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Case Studies

No matter how much planning goes into building a link or node location, you will inevitably have to jump in and actually install something. This is the moment of truth that demonstrates just how accurate your estimates and predictions prove to be.

It is a rare day when everything goes precisely as planned. Even after you install your 1st, 10th, or 100th node, you will still find that things do not always work out as you might have intended. This chapter describes some of our more memorable network projects. Whether you are about to embark on your first wireless project or you are an old hand at this, it is reassuring to remember that there is always more to learn.

General advice

The economies of developing countries are very different from the developed world, and thus a process or solution designed for a more developed country may not be suitable in West Africa, or Southern Asia. Specifically, the cost of locally produced materials and the cost of labour will be negligible, whereas imported goods can be much more expensive when compared to its cost in the developed world. For example, one can manufacture and install a tower for a tenth of the cost of a tower in the United States, but the price of an antenna might be double. Solutions that capitalize on local competitive advantages, namely cheap labour and locally found materials, will be the easiest to replicate.

Finding the right equipment is one of the most difficult tasks in developing markets. Because transportation, communication and economic systems are not developed, the right materials or equipment can be difficult and often impossible to find. A fuse, for example, is difficult to find, thus finding wire that has a burn-up at a certain amperage and can substitute is a great advantage. Finding local substitutes for materials also encourages local entrepreneurship, ownership, and can save money.

Equipment enclosures

Cheap plastics are everywhere in the developing world, but they are made of poor materials and are thin, thus mostly unsuitable for enclosing equipment. PVC tubing is far more resilient and is made to be waterproof. In West Africa, the most common PVC is found in plumbing, sized from 90mm to 220mm. Access points such as the Routerboard 500 and 200 can fit into such tubing, and with end-caps that are torched-on, they can make very robust waterproof enclosures. They also have the added benefit of being aerodynamic and uninteresting to passers-by. The resulting space left around the equipment assures adequate air circulation. Also, it is often best to leave an exhaust hole at the bottom of the PVC enclosure. The author did find that leaving open holes can become a problem. In one instance ants decided to nest 25 meters above ground inside the PVC holding the access point. Using a wire mesh cover made from locally available screen material is advised to secure the exhaust hole from infestations.

Antenna masts

Recovering used materials has become an important industry for the poorest countries. From old cars to televisions, any material that has value will be stripped, sold, or re-used. For example, you will see vehicles torn apart piece by piece and day by day. The resulting metal is sorted and then tossed into a truck to be sold. Local metal workers will already be familiar with how to make television masts from scrap metal. A few quick adaptations and these same masts can be re-purposed for wireless networks.

The typical mast is the 5 meter pole, comprised of a single 30mm diameter pipe which is then planted into cement. It's best to construct the mast in two parts, with a removable mast that fits into a base which is slightly larger in diameter. Alternately, the mast may be made with arms that can be securely cemented into a wall. This project is easy, but requires the use of a ladder to complete and therefore some caution is suggested.

This type of mast can be augmented by several meters with the use of guy lines. To sturdy the pole, plant three lines 120 degrees apart, forming an angle of at least 33 degrees with the tower.

Above all: involve the local community

Community involvement is imperative in assuring the success and sustainability of a project. Involving the community in a project can be the greatest challenge, but if the community is not involved the technology will not serve their needs, nor will it be accepted. Moreover, a community might be afraid and could subvert an initiative. Regardless of the complexity of the undertaking, a successful project needs support and buy-in from those it will serve.

An effective strategy in gaining support is to find a respected champion whose motives are palatable. Find the person, or persons whom are most likely to be interested in the project. Often, you will need to involve such champions as advisors, or as members of a steering committee. These people will already have the trust of the community, will know who to approach, and can speak the language of the community. Take your time and be selective in finding the right people for your project. No other decision will affect your project more than having effective, trusted local people on your team.

In addition, take note of key players in an institution, or community. Identify those people whom are likely to be opponents and proponents of your project. As early as possible, attempt to earn the support of the potential proponents and to diffuse the opponents. This is a difficult task and one that requires intimate knowledge of the institution or community. If the project does not have a local ally, the project must take time to acquire this knowledge and trust from the community.

Be careful in choosing your allies. A "town-hall" meeting is often useful to see local politics, alliances, and feuds in play. Thereafter, it is easier to decide on whom to ally, champion and whom to diffuse. Try to not build unwarranted enthusiasm. It is important to be honest, frank, and not to make promises that you cannot keep.

In largely illiterate communities, focus on digital to analog services such as Internet for radio stations, printing on-line articles and photos, and other non-textual applications. Do not try to introduce a technology to a community without understanding which applications will truly will serve the community. Often the community will have little idea how new technologies will help their problems. Simply providing new features is useless without an understanding of how the community will benefit.

When gathering information, verify the facts that you are given. If you want to know the financial status of a company/organization, ask to see an electricity bill, or phone bill. Have they been paying their bills? At times, potential beneficiaries will compromise their own values in hopes of winning funds or equipment. Most often, local partners who trust you will be very frank, honest, and helpful.

Another common pitfall is what I call "divorced parents" syndrome, where NGOs, donors, and partners are not told of each others involvement with the beneficiary. Savvy beneficiaries can earn handsome rewards by letting NGOs and donors lavish them with equipment, training and funds. It is important to know which other organizations are involved so you can understand how their activities might impact your own. For example, I once designed a project for a rural school in Mali. My team installed an open source system with used computers and spent several days training people how to use it. The project was deemed a success, but shortly after the installation, another donor arrived with brand-new Pentium 4 computers running Windows XP. The students quickly abandoned the older computers and lined-up to use the new computers. It would have been better to negotiate with the school in advance, to know their commitment to the project. If they had been frank, the computers that are now sitting unused could have been deployed to another school where they would be used.

In many rural communities in under-developed economies, law and policies are weak, and contracts can be effectively meaningless. Often, other assurances must be found. This is where pre-paid services are ideal, as they do not require a legal contract. Commitment is assured by the investment of funds before service is given.

Buy-in also requires that those involved invest in the project themselves. A project should ask for reciprocal involvement from the community.

Above all, the “no-go” option should always be evaluated. If a local ally and community buy-in cannot be had, the project should consider choosing a different community or beneficiary. There must be a negotiation; equipment, money, and training cannot be gifts. The community must be involved and they too must contribute.

—Ian Howard

Case study: Crossing the divide with a simple bridge in Timbuktu

Networks ultimately connect people together, and therefore always involve a political component. The cost of Internet in less developed economies is high and the ability to pay is low, which adds to the political challenges. Attempting to superimpose a network where human networks are not fully functioning is nearly impossible in the long term. Trying to do so can leave a project on unstable social ground, threatening its existence. This is where the low cost and mobility of a wireless network can be advantageous.

The author's team was asked by funders to determine how to connect a rural radio station with a very small (2 computer) telecentre to the Internet in Timbuktu, the desert capital of Mali. Timbuktu is widely known as an outpost in the most remote area of the world. At this site, the team decided to implement a model which has been called the ***parasitic wireless model***. This model takes a wireless "feed" that is spliced from an existing network, and extends that network to a client site using a simple bridged network. This model was chosen because it requires no significant investment by the supporting organization. While it added a source of revenue for the telecentre, it did not add a significant operational cost. This solution meant that the client site could get cheap Internet, albeit not as fast or as reliable as a dedicated solution. Because of opposed usage patterns between an office and a telecentre there was no perceptible slowing of the network for either party. Though in an ideal situation it would be best to encourage more development of the small telecentre into an ISP, neither the telecentre nor the market were deemed ready. As is often the case, there were serious concerns about whether this telecentre could become self-sustaining once its funders departed. Thus, this solution minimized the initial investment while achieving two goals: first, it extended the Internet to the target beneficiary, a radio station, at an affordable cost. Second, it added a small additional revenue source for the telecentre while not increasing its operational costs, or adding complexity to the system.

The people

Timbuktu is remote, though having a world renowned name. Being a symbol of remoteness, many projects have wanted to "stake a flag" in the sands of this desert city. Thus, there are a number of information and communications technologies (ICT) activities in the area. At last count there were 8 satellite connections into Timbuktu, most of which service special interests except for the two carriers, SOTELMA and Ikatel. They currently use VSAT to link their telephone networks to the rest of the country. This telecentre used an X.25 connection to one of these telcos, which then relayed the connection back to Bamako. Relative to other remote cities in the country, Timbuktu has a fair number of trained IT staff, three existing telecentres, plus the newly installed telecentre at the radio station. The city is to some degree over saturated with Internet, precluding any private, commercial interests from being sustainable.

Design Choices

In this installation the client site is only 1 km away directly by line of sight. Two modified Linksys access points, flashed with OpenWRT and set to bridge mode, were installed. One was installed on the wall of the telecentre, and the other was installed 5 meters up the radio station's mast. The only configuration parameters required on both devices were the ssid and the channel. Simple 14 dBi panel antennas (from *http://hyperlinktech.com/*)

were used. At the Internet side, the access point and antenna were fastened using cement plugs and screws onto the side of the building, facing the client site. At the client site, an existing antenna mast was used. The access point and antenna were mounted using pipe rings.

To disconnect the client, the telecentre simply unplugs the bridge on their side. An additional site will eventually be installed, and it too will have its own bridge at the telecentre so that staff can physically disconnect the client if they have not paid. Though crude, this solution is effective and reduces risk that the staff would make a mistake while making changes to the configuration of the system. Having a bridge dedicated to one connection also simplified installation at the central site. as the installation team was able to choose the best spot for connecting the client sites. Though it is not optimal to bridge a network (rather than route network traffic), when technology knowledge is low and one wants to install a very simple system this can be a reasonable solution for small networks. The bridge makes systems installed at the remote site (the radio station) appear as though they are simply connected to the local network.

Financial model

The financial model here is simple. The telecentre charges a monthly fee, about $30 per connected computer to the radio station. This was many times cheaper than the alternative. The telecentre is located in the court of the Mayor's office, so the principle client of the telecentre is the Mayor's staff. This was important because the radio station did not want to compete for clientele with the telecentre and the radio station's systems were primarily intended for the radio station staff. This quick bridge reduced costs, meaning that this selective client base could support the cost of the Internet without competing with the telecentre, its supplier. The telecentre also has the ability to easily disconnect the radio station should they not pay. This model also allowed sharing of network resources. For example, the radio station has a new laser printer, while the telecentre has a color printer. Because the client systems are on the same network, clients can print at either site.

Training

To support this network, very little training was required. The telecentre staff were shown how to install the equipment and basic trouble shooting, such as rebooting (power cycling) the access points, and how to replace the unit should one fail. This allows the author's team to simply ship a replacement and avoid the two day trek to Timbuktu.

Summary

The installation was considered an interim measure. It was meant to serve as a stop-gap measure while moving forward with a more complete solution. While it can be considered a success, it has not yet led to building more physical infrastructure. It has brought ICTs closer to a radio solution, and re-enforced local client/supplier relationships.

As it stands, Internet access is still an expensive undertaking in Timbuktu. Local politics and competing subsidized initiatives are underway, but this simple solution has proven to be an ideal use case. It took the team several months of analysis and critical thought to arrive here, but it seems the simplest solution provided the most benefit.

—Ian Howard

Case study: Finding solid ground in Gao

One day's drive east from Timbuktu, in Eastern Mali, is Gao. This rural city, which seems more more like a big village, sits up the the river Niger just before it dips South crossing into Niger and onto Nigeria. The city slopes into the river gently, and has few buildings taller than two stories. In 2004, a telecentre was installed in Gao. The project's goal was to provide information to the community in the hope that a better informed community would yield a healthier and more educated citizenry.

The centre provides information via CD-ROMs, films and radio, but the cornucopic source of information for the centre is the Internet. It is a standard telecentre, with 8 computers, an all-in-one printer, scanner, fax, a telephone and a digital camera. A small two room building was built to house the telecentre. It is located a bit outside of downtown, which is not an ideal location for attracting customers, but the site was chosen because of its sympathetic host. The site received funding for all construction needed, and equipment and initial training was supplied as well. The telecentre was expected to be self-sustaining after one year.

Several months after its opening, the telecentre was attracting few customers. It used a modem to dial-up to connect to an Internet provider in the capital. This connection was too slow and unreliable, and so the funder sponsored the installation of a VSAT system. There are a number of VSAT systems now available to the region; most of these services have just recently become available. Previously only C-band (which cover a larger area than Ku-band) systems were available. Recently, fiber has been laid in almost every subway tunnel and canal throughout Europe, and thus it has supplanted the more expensive satellite services. As a result, providers are now redirecting their VSAT systems to new markets, including middle and Western Africa, and South Asia. This has led to a number of projects which use satellite systems for an Internet connection.

