On a long wireless link for rural telemedicine in Malawi

M. Zennaro, C. Fonda, E. Pietrosemoli, A. Muyepa S. Okay, R. Flickenger, S.M. Radicella

Abstract— **In this paper we describe the process that brought us to setup a 162 km wireless link in Malawi: the first experiments in Venezuela and Italy, the equipment selection and the link deployment in August 2008. The network connects the University of Malawi College of Medicine in Blantyre with with the Mangochi Hospital as well as hospitals and research institutions in the cities of Blantyre, Zomba and Mangochi. We show that long-distance Wi-Fi links can be a practical, inexpensive alternative for providing network connectivity and access to the Internet in Developing Countries.**

Index Terms—**Wireless, Long links, Africa, low-cost.**

I. Introduction

Although it was initially developed for short links, Wi-Fi has proved to be effective for long distance applications too [1]. What differentiates long Wi-Fi links from local-access ones it that they involve significant infrastructure and planning, use highly directional antennas and require high antenna masts. They can be few tens of km to hundreds of km in length [2]. Such links are formed with the use of high-gain directional antennas. It is common to use antennas with gains of 24-32 dBi and beam-widths of about 8 degrees. Such high gain is necessary to achieve the long range.

For long distance backbone networks, fiber optics is nearly always the best choice, and has been widely deployed in Europe, North America and some regions of Asia. However, fiber networks in Africa and South America only reach the major cities and leave most of the rural areas underserved. Long distance wireless is often the only viable alternative for providing affordable telecommunications services to these areas. Satellite technologies are very efficient for broadcast (unidirectional) traffic, but are costly and severely limited in throughput for bidirectional Internet access.

The enormous commercial success of Wi-Fi has allowed for economies of scale that will be hard to beat by alternative technologies like WiMAX. Setting up a long Wi-Fi link is therefore not only the only alternative for many rural areas, but also the most cost effective one.

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C.Fonda, M.Zennaro and S.M.Radicella are with the Abdus Salam International Center For Theoretical Physics, Strada Costiera 11, 34014, Trieste, Italy. (+39) 040 2240 111 (e-mail:mzennaro@ictp.it).

Ermanno Pietrosemoli is with EsLaRED., Merida, Venezuela (e-mail: ermanno@ula.ve).

Stephen Okay is with Inveneo, San Francisco, CA. USA. +1-415- 901-1969 x1250 (e-mail:steveo@inveneo.org).

Rob Flickenger is with Hacker Friendly Publishing, Seattle, WA. USA. (e-mail:rob@hackerfriendly.com)

Anthony Muyepa is with the College of Medicine, Blantyre, Malawi (e-mail: muyepaa@medcol.mw)

II. First Experiments

To test the best equipment for long links, it is necessary to find a location with an unobstructed line-of-sight between two sites. As the distance between sites increases, the curvature of the Earth becomes a serious obstacle, requiring higher elevation at both ends. Installation on towers or other tall structures is mandatory, and the longest distance links are only possible from high elevations.

For the first experiment, our attention shifted to the Andes, whose steep slopes proved adequate to the task [3]. We selected Pico del Aguila as first site. It has an altitude of 4200 meters and provides clear line-of-sight to the town of El Baúl, in Cojedes State. Using the free software Radio Mobile [4], we found that there was no obstruction of the first Fresnel zone between Pico del Aguila and El Baúl (Figure 1). The distance between the two is of 280 km. We decided to test first the popular Linux based Linksys WRT54G wireless router. The big advantage of such equipment is that several customized firmware are available to modify transmission parameters. In particular, OpenWRT firmware [5] allows for the adjustment of the acknowledgment time of the MAC layer (the propagation time of the radio wave over a 300 km link is 1 ms, so it takes at least 2 ms for an acknowledgment to reach the transmitter), as well as the output power that can reach 200 mW. During this experiment, we used expensive signal generators and spectrum analyzers to align the antennas. After we adjusted the ACK time using the OpenWRT firmware we began receiving ICMP packets with a delay of about 5 ms. We proceeded to transfer several PDF files between our laptops, with speeds of about 65 kbps.

