the C.I.S.A.R. Italian radio amateur club, the International Centre for Theoretical Physics and Ubiquiti Networks, a 304 km long link using off the shelf commercial equipment was built, obtaining a combined maximum throughput of 354 Mbps, for a figure of merit of 107920 Mbps.km, a great improvement over the performance of the experiment conducted in 2007 over the same path that only showed a maximum speed of dozens of megabits per second.

We will keep doing measurements using different polarizations and over different weather conditions to gather more information about the performance of long wireless links over water, which are quite useful to provide Internet access on many island still lacking broadband access, specially in countries with limited financial means.

ACKNOWLEDGMENTS

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