After the VSAT was installed, the connection provided 128 kbps down and 64 kbps up, and cost about $400 per month. The site was having trouble earning enough revenue to pay for this high monthly cost, so the telecentre asked for help. A private contractor was hired, who had been trained by the author to install a wireless system. This system would split the connection between three clients: a second beneficiary, a radio station, and the telecentre, each paying $140. This collectively covered the costs of the VSAT, and the extra revenue from the telecentre and the radio station would cover support and administration of the system.

The people

Though capable and willing, the author's team did not do the actual installation. Instead, we encouraged the telecentre to hire the local contractor to do it. We were able to reassure the client by agreeing to train and support the contractor in the fulfillment of this installation. The premise of this decision was to discourage a reliance on a short-term NGO, and rather to build trust and relationships between domestic service providers and their clients. This design proved to be fruitful. This approach took much more time from the author's team, perhaps twice as much, but this investment has already begun to pay-off. Networks are still being installed and the author and his team are now home in Europe and North America.

Design choices

Initially, it was conceived that a backbone connection would be made to the radio station, which already had a 25 meter tower. That tower would be used to relay to the other clients, avoiding the need to install towers at the client sites, as this tower was well above any obstacles in the city. To do this, three approaches were discussed: installing an access point in repeater mode, using the WDS protocol, or using a mesh routing protocol. A repeater was not desirable as it would introduce latency (due to the one-armed repeater problem) to an already slow connection. VSAT connections need to send packets up to the satellite and back down, often introducing up to 3000 ms in delay for a round trip. To avoid this problem, it was decided to use one radio to connect to clients, and a second radio for to the dedicated backbone connection. For simplicity it was decided to make that link a simple bridge, so that the access point at the radio station would appear to be on the same physical LAN as the telecentre.

In testing this approach functioned, though in the real world, its performance was dismal. After many different changes, including replacing the access points, the technician decided that there must be a software or hardware bug affecting this design. The installer then decided to place the access point at the telecentre directly using a small 3 meter mast, and to not use a relay site at the radio station. The client sites also required small masts in this design. All sites were able to connect, though the connections were at times too feeble, and introduced massive packet loss.

Later, during the dust season, these connections became more erratic and even less stable. The client sites were 2 to 5 km away, using 802.11b. The team theorized that the towers on either side were too short, cutting off too much of the Fresnel zone. After discussing many theories, the team also realized the problem with the performance at the radio station: the radio frequency 90.0 MHz was about the same as the frequency of the high-speed (100BT) Ethernet connection. While transmitting, the FM signal (at 500 watts) was completely consuming the signal on the Ethernet cable. Thus, shielded cable would be required, or the frequency of the Ethernet link would need to be changed. The masts were then raised, and at the radio station the speed of the Ethernet was changed to 10 Mbps. This changed the frequency on the wire to 20 MHz, and so avoided interference from the FM transmission. These changes resolved both problems, increasing the strength and reliability of the network. The advantage of using mesh or WDS here would be that client sites could connect to either access point, either directly to the telecentre to the radio station. Eventually, removing the reliance on the radio station as a repeater likely made the installation more stable in the longer-term.

Financial model

The satellite system used at this site cost approximately $400 per month. For many IT for Development projects this expensive monthly cost is difficult to manage. Typically these projects can purchase equipment and pay for the establishment of a wireless network, but most are not able to pay for the cost of the network after a short period of time (including the recurring Internet costs and operational costs). It is necessary to find a model where the monthly costs for a network can be met by those who use. For most community telecenters or radio stations, this is simply too expensive. Often, the only feasible plan is to share the costs with other users. To make the Internet more affordable, this site used wireless to share the Internet to the community, allowing a greater number of organizations to access the Internet while reducing the cost per client.

Typically in Mali, a rural community has only a few organizations or companies that could afford an Internet connection. Where there are few clients, and the Internet connection cost is high, the model developed by his team included ***anchor clients***: clients whom are solid and are low-risk. For this region, foreign NGOs (Non Governmental Organizations), the United Nations Agencies and large commercial enterprises are among the very few whom qualify.

Among the clients selected for this project were three anchor clients, who collectively paid the entire monthly cost of the satellite connection. A second beneficiary, a community radio station, was also connected. Any revenue earned from the beneficiaries contributed to a windfall, or deposit for future costs, but was not counted upon due to the small margins that both of these community services operated on. Those clients could be disconnected and could resume their service once they can afford it again.

Training needed: who, what, for how long

The contractor taught the telecentre technician the basics of supporting the network, which was fairly rudimentary. Any non-routine work, such as adding a new client, was contracted out. Therefore it was not imperative to teach the telecentre staff how to support the system in its entirety.

Lessons learned

By sharing the connection, the telecentre is now self-sustaining, and in addition, three other sites have Internet access. Though it takes more time and perhaps more money, it is valuable to find the right local talent and to encourage them to build relationships with clients. A local implementor will be able to provide the follow-up support needed to maintain and expand a network. This activity is building local expertise, and demand, which will allow subsequent ICT projects to build on this base.

—Ian Howard

Case Study: Fantsuam Foundation's Community Wireless Network

Kafanchan is a community of 83,000 people located 200 km northeast of Abuja, in central Nigeria. Kafanchan used to be known as a busy and thriving town as it was the host of one of the main junctions of the national railway. When the railway industry was booming, almost 80% of Kafanchan's populations relied on it in one way or another. Following the complete breakdown of the Nigerian railway system, the population of Kafanchan has been forced to go back to its original source of income, which is agriculture.

Kafanchan is a poorly connected area in terms of fixed telephony and Internet connectivity. Today, no fixed telephony (PSTN) is available in the area and GSM only just arrived in 2005. However, the GSM coverage is just as poor as the quality of the service. At the moment, SMS services are the most reliable communication service because voice conversations tend to cut off in the middle and suffer heavy noise.

Poor access to electricity brings further challenges to the people of Kafanchan. The national electric power company of Nigeria, generally known as NEPA (National Electric Power Authority), is more commonly known to Nigerians as "Never Expect Power Always". In 2005, NEPA changed its name to Power Holding Company of Nigeria (PHCN).

Kafanchan is receiving power from NEPA on an average of 3 hours per day. For the remaining 21 hours, the population relies on expensive diesel generators or kerosene for illumination and cooking. When NEPA is available on the grid, it provides an unregulated voltage in the range of 100-120 V in a system designed for 240 V. This voltage must be regulated to 240 V before most loads can be connected. Only light bulbs can be fed straight to the grid power since they can handle the low voltage without damage.

Project participants

Given the challenging background of Kafanchan, how could anyone come up with the idea of establishing the first rural Wireless ISP in Nigeria there? Fantsuam Foundation did and they made it happen.

Fantsuam Foundation is a local, non-governmental organization that has been working together with the community of Kafanchan since 1996 to fight poverty and disadvantage through integrated development programs. Fantsuam's focus lies on micro finance, ICT services and social development in rural communities of Nigeria. Becoming the first rural wireless ISP in Nigeria was part of their mission to be a recognized leader in the provision of rural development initiatives, as well as the foremost rural knowledge economy driver in Nigeria.

The Wireless ISP of Fantsuam Foundation, also know as ***Zittnet***, is funded by IDRC, the International Development Research Centre of Canada. IT +46, a Swedish based consultancy company focusing on ICTs for development, has worked together with the Zittnet team to provide technical support for wireless communications, bandwidth management, solar energy, power backup systems and VoIP deployments.

Objectives

The main objective of Zittnet is to improve access to communications in the area of Kafanchan by implementing a community wireless network. The network provides intranet and Internet access to local partners in the community. The community network is formed by community-based organizations such as educational institutions, faith-based institutions, health services, small enterprises and individuals.

Power Backup System

In order to provide a reliable service to the community, Zittnet needed to be equipped with a stable power backup system that would make the network run independently of the NEPA.

A hybrid power system was designed for Fantsuam, consisting of a deep-cycle battery bank and 2 kW (peak) solar panels. The system can charge from three different sources: a diesel generator, a solar array, and from NEPA when electricity is available. The network operation center (NOC) of the organization runs completely from solar energy. The rest of the Fantsuam's premises runs from NEPA or the generator via the battery bank, which provides uninterrupted voltage stability. The NOC load has been separated from the rest of the load of Fantsuam to ensure a reliable power source to the critical infrastructure in the NOC, even when the battery bank is running low on power.

Figure 11.1: 24 solar panels with a nominal power of 80 W have been mounted to the roof of the NOC to provide power to the system 24/7.

Simulations with the best existing solar data reveal that Kaduna State, where Kafanchan is located, receives at least 4 sun peak hours during its worst months which stretch from June to August (the rainy season).

Each of the solar panels (Suntech 80 W peak) provides a maximum current of 5 A (when the solar radiation is highest during the day). In the worst months of the year, the system is expected to produce not less than 6 KWh/day.

The solar system has been designed to provide 12 and 24 V DC output in order to match the input voltage of all low power servers and workstations for NOC infrastructure and training classrooms.

The solar panels used are ***Suntech STP080S-12/Bb-1*** with the following specifications:

- Open-circuit Voltage (V_{OC}): **21.6 V**
- Optimum operating voltage (V_{MP}): **17.2 V**
- Short-circuit current (I_{SC}): **5 A**
- Optimum operating current (I_{MP}): **4.65 A**
- Maximum power at STC (P_{MAX}): **80 W (Peak)**

The minimum 6 KWh/day that feeds the NOC is used to power the following equipment:

Device	Hours/Day	Units	Power (W)	Wh
Access points	24	3	15	1080
Low power servers	24	4	10	960
LCD screens	2	4	20	160
Laptops	10	2	75	1500
Lamps	8	4	15	480
VSAT modem	24	1	60	1440
Total				**5620**

The power consumption for servers and LCD screens is based on Inveneo's Low Power Computing Station, *http://www.inveneo.org/?q=Computingstation*.

The total estimated power consumption of the NOC is 5.6 kWh/day which is less than the daily power generated from the solar panels in the worst month.

Figure 11.2: The NOC is built by locally made laterite brick stones, produced and laid by youths in Kafanchan.

Network Operating Center (NOC)

A new Network Operating Center was established to host the power backup system and server room facilities. The NOC was designed to provide a place safe from dust, with good cooling capabilities for the batteries and the inverters. The NOC uses natural methods and is made from locally available materials.

The building is comprised of four rooms: a battery storage room, a server room, a working space and a room for equipment storage.

The battery storage room hosts seventy 200 Ah deep cycle batteries, as well as five inverters (one of them pure sine wave), two solar regulators, power stabilizers and DC and AC disconnects. The batteries are stacked vertically on a metal shelf structure for better cooling.

The server space accommodates a rack unit for servers and a fan. The room has no regular windows, to avoid dust and overheating. The server room and battery room face south to improve natural cooling and to help keep the room at an appropriate temperature.

The server room and the battery space require effective low cost/low energy cooling as they need to operate 24x7. To achieve this goal, natural cooling techniques have been introduced in the NOC design: small fans and extractors and thick walls of bricks (double width) in the direction of the sunset.

The south side of the building hosts 24 solar panels in a shadow-free area on its metal roof. The roof was designed with an inclination of 20 degrees to host the panels and limit corrosion and dust. Extra efforts have been made to keep the panels easily reachable for cleaning and maintenance. The roof has also been strengthened in order to carry the extra load of 150-200 kg.

The NOC building is constructed of locally produced laterite mud bricks. The material is cheap since it is frequently used and comes from the top layer of soil. The bricks are produced locally by hand using a low-tech pressing technique. The NOC is unique for its kind in Kaduna State.

Figure 11.3: Omolayo Samuel, one of the staff of Zittnet, does not fear the height of the 45m tall tower as she is aligning the antennas hosted in the top of the tower.

Physical infrastructure: A communication mast

Most potential clients to Zittnet are located between 1 km and 10 km from the premises of Fantsuam. In order to reach these clients, Fantsuam established a communication mast on their premises. In October 2006, a 45m (150 foot) tall selfstanding mast was installed at Fantsuam Foundation. The mast was equipped with grounding and lighting protection as well as a mandatory signal light.

A metal ring was buried at the base of the tower at a depth of 4 feet. All three legs of the mast were then connected to the grounding circuit. A lightning rod was mounted at the highest point of the mast to protect the equipment against lighting strikes. The rod is made of pure copper and is connected to the earth ring at the base of the mast using copper tape.