One year after performing this experiment, we found the time and resources to repeat it. We used commercial 30 dBi antennas, and also a couple of wireless routers which had been modified by the TIER group Berkeley University [6]. These routers modify the standard Wi-Fi MAC replacing the CSMA Media Access Control with TDMA. The latter is better suited for long links because it does not require the reception of ACKs. Using the same Linksys WRT54G routers we used in the first experiment, a solid link was quickly established. This allowed for video transmission at a measured throughput of 65 kbps. With the TDMA routers, the measured throughput was 3 Mbps in each direction. This produced the total of 6 Mbps as predicted by simulations done at Berkeley.

Thrilled by these results, we tried a new link between El Aguila and Platillón, some 382 km away. Platillón is 1500 m above sea level and there is an unobstructed first Fresnel zone towards El Aguila. Again, the link was quickly established with the Linksys and the TIER supplied routers. The Linksys link showed approximately 1% packet loss, with an average round trip time of 12 ms. The TIER equipment showed no packet loss. This allowed for video transmission, but the link was not stable. We noticed considerable signal fluctuations that often interrupted the communication. When the received signal was sufficient, the measured throughput was a total of 6 Mbps bidirectional with the TIER routers implementing TDMA.

In February 2007, a 101 km wireless link was established between the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy, and Piancavallo. Piancavallo is about 1200 m above sea level, while the ICTP is 70 m above sea level. Being 100 km the distance where standard Wi-Fi equipment shows a drastic reduction in throughput, we decided to test a standard Wi-Fi device (with the ACK modification). Using the Metrix Mark II box and a 400mW SR2 radio card, we measured a throughput of around 85 kpbs up/down with the bitrate fixed at 36 Mbps. When we fixed the bitrate at 11 Mbps, we measured 592 kbps down / 616 kbps up. The link quality varied throughout the day. The available signal fluctuated from -64 dBm to -87 dBm (a difference of 23dB!). We noted that the signal level definitely varied with the wind speed. We assume that the link would have been far more stable with the large dish on the Piancavallo side fixed more securely in place. The best throughput we achieved was approximately 600 kbps, as measured by the TCP/IP performance tool iperf [7]. We used video conferencing, VoIP, chat, email, and the web over the link.

After the Piancavallo experiment, we decided to setup a permanent wireless testbed, to be able to test different equipment over a long period of time. We were hosted by a HAM association at Monte Cesen, some 133 km from the ICTP. Monte Cesen is 1500 m above sea level, and has clear line of sight to the ICTP. In November 2007 we installed one 2.4 GHz link and three 5 GHz links. We wanted to test commercial solutions: Mikrotik boards running Mikrotik Router OS with Ubiquity XR5 radios. The antennas were se up using both vertical and horizontal polarizations, to provide the opportunity to measure the performance of various equipment at each polarization. The total cost of the wireless equipment was approximately $600 per link, including the antennas. A control link (the 2.4 GHz one) was used to provide management and access to the testbed. The Mikrotik equipment uses a proprietary long distance protocol called Nstreme. We were able to measure an approximate throughput of 3 to 4 Mbps per link, over long periods of time.

What did we gain from these experiments, in different geographical locations and using different equipment? We found out that logistics plays a mayor role in such deployments. Being the sites so far away, it is difficult to reach the sites in short time. Communications must be guaranteed at all times in both sites. Due to the remoteness of the sites, there was no mobile phone coverage most of the time. We used VHF voice radios to communicate, with operating frequencies setup in advance. Antenna alignment turned out to be the most time consuming and difficult task. Being the sites so far away, it is difficult to perfectly align the antennas just using the software features offered by the radios (such as the Mikrotik). We used a signal generator on one end and a spectrum analyzer on the other [8]. This is expensive equipment, not within the reach of most Universities in Developing Countries. We tried to develop our own low-cost solution for antenna alignment based in this experience. Finally, we found that Mikrotik equipment performed very well at such long distances.