The signal light mounted at the top of the mast is a requirement from the Civil Aviation Authorities. The light is equipped with a photocell which enables automated switching based on the level of ambient light. In this way, the light comes on at night and goes off during the day.

Wireless backbone infrastructure

The wireless backbone infrastructure is built using SmartBridges multi-band access points and client units from the Nexus PRO™ TOTAL series. The units are designed for service providers and enterprises to establish high performance point-to-multipoint outdoor wireless links. They come with an integrated multi-band sectoral antenna that can operate both in 2.4 GHz and 5.1-5.8 GHz frequencies. The Nexus PRO™ TOTAL series offers QoS for traffic prioritization and bandwidth management per client using the IEEE 802.11e compliant WMM (WiFi Multimedia) extensions.

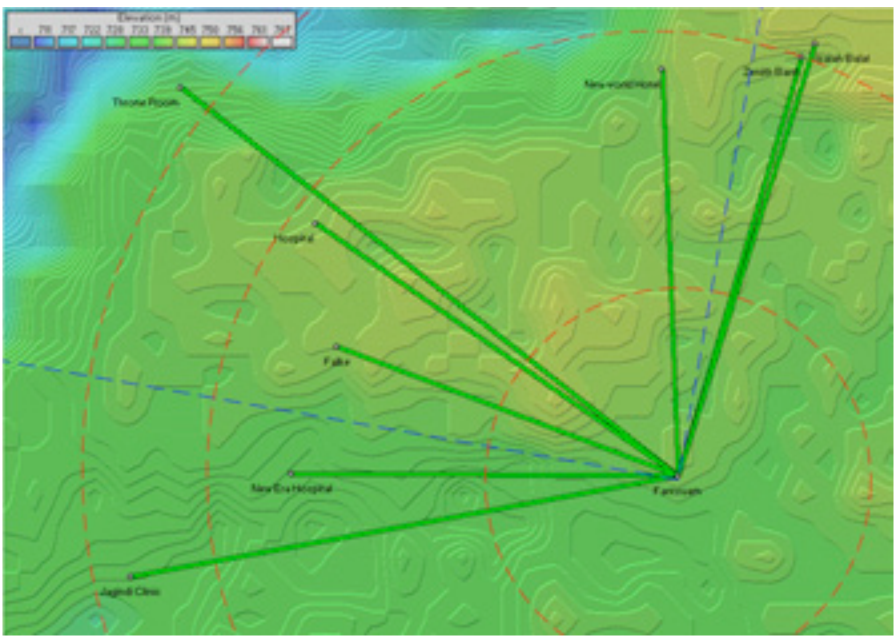

Figure 11.4: The network topology of Zittnet in October 2007.

Currently, the topology of the network is a star topology with two access points in the communication mast at Fantsuam's premises. One access point hosts a 90 degree sectoral antenna (blue dotted lines) and the other access point provides omnidirectional coverage to the surroundings (red dotted rings). Clients that are located within the area between the dotted lines are connected to the sectoral antenna, while the remaining clients are connected to the omnidirectional antenna.

Plans are underway to expand the wireless backbone by setting up two wireless repeaters. One repeater will be located in Kafanchan city using an existing NITEL tower to enhance the wireless coverage in the city center. The second repeater will be established in the Kagoro Hills, a small mountain group with a relative altitude to Kafanchan of about 500m, which is located about 7 km from Kafanchan. This repeater will provide coverage to many surrounding towns and may even enable a long-distance link to Abuja.

Zittnet connected its first client in early August 2007. Two months later, no less than eight clients are connected to Zittnet. These clients include:

- The general hospital
- New Era Hospital
- Jagindi Street Clinic (health clinic)
- Zenith Bank (for private use)
- Isaiah Balat (Internet café)
- New World Hotel
- Throne Room GuestHouse
- Fulke

Problems encountered

A few problem areas that have been constantly present throughout the project are as follows.

Low buildings

Most client premises are single-story buildings with a height of no more than 3 meters. Many houses have very weak roof structures which makes it impossible to mount equipment on the roof, as physical access is not possible. The low buildings force us to mount the equipment at a fairly low height, as clients can not afford to invest in small (10 m) masts to host the equipment. Most installations make use of water tanks or a simple 3 meter metal pole attached to the wall of the premise.

When the equipment is mounted low, the first Fresnel zone is not cleared and lower throughput is experienced. Although the landscape in Kafanchan is very flat, vegetation in the form of thick mango trees easily block the line-of-sight.

Lightning strikes

Heavy thunder storms are frequent during the rainy season in Kafanchan. In September 2007, a nearby lightning strike damaged equipment mounted on a mast, as well as its power supply. At the moment, the access point and its PoE injector are grounded to the tower itself. Further means need to be investigated to prevent damage to equipment caused by nearby lightning. The Zittnet team is currently working on improving the surge protection by adding extra coaxial surge arrestors. Furthermore, the shield of the UTP cable connecting the access point with the NOC will be grounded using grounding blocks and fasteners.

Low Quality Equipment

Unfortunately, a lack of quality products on the market is a widespread problem across the whole African continent. As most sub-Sahara countries lack policies for quality assurance of imported goods, the market is flooded by "cheap" and very low quality articles. Since quality products are hard to find, you often find yourself buying locally available merchandise that breaks even before it is put into operation. As no sort of warranty exists for these minor purchases, this ends up being very expensive. This problem is almost always present in common accessories such as power sockets, power bars, RJ45 connectors, CAT5 cabling, and other low-tech equipment.

Business Model

The only alternative for Internet access in Kafanchan is via satellite. During 2006, Fantsuam had a subscription of 128/64 kbps dedicated bandwidth at a cost of $1800 USD/month. This huge monthly cost of connectivity has been a big burden for Fantsuam and a constant stress of being unable to meet the monthly bill.

As an alternative to the high risk "flat fee" model, Fantsuam has implemented a system called ***HookMeUP*** provided by Koochi Communications. The system offers flexible Pay-As-You-Go charges over broadband VSAT Internet connections to countries across sub-Sahara Africa.

This kind of access model is typically found in airports, hotels or large shopping malls in western countries where end-users buy vouchers online and log in using an access code.

The HookMeUP system offers a 512/256 kbps dedicated VSAT connection to Fantsuam (from their ground station in the UK). Fantsuam buys vouchers from Koochi Communications and resells them to its local clients in Kafanchan. In this way, Fantsuam is no longer stuck with a fixed monthly cost but has only to pay Koochi for the bandwidth they actually have consumed. The risk of buying expensive international bandwidth has now been transferred to the Internet provider instead of the end user, at a cost of a higher price for the end user.

Fantsuam foundation now acts as a reseller of vouchers from Koochi and a supplier of wireless infrastructure to the end users. The Wireless Community Network now provides the Fantsuam Foundation with five sources of income:

1. Installation of client premises equipment (one occasion per client)
2. Leasing of wireless equipment (monthly cost per client)
3. Reselling wireless equipment (one occasion per client)
4. Installation of wireless hotspot at client's premise (one occasion per client)
5. Reselling of vouchers (continuously)

The voucher system is based on three parameters: ***access time***, ***data limit*** and ***validity time***. Whichever parameter runs out first will consume the voucher.

Access time	Data limit (MB)	Validity time	Price (USD)	USD / h	USD / 700 MB
30 min	5	1 day	0.80	1.60	112.00
60 min	10	5 days	1.28	1.28	89.60
12 hours	60	14 days	10.40	0.87	121.33
24 hours	150	30 days	26.00	1.08	121.33
1 month	500	1 month	71.50	0.10	100.10
3 months	1600	3 months	208.00	0.10	91.00
6 months	3500	6 months	416.00	0.10	83.20
12 months	7500	12 months	728.00	0.08	67.95

The greatest advantage of this system is that Fantsuam Foundation no longer has the burden of a huge monthly bill for international bandwidth. Having a flat-fee model means that you are forced to sell a certain amount of bandwidth every month. With the Pay-As-You-Go (PAYG) model, Fantsuam's income from reselling vouchers depends on how much bandwidth their clients consume. The client pays in advance (pre-paid model) with the result that Fantsuam will never end up in huge debt with the provider.

The pre-paid model works well in Africa since people are familiar with this model from mobile operators. It is even used by electricity companies in some counties. The pre-paid model is appreciated by many as it helps them to keep track of their expenditures. One of the main limitations of the PAYG model is the lack of flexibility and transparency. The current PAYG system provides very little feedback to the user about consumed time or volume. Only when the user logs off will he/she be informed about how many minutes are left to spend.

However, the business model seems to fit the local reality of Kafanchan and many other rural communities in Africa quite well. Although there is room for improvement, the advantage of avoiding debts is far greater than the disadvantages. With time, when the number of clients have increased and they can rely on a substantial monthly income from the wireless network, it might be beneficial to go back to the flat-fee model again.

Clients

The clients are free to use the Internet access for any purpose. For example, Isaiah Balat is reselling vouchers (that he bought from Fantsuam) to his clients. His Internet café hosts 10 computers that all are connected to Zittnet. The clients purchase vouchers from the owner with a margin of 25% over the price offered by Fantsuam. In return, clients that do not have access to a computer connected to Zittnet can access the network though the PC's at Isaiah Balat's café.

The New World Hotel is another client that aims to create a similar business model but on a larger scale. They will provide wireless Internet access to all of their rooms and offer access to Zittnet's uplink by reselling vouchers.

Other clients, like the General Hospital and the Jagindi Street Clinic, are using the Internet access for professional and private use without reselling access to its clients.

--Louise Berthilson

Case study: The quest for affordable Internet in rural Mali

For several years the international development community has promoted the idea of closing the digital divide. This invisible chasm that has formed separating access to the wealth of information and communications technologies (ICT) between the developed and the developing world. Access to information and communications tools has been shown to have a dramatic impact on quality of life. For many donors fatigued by decades of supporting traditional development activities, the installation of a telecentre in the developing world seems like a realizable and worthwhile effort. Because the infrastructure does not exist, this is much more expensive and difficult to do in the developing world than it is in the West. Moreover, few models have been shown to sustain these activities. To help mitigate some of the cost of bringing the Internet to rural areas of the developed world, the author's team has promoted the use of wireless systems to share the cost of an Internet connection. In November of 2004, an affiliated project asked the author's team to pilot such a wireless system at a recently installed telecentre in rural Mali, 8 hours South-West by four-by-four from Bamako, the capital.

This rural city, located on the margin of a man-made reservoir, holds water for the Manitali dam that powers a third of the country. This location is fortunate as hydroelectric power is much more stable and available than diesel generated power. While diesel generated power is far less stable, some rural communities are lucky to have any electricity at all.

The city is also endowed to be in one of the most fertile regions of the country, in its cotton belt, Mali's main cash crop. It was believed that this site would be the least difficult of the rural areas in Mali to make a self-sustaining telecentre. Like many experiments, this pilot was fraught with challenges.

Technologically it was a simple task. In 24 hours the team installed an 802.11b wireless network that shares the telecenter's VSAT Internet connection with 5 other local services: the Mayor, the Governor, the health service, the district's Mayor's council (CC) and the community advisory service (CCC).

These clients had been selected during a reconnaissance two months prior. During that visit the team had interviewed potential clients and determined which clients could be connected without complicated or expensive installations. The telecentre itself is housed at the community radio station. Radio stations tend to be great sites to host wireless networks in rural Mali as they are often well placed, have electricity, security and people who understand at least the basics of radio transmissions. They are also natural hubs for a village. Providing Internet to a radio station provides better information to its listeners. And for a culture which is principally oral, radio happens to be the most effect means to provide information.

From the list of clients above, you will note that the clients were all government or para-governmental. This proved to be a difficult mix, as there is considerable animosity and resentment between the various levels of government, and there were continuing disputes regarding taxes and other fiscal matters. Fortunately the director of the radio station, the network's champion, was very dynamic and was able to wade through most of these politics, though not all.

Design choices

The technical team determined that the access point would be installed at 20 meters up the radio station tower, just below the FM radio dipoles, and not so high as to interfere with coverage to client sites below in the bowl-like depression where most were found. The team then focused on how to connect each client site to this site. An 8 dBi omni (from Hyperlinktech, *http://hyperlinktech.com/*) would suffice, providing coverage to all client sites. The 8 dBi antenna that was chosen has a 15 degree vertical beamwidth, assuring that the two clients less than a kilometer away could still receive a strong signal. Some antennae have very narrow beam width and thus "overshoot" sites that are close. Panel antennae were considered, though at least two would be required and either a second radio or a channel splitter. It was deemed unnecessary for this installation. The following calculation shows how to calculate the angle between the client site's antenna and the base station's antenna, using standard trigonometry.

```
tan(x) = difference in elevation
       + height of base station antenna
       - height of CPE antenna
       / distance between the sites

    tan(x) = 5m + 20m - 3m / 400m
         x = tan-1 (22m / 400m)
         x =~ 3 degrees
```

In addition to the equipment in the telecentre (4 computers, a laser printer, 16 port switch), the radio station itself has one Linux workstation installed by the author's project for audio editing. A small switch was installed in the radio station, an Ethernet cable was run through plastic tubing buried at 5 cm across to the telecentre, across the yard.

From the main switch, two cables run up to a Mikrotik RB220, access point. The RB220 has two Ethernet ports, one that connects to the VSAT through a cross-over cable, and the second that connects to the radio station's central switch. The RB 220 is housed in a D-I-Y PVC enclosure and an 8 dBi omni (Hyperlink Technologies) is mounted directly to the top of the PVC cap.

The RB220 runs a derivative of Linux, Mikrotik version 2.8.27. It controls the network, providing DHCP, firewall, and DNS-caching services, while routing traffic to the VSAT using NAT. The Mikrotik comes with a powerful command line and a relatively friendly and comprehensive graphical interface. It is a small x86 based computer, designed for use as an access point or embedded computer. These access points are POE capable, have two Ethernet ports, a mini-pci port, two PCMCIA slots, a CF reader (which is used for its NVRAM), are temperature tolerant and support a variety of x86 operating systems. Despite that the Mikrotik software requires licensing, there was already a substantial user base in Mali. The system has a powerful and friendly graphical interface that was superior to other products. Due to the above factors the team agreed to use these systems, including the Mikrotik software to control these networks. The total cost of the RB220, with License Level 5, Atheros mini-pci a/b/g and POE was $461. You can find these parts at Mikrotik online at *http://www.mikrotik.com/routers.php#linx1part0.*

The network was designed to accommodate expansion by segregating the various sub-networks of each client; 24 bit private subnets were alloted. The AP has a virtual interface on each subnet and does all routing between, also allowing fire-walling at the IP layer. Note: this does not provide a firewall at the network layer, thus, using a network sniffer like tcpdump one can see all traffic on the wireless link.

To limit access to subscribers, the network uses MAC level access control. There was little perceived security risk to the network. For this first phase, a more thorough security system was left to be implemented in the future, when time could be found to find an easier interface for controlling access. Users were encouraged to use secure protocols, such as https, pops, imaps etc.

The affiliate project had installed a C-band VSAT (DVB-S) system. These satellite systems are normally very reliable and are often used by ISPs. It is a large unit, in this case the dish was 2.2 meters in diameter and expensive, costing approximately $12,000 including installation. It is also expensive to operate. A 128 kbps down and 64 kbps up Internet connection costs approximately $700 per month. This system has several advantages compared to a Ku system though, including: greater resilience to bad weather, lower contention rates (number of competing users on the same service) and it is more efficient at transferring data.

The installation of this VSAT was not ideal. Since the system ran Windows, users were able to quickly change a few settings, including adding a password to the default account. The system had no UPS or battery back up, so once a power outage occurred the system would reboot and sit waiting for a password, which had since been forgotten. To make this situation worse, because the VSAT software was not configured as an automatic background service it did not automatically launch and establish the link. Though the C-band systems are typically reliable, this installation caused needless outages which could have been resolved with the use of a UPS, proper configuration of the VSAT software as a service, and by limiting physical access to the modem. Like all owners of new equipment, the radio station wanted to display it, hence it was not hidden from view. Preferably a space with glass doors would have kept the unit secure while keeping it visible.

The wireless system was fairly simple. All of the client sites selected were within 2 km of the radio station. Each site had a part of the building that could physically see the radio station. At the client site, the team chose to use commercial, client grade CPEs: Based on price, the Powernoc 802.11b CPE bridge, small SuperPass 7 dBi patch antennas and home-made Power Over Ethernet (POE) adaptors. To facilitate installation, the CPE and the patch antenna were mounted on a small piece of wood that could be installed on the outside wall of the building facing the radio station.

In some cases the piece of wood was an angled block to optimize the position of the antenna. Inside, a POE made from a repurposed television signal amplifier (12V) was used to power the units. At the client sites there were not local networks, so the team also had to install cable and hubs to provide Internet for each computer. In some cases it was necessary to install Ethernet adapters and their drivers (this was not determined during the assessment). It was decided that because the client's networks were simple, that it would be easiest to bridge their networks. Should it be required, the IP architecture could allow future partitioning and the CPE equipment supported STA mode. We used a PowerNOC CPE bridge that cost $249.

Local staff were involved during the installation of the wireless network. They learned everything from wiring to antenna placement. An intensive training program followed the installation. It lasted several weeks, and was meant to teach the staff the day to day tasks, as well as basic network troubleshooting.

A young university graduate who had returned to the community was chosen to support the system, except for the cable installation, which the radio station technician quickly learned. Wiring Ethernet networks is very similar to coaxial cable repairs and installations which the radio technician already performed regularly. The young graduate also required little training. The team spent most of its time helping him learn how to support the basics of the system and the telecentre. Soon after the telecentre opened, students were lined up for the computer training, which offered 20 hours of training and Internet use per month for only $40, a bargain compared to the $2 an hour for Internet access. Providing this training was a significant revenue and was a task that the young computer savvy graduate was well suited for.

Unfortunately, and somewhat unsurprisingly, the young graduate left for the capital, Bamako, after receiving an offer for a government job. This left the telecentre effectively marooned. Their most technically savvy member, and the only one who was trained in how to support the system, had left. Most of the knowledge needed to operate the telecentre and network left with him. After much deliberation, the team determined that it was best not to train another tech savvy youth, but rather to focus on the permanent local staff, despite their limited technical experience. This took much more time. Our trainers have had to return for a total of 150 hours of training. Several people were taught each function, and the telecentre support tasks were divided among the staff.

Training did not stop there. Once the community services were connected, they too needed access. It seemed that although they were participating, the principals, including the mayor, were not using the systems themselves. The team realized the importance of assuring that the decision makers used the system, and provided training for them and their staff. This did remove some of the mystique of the network and got the city's decision makers involved.

Following training, the program monitored the site and began to provide input, evaluating ways that this model could be improved. Lessons learned here were applied to other sites.

Financial Model

The community telecentre was already established as a non-profit, and was mandated to be self-sustaining through the sale of its services. The wireless system was included as a supplementary source of revenue because early financial projections for the telecentre indicated that they would fall short of paying for the VSAT connection.

Based on the survey, and in consultation with the radio station that manages the telecentre, several clients were selected. The radio station negotiated contracts with some support from its funding partner. For this first phase, clients were selected based on ease of installation and expressed ability to pay. Clients were asked to pay a subscription fee, as described later.

Deciding how much to charge was a major activity which required consultation and expertise that the community did not have in financial projections. The equipment was paid for by the grant, to help offset the costs to the community, but clients were still required to pay a subscription fee, which served to assure their commitment. This was equivalent to one month of the service fee.

To determine the monthly cost for an equal slice of bandwidth we started with the following formula:

```
VSAT + salaries + expenses (electricity, supplies) =
telecentre revenue + wireless client revenue
```

We had estimated that the telecentre should earn about $200 to $300 per month in revenue. Total expenses were estimated to be $1050 per month, and were broken down as: $700 for the VSAT, $100 for salaries, $150 for electricity, and about $100 for supplies. About $750 in revenue from the wireless clients was required to balance this equation. This amounted to roughly $150 from each client. This was just tolerable by the clients, and looked feasible, but required fair weather, and had no room for complications.

Because this was becoming complicated, we brought in business geeks, who modified the formula as such:

```
Monthly expenses + amortization + safety funds = total
revenue
```

The business experts were quick to point out the need of amortization of the equipment, or one could say "re-investment funds" as well as safety funds, to assure that the network can continue if a client defaults, or if some equipment breaks. This added about $150 per month for amortization (equipment valued at about $3,000, amortized over 24 months) and the value of one client for default payments, at $100. Add another 10% to account for currency devaluation ($80), and that equals an expense of $1380 per month. In trying to implement this model, it was finally determined that amortization is a concept that was too difficult to convey to the community, and that they would not consider that clients might default on payment. Thus, both formulae were used, the first by the telecentre and the second for our internal analysis.

As was soon discovered, regular payments are not part of the culture in rural Mali. In an agrarian society everything is seasonal, and so too is income. This means that the community's income fluctuates wildly. Moreover, as many public institutions were involved, they had long budget cycles with little flexibility. Although they theoretically had the budget to pay for their service, it would take many months for the payments to be made. Other fiscal complications arose as well. For example, the mayor signed on and used the back-taxes owed by the radio to pay for its subscription. This of course did not contribute to cash flow. Unfortunately, the VSAT providers have little flexibility or patience, as they have limited bandwidth and only have room for those that can pay.

Cash flow management became a primary concern. First, the revenue foreseen in financial projections showed that even with an optimistic outlook, they would not only have trouble earning enough revenue on time to pay the fee, but getting the money to the Bamako-based bank also presented a problem. Roads near the village can be dangerous, due to the number of smugglers from Guinea and wayward rebels from the Ivory Coast. As projected, the telecentre was not able to pay for its service and its service was suspended, thereby suspending payment from their clients as well.

Before the project was able to find solutions to these problems, the cost of the VSAT already began to dig the telecentre into debt. After several months, due to technical problems, as well as concerns raised in this analysis, the large C-band VSAT was replaced with a cheaper Ku band system. Although cheaper, it still sufficed for the size of the network. This system was only $450, which by ignoring amortization and safety margins is affordable by the network. Unfortunately, due to default payments, the network was not able to pay for the VSAT connection after the initial subsidized period.

Conclusions

Building a wireless network is relatively easy, but making it work is much more of a business problem than a technical problem. A payment model that considers re-investment and risk is a necessity, or eventually the network will fail. In this case, the payment model was not appropriate as it did not conform to fiscal cycles of the clients, nor did it conform to social expectations. A proper risk analysis would have concluded that a $700 (or even a $450) monthly payment left too narrow a margin between revenue and expenses to compensate for fiscal shortcomings. High demand and education needs limited the expansion of the network.

Following training the network operated for 8 months without significant technical problems. Then, a major power surge caused by a lightning strike destroyed much of the equipment at the station, including the access point and VSAT. As a result, the telecentre was still off-line at the time that this book was written. By that time this formula was finally deemed an unsuitable solution.

—Ian Howard

Case study: Commercial deployments in East Africa

Describing commercial wireless deployments in Tanzania and Kenya, this chapter highlights technical solutions providing solid, 99.5% availability Internet and data connectivity in developing countries. In contrast to projects devoted to ubiquitous access, we focused on delivering services to organizations, typically those with critical international communications needs. I will describe two radically different commercial approaches to wireless data connectivity, summarizing key lessons learned over ten years in East Africa.

Tanzania

In 1995, with Bill Sangiwa, I founded CyberTwiga, one of the first ISPs in Africa. Commercial services, limited to dialup email traffic carried over a 9.6 kbps SITA link (costing over $4000/month!), began in mid-1996. Frustrated by erratic PSTN services, and buoyed by a successful deployment of a 3-node point-multipoint (PMP) network for the Tanzania Harbours authority, we negotiated with a local cellular company to place a PMP base station on their central mast. Connecting a handful of corporations to this WiLan proprietary 2.4 GHz system in late 1998, we validated the market and our technical capacity to provide wireless services.

As competitors haphazardly deployed 2.4 GHz networks, two facts emerged: a healthy market for wireless services existed, but a rising RF noise floor in 2.4 GHz would diminish network quality. Our merger with the cellular carrier, in mid-2000, included plans for a nationwide wireless network built on the existing cellular infrastructure (towers and transmission links) and proprietary RF spectrum allocations.

Infrastructure was in place (cellular towers, transmission links, etc.) so wireless data network design and deployment were straightforward. Dar es Salaam is very flat, and because the cellular partner operated an analog network, towers were very tall. A sister company in the UK, Tele2, had commenced operations with Breezecom (now Alvarion) equipment in 3.8/3.9 GHz, so we followed their lead.

By late 2000, we had established coverage in several cities, using fractional E1 transmission circuits for backhaul. In most cases the small size of the cities connected justified the use of a single omnidirectional PMP base station; only in the commercial capital, Dar es Salaam, were 3-sector base stations installed. Bandwidth limits were configured directly on the customer radio; clients were normally issued a single public IP address. Leaf routers at each base station sent traffic to static IP addresses at client locations, and prevented broadcast traffic from suffocating the network. Market pressures kept prices down to about $100/month for 64 kbps, but at that time (mid/late 2000) ISPs could operate with impressive, very profitable, contention ratios. Hungry applications such as peer-peer file sharing, voice, and ERPs simply did not exist in East Africa. With grossly high PSTN international charges, organizations rapidly shifted from fax to email traffic, even though their wireless equipment purchase costs ranged from $2000-3000.