III. Equipment Selection

We started thinking about a long link in Malawi in 2007, during the visit of Prof. Gombachika from University of Malawi to the ICTP. The idea was to connect rural telemedicine centers using a long wireless link. The sites of Blantyre and Mangochi were selected, with Zomba Peak to serve as high central site. Since there is not line of sight between Blantyre and Zomba Peak, an intermediate repeater at Mpingwe Hill had to be used. The total distance is 162 km, with the Blantyre- Mpingwe-Zomba link accounting for 62 km and the Zomba-Mangochi for 100 km. It is noteworthy to mention that this last link had been the subject of previous unsuccessful attempts, so we were prepared to have to introduce two extra repeaters in Ulongwe and Ntaja. Fortunately, the site survey confirmed what our simulations had predicted: there are no obstacles in the 100 km path that might block the line of sight. Indeed we did not have to install the antennas at the very top of the towers since we were able to clear 160 % of the first Fresnel zone in this critical path, as shown in Figure 1.

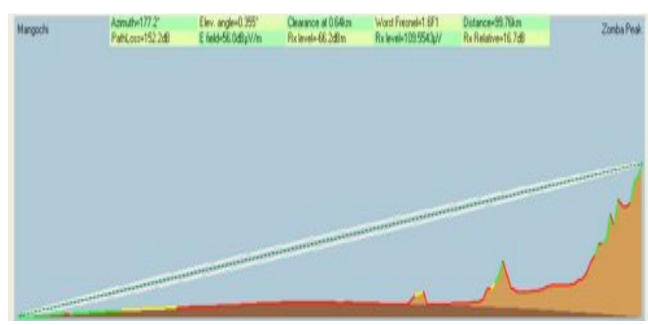

Figure 1. Profile of the 100 km link between Mangochi and Zomba Peak. Notice that the earth curvature is clearly noticeable, but does not block the line of sight.

The first task was then to select the appropriate equipment for such long links that could also offer a good throughput to sustain advanced telemedicine applications and also the future extension of the backbone further north.

We decided to look into products made by Mikrotik [9]. Mikrotik is a company based in Riga, Latvia, with many years of experience in wireless networks. It has developed its own routing software and sells the respective licensing at reasonable prices according to the required performance. Their star product, RouterOS, is Linux-based and offers most functionalities required by a router, with functions like firewalls, virtual private networks (VPN), traffic shaping, and also access point and wireless bridge functionalities. This software implements a router with any Linux-supporting PC with the required interfaces. Mikrotik also provides devices known as routerboards, as in Figure 2, which represent a specific case of single board computers (SBC) specifically designed for routing purposes, hence supporting several network interfaces, some of which can be wireless, generally using the miniPCI format. Mikrotik also has a more sophisticated software, called Nstreme, that facilitates the implementation of links of hundreds of kilometers by simply setting the distance at which it will operate. Nstreme2 furthermore allows the implementation of Frequency Diversity Duplexing (FDD), so in platforms with two radios, simultaneous transmission and reception can be achieved with the consequent increase in performance. Nstreme can also operate in point-to-multipoint mode, in which case it uses polling to provide a more efficient medium access at long distances than CSMA /CA.

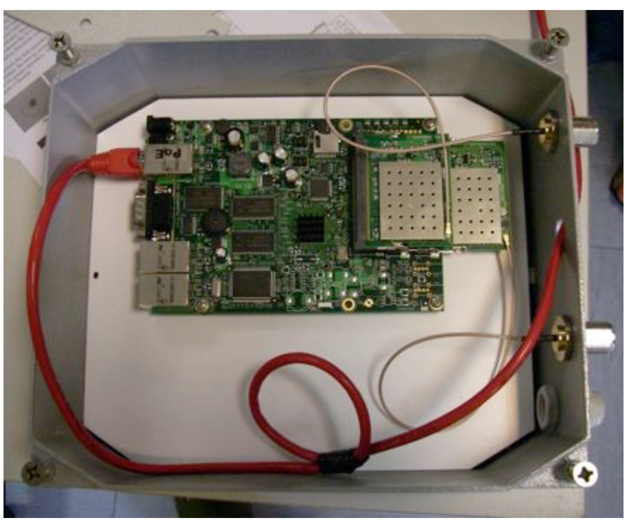

Figure 2. Mikrotik 433H wireless router fitted with two XR5 radios inside the weather proof housing. Notice the pigtails for connection to the external antennas and the UTP cable that provides also PoE.

Note that Mikrotik devices can be connected with standard compliant802.11 gear, but sacrificing the features of greater range and transmission speed.