Technical capabilities were developed in-house, requiring staff training overseas in subjects such as SNMP and UNIX. Beyond enhancing the company skills set, these training opportunities generated staff loyalty. We had to compete in a very limited IT labor market with international gold mining companies, the UN, and other international agencies.

To insure quality at customer sites, a top local radio and telecoms contractor executed installations, tightly tracking progress with job cards. High temperatures, harsh equatorial sunlight, drenching rain, and lightning were among the environmental insults tossed at outside plant components; RF cabling integrity was vital.

Customers often lacked competent IT staff, burdening our employees with the task of configuring many species of network hardware and topology.

Infrastructure and regulatory obstacles often impeded operations. The cellular company tightly controlled towers, so that if there was a technical issue at a base station hours or days could pass before we gained access. Despite backup generators and UPS systems at every site, electrical power was always problematic. For the cellular company, electrical mains supplies at base stations were less critical. Cellular subscribers simply associated with a different base station; our fixed wireless data subscribers went offline.

On the regulatory side, a major disruption occurred when the telecoms authority decided that our operation was responsible for disrupting C-band satellite operations for the entire country and ordered us to shut down our network.

Despite hard data demonstrating that we were not at fault, the regulator conducted a highly publicized seizure of our equipment. Of course the interference persisted, and later was determined to emanate from a Russian radar ship, involved in tracking space activities. We quietly negotiated with the regulator, and ultimately were rewarded with 2 x 42 MHz of proprietary spectrum in the 3.4/3.5 GHz bands. Customers were switched over to dialup in the month or so it took to reconfigure base stations and install new CPE.

Ultimately the network grew to about 100 nodes providing good, although not great, connectivity to 7 cities over 3000+km of transmission links. Only the merger with the cellular operator made this network feasible—the scale of the Internet/data business alone would not have justified building a data network of these dimensions and making the investments needed for proprietary frequencies. Unfortunately, the cellular operator took the decision to close the Internet business in mid-2002.

Nairobi

In early 2003 I was approached by a Kenyan company, AccessKenya, with strong UK business and technical backup to design and deploy a wireless network in Nairobi and environs. Benefiting from superb networking and business professionals, improved wireless hardware, progress in internetworking, and bigger market we designed a high availability network in line with regulatory constraints.

Two regulatory factors drove our network design. At the time in Kenya, Internet services were licensed separately from public data network operators, and a single company could not hold both licenses. Carrying traffic of multiple, competing ISPs or corporate users, the network had to operate with total neutrality. Also, “proprietary” frequencies, namely 3.4/3.5 GHz, were not exclusively licensed to a single provider, and we were concerned about interference and the technical ability/political will of the regulator to enforce. Also, spectrum in 3.4/3.5 GHz was expensive, costing about USD1000 per MHz per year per base station. Restated, a base station using 2 x 12 MHz attracted license fees of over $10,000 year. Since Nairobi is a hilly place with lots of tall trees and valleys, wireless broadband networks demanded many base stations. The licensing overheads simply were not sensible. In contrast, 5.7/5.8 GHz frequencies were subject only to an annual fee, about USD 120, per deployed radio.

To meet the first regulatory requirement we chose to provide services using point-point VPN tunnels, not via a network of static IP routes. An ISP would deliver a public IP address to our network at their NOC. Our network conducted a public-private IP conversion, and traffic transited our network in private IP space. At the customer site, a private-public IP conversion delivered the globally routable address (or range) to the customer network.

Security and encryption added to network neutrality, and flexibility, as unique sales properties of our network. Bandwidth was limited at the VPN tunnel level. Based on the operating experience of our sister UK company, VirtualIT, we selected Netscreen (now subsumed under Juniper Networks) as the vendor for VPN firewall routers.

Our criteria for wireless broadband equipment eliminated big pipes and feature-rich, high performance gear. Form factor, reliability, and ease of installation and management were more important than throughput. All international Internet connections to Kenya in 2003, and at this writing, are carried by satellite. With costs 100X greater than global fiber, satellite connectivity put a financial ceiling on the amount of bandwidth purchased by end-users. We judged that the bulk of our user population required capacity on the order of 128 to 256 kbps. We selected Motorola’s recently introduced Canopy platform in line with our business and network model.

Broadband Access, Ltd., went live in July 2003, launching the “Blue” network. We started small, with a single base station. We wanted demand to drive our network expansion, rather than relying on a strategy of building big pipes and hoping we could fill them.

Canopy, and third-party enhancements such as omnidirectional base stations, permitted us to grow our network as traffic grew, softening initial capital expenditures. We knew the tradeoff was that as the network expanded, we would have to sectorize traffic and realign client radios. The gentle learning curve of a small network paid big dividends later. Technical staff became comfortable with customer support issues in a simple network environment, rather than have to deal with them on top of a complex RF and logical framework. Technical staff attended two-day Motorola training sessions.

A typical PMP design, with base stations linked to a central facility via a Canopy high-speed microwave backbone, the network was deployed on building rooftops, not antenna towers. All leases stipulated 24x7 access for staff, mains power and, critically, protected the exclusivity of our radio frequencies. We did not want to restrict landlords from offering roof space to competitors, rather to simply guarantee that our own services would not be interrupted.

Rooftop deployments provided many advantages. Unlimited physical access, unconstrained by night or rain, helped meet the goal of 99.5% network availability. Big buildings also housed many big clients, and it was possible to connect them directly into our core microwave network. Rooftop sites did have the downside of more human traffic—workers maintaining equipment (a/c) or patching leaks would occasionally damage cabling. As a result all base stations were set up with two sets of cabling for all network elements, a primary and a spare.

Site surveys confirmed radio path availability and client requirements. Survey staff logged GPS positions for each client, and carried a laser rangefinder to determine height of obstacles. Following receipt of payment for hardware, contractors under the supervision of a technical staffer performed installations. Canopy has the advantage that the CPE and base station elements are light, so that most installations do not need extensive civil works or guying. Cabling Canopy units was also simple, with outdoor UTP connecting radios directly to customer networks. Proper planning enabled completion of many installations in less than an hour, and contractor crews did not need any advanced training or tools.

As we compiled hundreds of customer GPS positions we began to work closely with a local survey company to overlay these sites on topographical maps. These became a key planning tool for base station placement.

Note that the point-point VPN tunnel architecture, with its separate physical and logical layers, required clients to purchase both wireless broadband and VPN hardware. In order to tightly control quality, we categorically refused to permit clients to supply their own hardware—they had to buy from us in order to have service and hardware guarantees. Every client had the same hardware package. Typical installations cost on the order of USD 2500, but that compares to the $500-600 monthly charges for 64 to 128 kbps of bandwidth. A benefit of the VPN tunnel approach was that we could prevent a client's traffic from passing over the logical network (i.e. if their network was hit by a worm or if they didn't pay a bill) while the radio layer remained intact and manageable.

As it grew from one base station to ten, and service was expanded to Mombasa, the network RF design evolved and wherever possible network elements (routers) were configured with fallover or hot swap redundancy. Major investments in inverters and dual conversion UPS equipment at each base station were required to keep the network stable in the face of an erratic power grid. After a number of customer issues (dropped VPN connections) were ascribed to power blackouts, we simply included a small UPS as part of the equipment package.

Adding a portable spectrum analyzer to our initial capital investment was costly, but hugely justified as we operated the network. Tracing rogue operators, confirming the operating characteristics of equipment, and verifying RF coverage enhanced our performance.

Fanatical attention to monitoring permitted us to uptweak network performance, and gather valuable historical data. Graphed via MRTG or Cacti (as described in chapter six), parameters such as jitter, RSSI, and traffic warned of rogue operators, potential deterioration of cable/connectors, and presence of worms in client networks. It was not uncommon for clients to claim that service to their site had been interrupted for hours/days and demand a credit. Historical monitoring verified or invalidated these claims.

The Blue network combined a number of lessons from Tanzania with improved RF and networking technologies.

Lessons learned

For the next few years satellite circuits will provide all international Internet connectivity in East Africa. Several groups have floated proposals for submarine fiber connectivity, which will energize telecommunications when it happens. Compared to regions with fiber connectivity, bandwidth costs in East Africa will remain very high.

Wireless broadband networks for delivery of Internet services therefore do not need to focus on throughput. Instead, emphasis should be placed on reliability, redundancy, and flexibility.

Reliability for our wireless networks was our key selling point. On the network side this translated into sizable investments in infrastructure substitution, such as backup power, and attention to details such as crimping and cabling. The most ordinary reasons for a single customer to lose connectivity were cabling or crimping issues. Radio failures were essentially unheard of. A key competitive advantage of our customer installation process is that we pushed contractors to adhere to tight specifications. It was common for well-managed customer sites to remain connected for hundreds of days with zero unscheduled downtime. We controlled as much of our infrastructure as possible (i.e building rooftops).

As attractive as potential alliances with cellular providers seem, in our experience they raise more problems than they solve. In East Africa, Internet businesses generate a fraction of the revenue of mobile telephony, and so are marginal to the cellular companies. Trying to run a network on top of infrastructure that doesn't belong to you and is, from the point of view of the cellular provider, a goodwill gesture, will make it impossible to meet service commitments.

Implementing fully redundant networks, with fail-over or hotswap capability is an expensive proposition in Africa. Nonetheless the core routers and VPN hardware at our central point of presence were fully redundant, configured for seamless fail-over, and routinely tested. For base stations we took the decision not to install dual routers, but kept spare routers in stock. We judged that the 2-3 hours of downtime in the worst case (failure at 1AM Sunday morning in the rain) would be acceptable to clients. Similarly weekend staff members had access to an emergency cupboard containing spare customer premises equipment, such as radios and power supplies.

Flexibility was engineered into both the logical and RF designs of the network. The point-to-point VPN tunnel architecture rolled out in Nairobi was extraordinarily flexible in service of client or network needs. Client connections could be set to burst during off-peak hours to enable offsite backup, as a single example. We could also sell multiple links to separate destinations, increasing the return on our network investments while opening up new services (such remote monitoring of CCTV cameras) to clients.

On the RF side we had enough spectrum to plan for expansion, as well as cook up an alternative radio network design in case of interference. With the growing number of base stations, probably 80% of our customer sites had two possible base station radios in sight so that if a base station were destroyed we could restore service rapidly.

Separating the logical and RF layers of the Blue network introduced an additional level of complexity and cost. Consider the long-term reality that radio technologies will advance more rapidly than internetworking techniques. Separating the networks, in theory, gives us the flexibility to replace the existing RF network without upsetting the logical network. Or we may install a different radio network in line with evolving technologies (Wimax) or client needs, while maintaining the logical network.

Finally, one must surrender to the obvious point that the exquisite networks we deployed would be utterly useless without unrelenting commitment to customer service. That is, after all, what we got paid for.

More information

- Broadband Access, Ltd.: *http://www.blue.co.ke/*
- AccessKenya, Ltd.: *http://www.accesskenya.com/*
- VirtualIT: *http://www.virtualit.biz/*

--Adam Messer, Ph.D

Case study: Dharamsala Community Wireless Mesh Network

The Dharamsala Wireless-Mesh Community Network came to life in February 2005, following the deregulation of WiFi for outdoor use in India. By the end of February 2005, the mesh had already connected 8 campuses.

Extensive testing during February of 2005 showed that the hard mountainous terrain is most suitable for mesh networking, as conventional point-to-multipoint networks, cannot overcome the line-of-sight limitations presented by the mountains. mesh topology also offered much larger area coverage, while the “self healing” nature of mesh routing, proved to be essential in places where electricity supply is very erratic at best.

The mesh backbone includes over 30 nodes, all sharing a single radio channel. Broadband Internet services are provided to all mesh members. The total upstream Internet bandwidth available is 6 Mbps. There are over 2,000 computers connected to the mesh, The broadband internet connection is putting the mesh under great load. At present, the system seems to handle the load without any increase in latency or packet-loss. It is clear that scalability will become an issue if we continue to use a single radio channel. To solve this problem, new mesh routers with multiple radio channel support are being developed and tested in Dharamsala, with an emphasis on products that meet our technical requirements and our economically viable. The initial results are very promising.

The mesh network is based on recurring deployments of a hardware device, which is designed and built locally – known as the ***Himalayan-Mesh-Router*** (*http://drupal.airjaldi.com/node/9*). The same mesh-routers are installed at every location, with only different antennas, depending on the geographical locations and needs. We use a wide range of antennas, from 8 - 11 dBi omnidirectional, to 12 - 24 dBi directional antennas and occasionally some high-gain (and cost) sector antennas.

The mesh is primarily used for:

- Internet access
- File-sharing applications
- Off-site backups
- Playback of high quality video from remote archives.

A central VoIP, software-based PBX is installed (Asterisk) and it provides advanced telephony services to members. The Asterisk PBX is also interfacing the PSTN telephone network. However, due to legal issues it is presently used only for incoming calls into the mesh. Subscribers use a large variety of software-phones, as well as numerous ATAs (Analog Telephone Adaptors) and full-featured IP phones.

Figure 11.5: Dharamsala installer working on a tower

The encrypted mesh back-bone does not allow access to roaming mobile devices (notebooks and PDAs), so we have placed multiple 802.11b access-points at many of the same locations where mesh-routers are installed. The mesh provides the backbone infrastructure while these APs provide access to mobile roaming devices, where needed.

Access to the mesh back-bone is only possible by mesh-routers. Simple wireless clients lack the intelligence needed to “speak” the mesh routing protocols and strict access policies. The mesh channel is therefore encrypted (WPA), and also “hidden” to prevent mobile devices from finding it or attempting to access it. Allowing access to the mesh only by mesh-routers allows for strict access control policies and limitations to be enforced at the CPE (Client Premises Equipment) which is a crucial element needed to achieve end-to-end security, traffic-shaping, and quality-of-service.

Power consumption of the mesh-Router is less than 4 Watts. This makes them ideal for using with solar panels. Many of the Dharamsala Mesh routers are powered solely by small solar panels. The use of solar power in combination with small antennas and low power routers is ideally suitable for disaster areas, as it very likely to survive when all other communication infrastructure is damaged.

--AirJaldi, http://airjaldi.com/

Case study: Networking Mérida State

The city of Mérida lies at the foot of the highest mountain in Venezuela, on a plateau at about 1600 m. It is the capital of the state of Mérida, and home to a two- centuries-old university, with some 35,000 students. The University of Los Andes (ULA) deployed the first academic computer network in 1989 which, despite economic limitations, has grown to encompass 26 km of fiber optic cable over which both a TDM and an ATM (asynchronous transfer mode) network are overlaid. In 2006, over the same fiber optic cable, a 50 km Gigabit Ethernet network has been deployed.

Figure 11.6: Mérida is one of the three mountainous states of Venezuela, where the Andes reach 5000 m.

Nevertheless, many places in the city and the surrounding villages are out of reach of the fiber optic ring. The university operates a communication server with telephone lines to provide remote access to its network, but local calls are charged by the minute and many villages lack phone lines altogether.

For these reasons, efforts to develop wireless access to the university's network, called RedULA, were undertaken from the very beginning. The first attempts took advantage of the existing packet network operated by radio amateurs. As early as 1987, amateurs had a gateway with an ***HF*** (***High Frequency***) station working at 300 bps for contacts overseas, as well as several ***VHF*** (***Very High Frequency***) stations linked at 1200 bps that crisscrossed the country.

While the rugged mountains of the region are a big obstacle for laying cables and building roads, they can be helpful in deploying a radio network. This task is aided by the existence of a cable car system, reputedly the highest in the world, which links the city to a 4765 m peak.

Figure 11.7: On its way to the peak, the cable car passes by an intermediate station called La Aguada, which is 3450 m high and has an astounding view of the city of Mérida and other villages at distances up to 50 km.

Packet radio

Local amateurs operate a packet radio network. Initially it worked at 1200 bps, using VHF amateur FM voice radios connected to a personal computer by means of a ***terminal node controller*** (***TNC***). The TNC is the interface between the analog radio and the digital signals handled by the PC.

The TNC keys the Push To Talk circuits in the radio to change from transmit to receive, performs modulation/demodulation and the assembly/disassembly of packets using a variation of the X.25 protocol known as ***AX.25***. Gateways between VHF and HF radios were built by attaching two modems to the same TNC and computer. Typically, a gateway would connect the local VHF packet network to stations overseas by means of HF stations that could span thousands of kilometers, albeit at a speed of only 300 bps. A national packet radio network was also built, which relayed on ***digipeaters*** (digital repeaters, essentially a TNC connected to two radios with antennas pointing in different directions), to extend the network from Mérida to Caracas by means of just two such repeater stations. The digipeaters operated at 1200 bps and allowed for the sharing of programs and some text files among amateurs.

Phil Karn, a radio amateur with a strong background in computer networks, wrote the KA9Q program that implements TCP/IP over AX.25. Using this program, named after the call sign of its developer, amateurs all over the world were soon able to connect to the Internet using different kinds of radios. KA9Q keeps the functions of the TNC to a bare minimum, harnessing the power of the attached PC for most processing functions. This approach allows for much greater flexibility and easy upgrades. In Mérida, we were soon able to upgrade our network to 9600 bps by use of more advanced modems, and several radio amateurs were now able to access the Internet through the RedULA wired network. The limit on the radio bandwidth available on the VHF band puts a cap on the highest attainable speed. To increase that speed, one must move to higher frequency carriers.

Amateurs are allowed to use 100 kHz wide channels using ***UHF*** (***Ultra-High Frequency***) signals. Digital radios coupled with 19.2 kbps modems doubled the transmission bandwidth. A project was developed using this technology to link the House of Science in the city of El Vigia, to Mérida and the Internet. UHF antennas were built at LabCom, the communications laboratory of ULA.

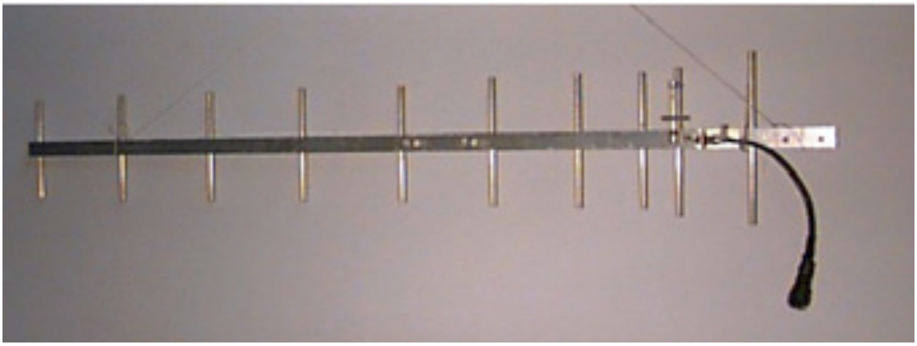

Figure 11.8: A UHF antenna for packet radio developed at ULA, LabCom.

Although El Vigia is only 100 km from Mérida by road, the mountainous terrain called for the use of two repeaters. One is located at La Aguada, at 3600 m altitude, and the other at Tusta, at 2000 m. The project was financed by FUNDACITE MERIDA, a government institution that promotes science and technology in the state. FUNDACITE also operates a pool of 56 kbps telephone modems to provide Internet access for institutions and individuals. The need for two repeater stations underscores the limitations imposed by using higher frequency carriers, which require line of sight to establish a reliable transmission. In the much lower VHF band, signals are easily reflected and can reach beyond hills.

Sometimes it is possible to reflect signals using a ***passive repeater,*** which is made by connecting two directional antennas back to back with a coaxial cable, without any radio. This scheme was tested to connect my residence to LabCom. The distance is only 11 km, but there is a hill in between that blocks radio signals. A connection was made by using a passive repeater to reflect off La Aguada, with the two antennas of the repeater pointing 40 degrees apart. While this was very exciting and certainly much cheaper than access through the telephone modems, a faster medium would obviously be needed for a wireless backbone to connect remote villages.

We therefore explored the use of 56 kbps modems developed by Dale Heatherington. These modems are housed in a PI2 card built by Ottawa amateurs, and connected directly to a PC using Linux as the network operating system. While this system functions very well, the emergence of the World Wide Web with its plethora of images and other bandwidth-hogging files made it clear that if we were to satisfy the needs of schools and hospitals we had to deploy a higher bandwidth solution, at least on the backbone. This meant the use of even higher carrier frequencies in the microwave range, which entailed high costs.

Fortunately, an alternative technology widely used in military applications was becoming available for civilian uses at affordable prices. Called ***spread spectrum***, it first found a use in civilian applications as a short-reach wireless local area network, but soon proved to be very useful in places where the electromagnetic spectrum is not overcrowded, allowing the bridging of distances of several kilometers.

Spread spectrum

Spread spectrum uses low power signals with its spectrum expanded on purpose to span all the allocated bandwidth, while at the same time allowing a number of users to share the medium by using different codes for each subscriber.

There are two ways to accomplish this: ***Direct Sequence Spread Spectrum*** (***DSSS***) and ***Frequency Hopping Spread Spectrum*** (***FHSS***).

- In DSSS the information to be transmitted is digitally multiplied by a higher frequency sequence, thereby augmenting the transmission bandwidth. Although this might seem to be a waste of bandwidth, the recovery system is so efficient that it can decode very weak signals, allowing for the simultaneous use of the same spectrum by several stations.

- In FHSS, the transmitter is constantly changing its carrier frequency inside the allotted bandwidth according to a specified code. The receiver must know this code in order to track the carrier frequency.

Both techniques exchange transmission power for bandwidth, allowing many stations to share a certain portion of the spectrum. During the First Latin American Networking School (EsLaRed '92), held in Mérida in 1992, we were able to demonstrate this technique. We established some trial networks making use of external antennas built at the LabCom, allowing transmission at several kilometers. In 1993, the Venezuelan Ministry of Telecommunications opened up four bands for use with DSSS:

- 400 - 512 MHz
- 806 - 960 MHz
- 2.4 - 2.4835 GHz
- 5.725 - 5.850 GHz

In any of the above bands, maximum transmitter power was restricted to 1 Watt and the maximum antenna gain to 6 dBi, for a total EIRP (effective isotropic radiated power) of 36 dBm. This ruling paved the way for the deployment of a DSSS network with a nominal bandwidth of 2 Mbps in the 900 MHz band. This technology satisfied the needs caused by the surge in World Wide Web activity.

The network started at LabCom, where the connection to RedULA was available. LabCom housed an inhouse-built Yagi antenna pointed towards a corner reflector at Aguada. This provided a 90 degree beamwidth, illuminating most of the city of Mérida. Several subscriber sites, all sharing the nominal 2 Mbps bandwidth, were soon exchanging files, including images and video clips. Some subscriber sites that required longer cables between the antenna and the spread spectrum radio were accommodated by the use of bidirectional amplifiers.

These encouraging results were reported to a group set up at the International Centre for Theoretical Physics (ICTP) in Trieste, Italy, in 1995. This group was aimed at providing connectivity between the Computer Center, Physical Sciences Building, and the Technology Building at the University of Ile-Ife in Nigeria. Later that year, the network was set up by ICTP staff with funding from the United Nations University and has been running satisfactorily ever since, proving to be a much more cost-effective solution than the fiber optic network originally planned would have been.

Back in Mérida, as the number of sites increased, the observed throughput per user declined. We started looking at the 2.4 GHz band to provide additional capacity. This band can carry three simultaneously independent 2 Mbps streams, but the effective range is lower than what can be achieved in the 900 MHz band. We were very busy planning the extension of the backbone using

2.4 GHz when we found out about a start-up company that was offering a new solution that promised longer distances, dramatically higher throughput, and the possibility of frequency reuse with narrowband microwaves.

Broadband delivery system

After visiting the Nashua, New Hampshire, facilities of Spike Technologies, we were convinced that their proprietary antenna and radio system was the best solution for the requirements of our state network, for the following reasons:

Their broadband delivery system employs a special sectored antenna (**Figure 11.9**), with 20 dBi gain on each of up to 22 independent sectors. Each sector transmits and receives on independent channels at 10 Mbps full duplex, for an aggregate throughput of 440 Mbps. Frequency reuse on interleaved sectors makes for a spectrally efficient system.