For the shorter links, for example from Zomba Peak to Zomba hospital, we decided to use Ubiquiti Power Stations [10]. These wireless routers are inexpensive and are available in both the 2.4 and 5.8 GHz band. From the practical point of view, their main advantage is that they consist of a low-profile enclosure housing an integrated antenna and SBC making them ideal for installation either in towers or in slim masts. The SBC firmware is Linux-based and can be configured as Base Station, Client or Bridge.

We decided to use 5 GHz for the main backhaul: we supposed we were going to find less interference and the antennas would be smaller in size and would have a higher gain. We selected 32 dBi solid dishes for the backhaul.

IV. BLANTYRE-MANGOCHI LINK

Our final goal was to connect the College of Medicine in Blantyre with the hospital in Mangochi, with enough throughput to allow for further expansions of this backbone. Our simulations [4] were based on using existing towers and minimizing the number of repeater sites required, since each repeater adds to the latency, and reduces throughput and reliability, while increasing the cost of the system. A further requirement was that the town of Zomba has several health institutions and university premises that are also to be served by the network being built. Unfortunately, Zomba Peak does not offer direct line of sight to Zomba University or the Library at Chancellor College, so an additional repeater is needed inside the town to provide services to these locations, as depicted in Figure 3.

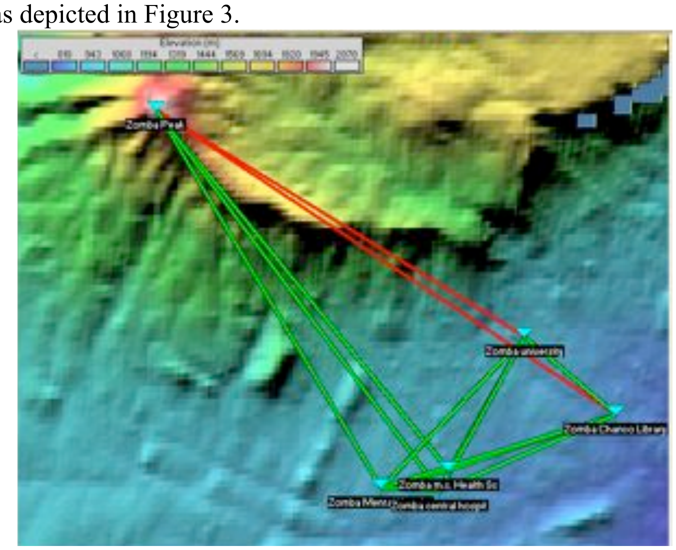

Figure 3. Coverage of Zomba´s institutions from Zomba Peak. Zomba University and Chancellor College Library cannot be serviced directly.

The final layout of the backbone is shown in Figure 4.

In order to provide high reliability and throughput each leg of the backbone was implemented with a completely redundant system using FDD (Frequency Diversity Duplexing), by means of 433H routerboards fitted with dual

Ubiquiti radios feeding dual polarizations 32 dBi solid parabolic antennas. If fading or equipment failure should bring down one link, the other link will maintain service.

V. Preliminary Results

A crucial aspect of a multi-hop microwave system is a thorough planning of the frequencies to be used, in order to avoid interference between transmitters and receivers. We spent some time trying different solutions and measuring the resulting throughput, until we achieved an end to end throughput between Blantyre College of Medicine and Mangochi exceeding 20 Mbps in each direction, for a total greater than 40 Mbps due to the frequency duplexing used.

This is enough to support several concurrent sessions of good quality video conference as well as the transfer of high resolution images at reasonable speed even with the requirements of loss-less compression imposed by the nature of medical imaging. VoIP allows for the provision of telephony services at low cost within the system. Given the great number of Malawian doctors working abroad, it is expected that this system will greatly facilitate the consulting of local doctors at remote health institutions with their peers worldwide, improving the quality of health care provided.

VI. Conclusions

In this paper we described the process that brought us to setup a 162 km wireless link in Malawi. From the first experiments in Venezuela and Italy, where we were able to establish successful links and that helped us gain experience in this field, up to equipment selection and link deployment in Malwi in August 2008. We showed that long-distance Wi-Fi links are a practical, inexpensive alternative for providing network connectivity in remote areas that wouldn't otherwise be served.

Figure 3. Map showing the complete backbone network, from Blantyre to Mangochi via Zomba Peak.

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