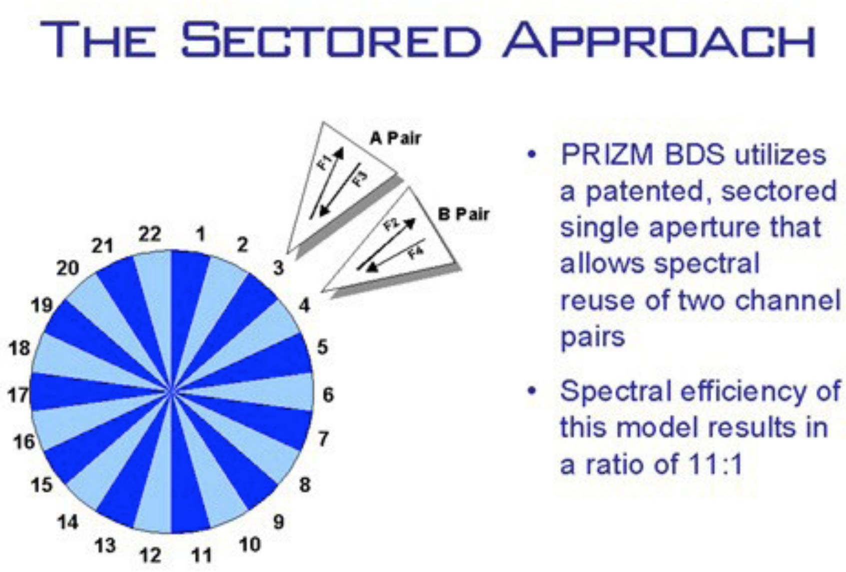

Figure 11.9: Spike Technologies' full duplex, high density sectoral system.

The narrowband digital radios can operate anywhere from 1 to 10 GHz, with a coverage of up to 50 km. The radios work with a variety of cable TV modems, delivering a standard 10Base-T LAN connection to the subscriber. At the base station, the sectors are interconnected with a high-speed switch that has a very small latency (see **Figure 11.10**), allowing applications such as streaming video at up to 30 frames per second. Each sector acts as an independent Ethernet LAN.

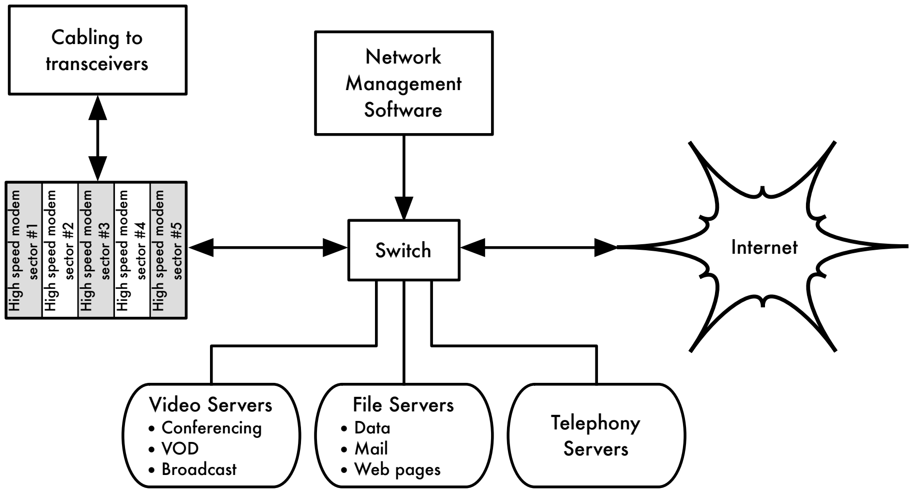

Figure 11.10: Spike Technologies' system interconnections.

At the subscriber site, a similar radio and modem provide a 10BaseT connection to the local Ethernet.

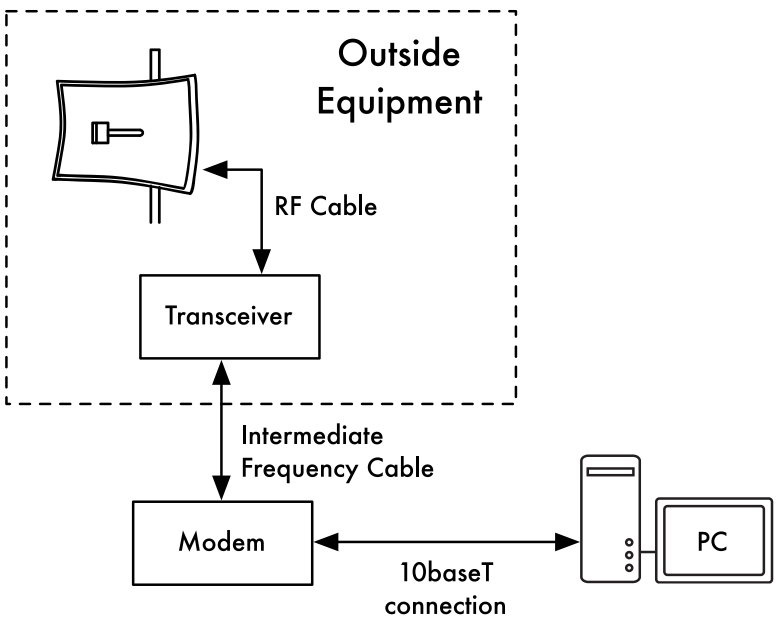

Figure 11.11: The subscriber end of the link.

With funding from Fundacite, a trial system was soon installed in Mérida, with the base station located just above the cable car station of La Aguada at an altitude of 3600 m.

Figure 11.12: Installation above Mérida at La Aguada, at 3600 meters.

Initially only 5 sectors were installed, with a beamwidth of 16 degrees each. The first subscriber site was at Fundacite´s premises, where a satellite system provides Internet access. Sector two served the Governor's Palace. Sector three served FUNDEM, a relief organization of the local government. Sector four served a penitentiary near the town of Lagunillas, about 35 km from Mérida. The fifth sector transmitted to a mountaintop repeater close to the village of La Trampa, 40 km from La Aguada. From La Trampa, another 41 km link extended the network to the House of Science in the town of Tovar.

On January 31, 1998, a videoconference between the penitentiary and the Justice Palace in Mérida proved that, aside from Internet access, the system could also support streaming video. In this case it was used for the arraignment of prisoners, thus avoiding the inconveniences and risks of their transportation.

The success of the trial prompted the state government to allocate the funding for a complete system to give high-speed Internet access to the state health system, educational system, libraries, community centers, and several governmental agencies. In January 1999 we had 3 hospitals, 6 educational institutions, 4 research institutions, 2 newspapers, 1 TV station, 1 public library, and 20 social and governmental institutions sharing information and accessing the Internet. Plans call for 400 sites to be connected within this year at full duplex 10 Mbps speed, and funding has already been allocated for this purpose.

Figure 11.13 shows a map of the state of Mérida. The dark lines show the initial backbone, while the light lines show the extension.

Figure 11.13: The Mérida State network

Among the many activities supported by the network, it is worthwhile to mention the following:

- **Educational**: Schools have found an endless supply of material of the highest quality for pupils and teachers, especially in the areas of geography, languages, and sciences, and as a tool to communicate with other groups that share common interests. Libraries have rooms with computers accessible to the general public with full Internet capabilities. Newspaper and TV stations have an amazing source of information to make available to their audience.
- **Health**: The university hospital has a direct link to the intensive care unit, where a staff of specialist physicians is always on duty. These doctors are available to be queried by their colleagues in remote villages to discuss specific cases. A group of researchers at the university is developing several telemedicine applications based on the network.

- **Research**: The astronomic observatory of Llano del Hato, located on a mountain at 3600 m and 8 degrees off the equator will soon be linked, allowing astronomers from all over the world access to the images collected there. Field researchers in many villages will enjoy Internet access.
- **Government**: Most government agencies are already connected and starting to put information online for the citizens. We expect this to have a profound impact on the relationship of citizens with the government. Relief agencies and law enforcement agencies make heavy use of the network.
- **Entertainment and Productivity**: For people living outside the city, the opportunities offered by the Net have a significant impact on the quality of their lives. We hope that this will help to reverse the trend of migrating out of the countryside, alleviating the overcrowding of the urban areas. Farmers have access to information about the commanding prices of their crops and supplies, as well as improved agricultural practices.

SUPERCOMM '98, held in Atlanta in June, cited the Mérida broadband delivery network as winner of the SUPERQuest award in category 8-Remote Access as the best in that particular field of nominees.

Training

Since our earliest efforts to establish a computer network, we realized that training was of paramount importance for the people involved in the network construction, management, and maintenance. Given our very limited budget, we decided that we had to pool our resources with those of other people who also required training. In 1990 the ICTP organized the First International School on computer network analysis and management, which was attended by Professor Jose Silva and Professor Luis Nunez from our university. Upon returning to Mérida, they proposed that we should somehow emulate this activity in our university. To this end, taking advantage of my sabbatical, I spent three months at Bellcore in Morristown, New Jersey, and three more months at the ICTP helping in the preparation of the Second Networking School in 1992, where I was joined by my colleague Professor Edmundo Vitale. I spent the rest of my sabbatical at SURANET in College Park, Maryland, under the guidance of Dr. Glenn Ricart, who introduced me to Dr. Saul Hahn of the Organization of American States, who offered financial support for a training activity in Latin America. These experiences allowed us to launch the First Latin American Networking School (EsLaRed'92) in Mérida, attended by 45 participants from 8 countries in the region, with instructors from Europe, the United States, and Latin America. This hands-on training lasted three weeks, and wireless technologies were emphasized.

EsLaRed'95 gathered again in Mérida with 110 participants and 20 instructors. EsLaRed'97 had 120 participants, and it was endorsed by the Internet Society, which also sponsored a Spanish and Portuguese first Networking

Workshop for Latin America and the Caribbean, held in Rio de Janeiro in 1998 with EsLaRed responsible for the training content. Now ten years later, EsLaRed continues to expand its training efforts throughout South America.

Concluding remarks

The Internet has an even more profound impact in developing countries than elsewhere, owing to the high cost of international phone calls, faxes, magazines, and books. This is obviously exacerbated by the lower average income of people. Some dwellers in remote villages that do not have telephones are experiencing a transition from the 19th to the 21st century thanks to wireless networking. It is hoped that this will contribute to the improvement of lifestyles in the fields of health, education, entertainment, and productivity, as well as create a more equitable relationship between citizens and government.

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- Escuela Latinoamericana de Redes, *http://www.eslared.org.ve/*

--Ermanno Pietrosemoli

Case study: Chilesincables.org

Recent wireless data transmission technologies allow the creation of high speed, geographically separated networks at a relatively low cost. If these networks are built around the idea of removing restrictions to data access, we call them ***free networks.*** Such networks can bring great benefits to every user, independent of the their political, economic, or social conditions. This kind of network is a direct response to the often restrictive commercial model ruling over much of our modern western society.

In order for free networks to flourish, wireless technologies must be adapted and put to the best possible use. This is carried out by groups of hackers who do the research, investigation, development and implementation of projects, as well as permit free access to the knowledge gained.

Chilesincables.org endeavors to promote and organize wireless free networks in Chile in a professional way. We do this by providing education about the related legal and technical aspects of wireless networking; encouraging the adaptation of new technologies through adequate research; and stimulating the adaptation of these technologies to meet the specific needs of Chilean communities and society.

Description of technology

We employ a variety of wireless technologies, including IEEE 802.11a/b/g. We are also investigating recent innovations in the field, such as WiMAX. In most cases, the equipment has been modified in order to be accept external locally built antennas which meet local telecommunications regulations.

Even though a majority of wireless hardware available on the market will suit our goals, we encourage utilization and exploration of a few vendors that allow for better control and adaptation to our needs (without necessarily increasing the prices). These include Wi-Fi cards with chipsets offered by Atheros, Prism, Orinoco, and Ralink, as well as some models of access points manufactured by Linksys, Netgear, and Motorola. The hacker community has developed firmware that provides new functionality on this equipment.

For the network backbone itself, we employ Open Source operating systems, including GNU/Linux, FreeBSD, OpenBSD, and Minix. This fits our needs in the areas of routing as well as implementation of services such as proxies, web and FTP servers, etc. In addition, they share our project's philosophy of being free technology with open source code.

Uses and applications

The networks implemented so far allow the following tasks:

- Transfer of data via FTP or web servers
- VoIP services
- Audio and video streaming
- Instant messaging
- Exploration and implementation of new services such as LDAP, name resolution, new security methods, etc.
- Services provided by the clients. The users are free to use the net's infrastructure in order to create their own services.

Administration and maintenance

The operational unit of the network is the ***node***. Each node allows clients to associate to the network and obtain basic network services. In addition, each node must be associated to at least another node, by convention. This allows the network to grow and to make more services available to every client.

A node is maintained by an administrator who is a member of the community committed to the following tasks:

- Maintenance of an adequate uptime (over 90%).
- Providing basic services (typically web access).
- Keeping the clients updated about the node's services (for example, how to get access to the network). This is generally provided by a captive portal.

The general administration of the network (specifically, tasks related to deployment of new nodes, selection of sites, network's topology, etc.) is carried out by the board of the community, or by technicians trained for this purpose.

Chilesincables.org is currently in the process of acquiring legal organization status, a step that will allow the regulation of its internal administrative procedures and the formalization of the community in our society.

Training and capacity building

Chilesincables.org considers training of its members and clients to be of vital importance for the following reasons:

- The radio spectrum must be kept as clear as possible in order to guarantee adequate quality of wireless connections. Therefore, training in radio communications techniques is essential.
- The employment of materials and methods approved by the current regulations is a requirement for the normal development of the activities.
- In order to comply with Internet standards, all of our network administrators are trained in TCP/IP networking.
- To ensure continuity in network operations, knowledge of networking technology must be transferred to the users.

To support these principles, Chilesincables.org undertakes the following activities:

- **Antenna Workshop.** Attendees are trained in the construction of antennas, and introduced to basic concepts of radio communication.
- **Operating Systems Workshop.** Training on the implementation of routers and other devices based on GNU/Linux or other software such as m0n0wall or pfsense. Basic networking concepts are also taught.
- **Promotion and Advertising.** Events for different communities that pursue our same goals are promoted. These include college workshops, lectures, free software gatherings, etc.
- **Updating of Materials.** Chilesincables.org maintains a number of free-access documents and materials made available to people interested in a specific activity.

The pictures on the following pages present a brief account of the activities in our community.

Figure 11.14: Omnidirectional slotted antenna workshop. In this session, attendants learned about building antennas and related theory.

Figure 11.15: One of our staff members lecturing on the implementation of a m0nowall-based router in the administration of a node.

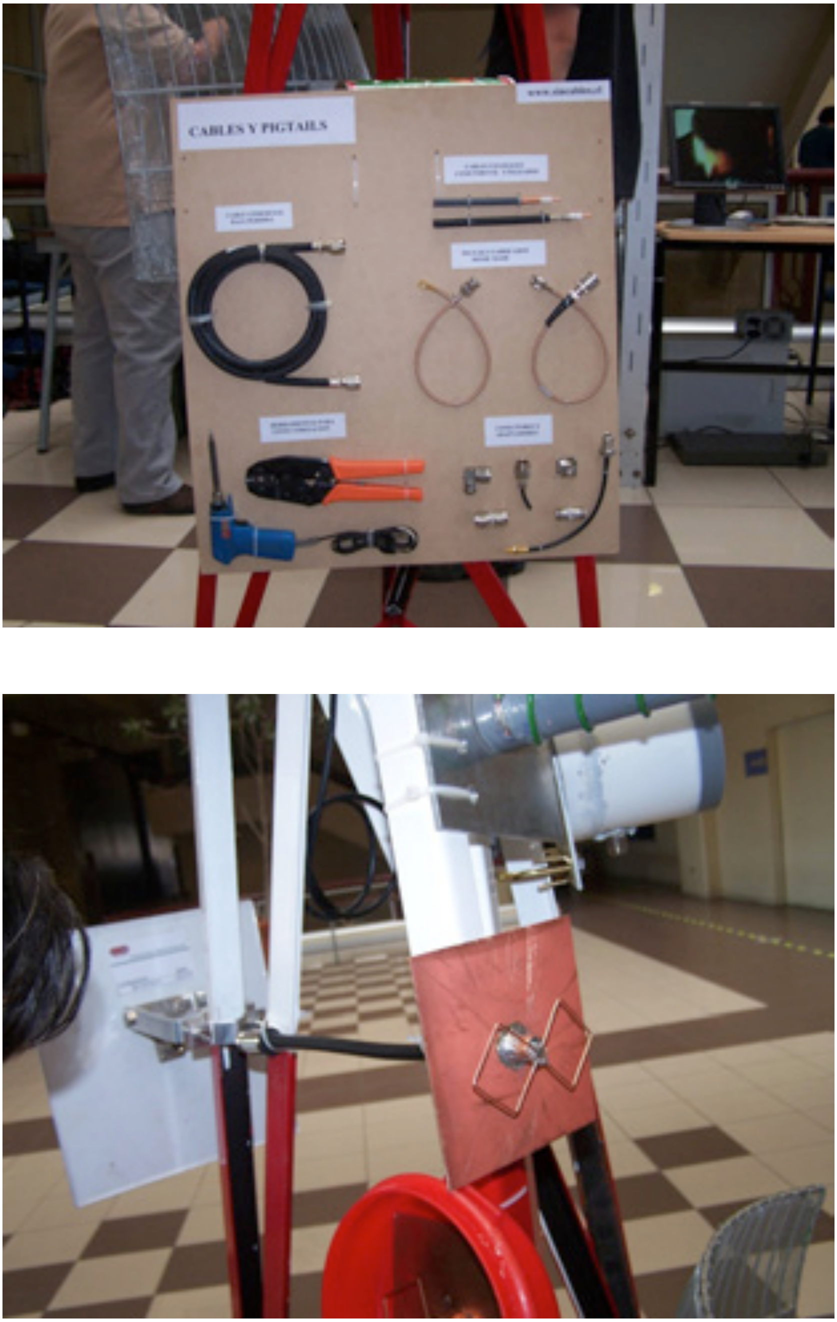

Figure 11.16: Detail of mini tower with samples of antennas, cables and pigtails.

Figure 11.17: Wireless station and parabolic antenna used for the transmission of Santiago-2006 FLISOL via streaming video.

Figure 11.18: Location of the other end of the link.

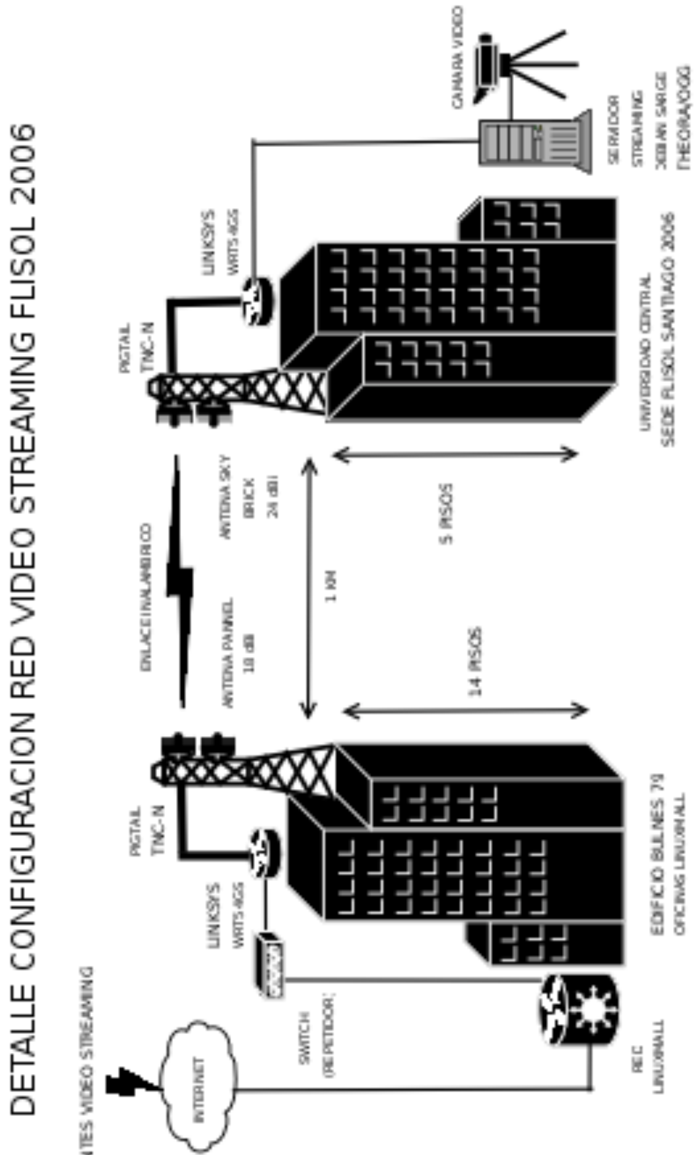

Figure 11.19: Schematic representing Santiago-2006 FLISOL video streaming transmission, using free software. The wireless transmission speed achieved was 36 Mbps at 1 km.

Figure 11.20: Quiani node. This is one of the world's highest nodes. Its located at an elevation of 4000 m, about 2000 km north of the country's capital.

Figure 11.21: Node in southern Santiago, consisting of a 15 m tower, a Trevor Marshall 16+16 antenna, and 30 clients. The node is connected to a downtown node more than 12 km away.

Figure 11.22: Panoramic view of a node from the top of the tower.

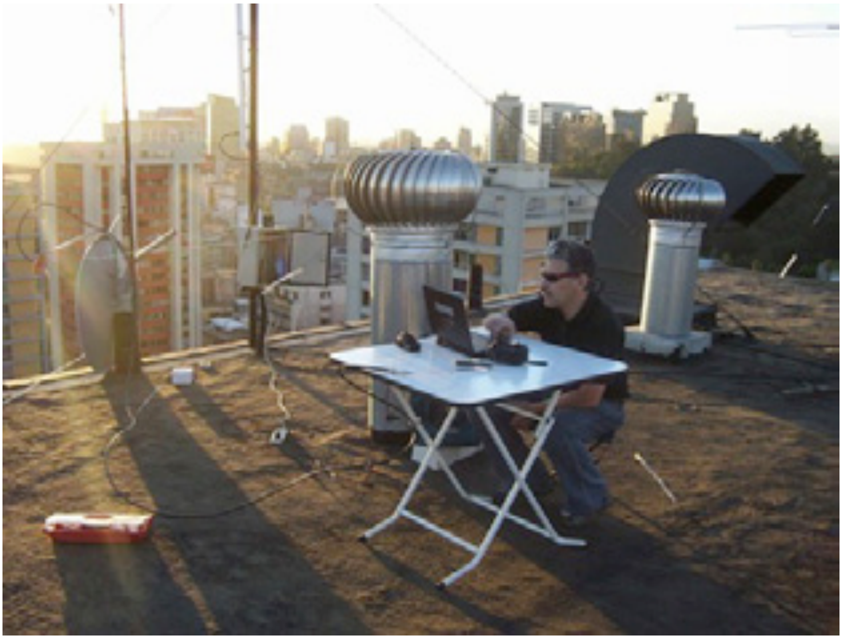

Figure 11.23: Downtown node connected to the Santiago southern node. Note the parabolic antenna for backhaul and the slotted antenna to connect the clients.

Figure 11.24: Implementation of node over a water tower in Batuco, Metropolitan Region, providing backhaul to Cabrati telecenter.

Figure 11.25: Workshop on Yagi antennas organized by our community. Participants are building their own antennas.

Credits

Our community is made up of a group of committed volunteer associates among which are worthy of notice:

Felipe Cortez (Pulpo), Felipe Benavides (Colcad), Mario Wagenknecht (Kaneda), Daniel Ortiz (Zaterio), Cesar Urquejo (Xeuron), Oscar Vasquez (Machine), Jose San Martin (Packet), Carlos Campano (Campano), Christian Vasquez (Crossfading), Andres Peralta (Cantenario), Ariel Orellana (Ariel), Miguel Bizama (Picunche), Eric Azua (Mr. Floppy), David Paco (Dpaco), Marcelo Jara (Alaska).

--Chilesincables.org

Case study: Long Distance 802.11

Thanks to a favorable topography, Venezuela already has some long range WLAN links, like the 70 km long operated by Fundacite Mérida between Pico Espejo and Canagua.

To test the limits of this technology, it is necessary to find a path with an unobstructed line of sight and a clearance of at least 60% of the first Fresnel zone.

While looking at the terrain in Venezuela, in search of a stretch with high elevation at the ends and low ground in between, I 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.

My attention shifted to the Andes, whose steep slopes (rising abruptly from the plains) proved adequate to the task. For several years, I have been traveling through sparsely populated areas due to my passion for mountain biking. In the back of my head, I kept a record of the suitability of different spots for long distance communications.

Pico del Aguila is a very favorable place. It has an altitude of 4200 m and is about a two hour drive from my home town of Mérida. For the other end, I finally located the town of El Baúl, in Cojedes State. Using the free software Radio Mobile (available at *http://www.cplus.org/rmw/english1.html*), I found that there was no obstruction of the first Fresnel zone (spanning 280 km) between Pico del Aguila and El Baúl.

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. Sporting an output power of 15 dBm and receive threshold of -84 dBm, they are robust and trustworthy. 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. The Open Source community has written several firmware versions for it 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 was configured 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 is very severe and spurious signals are generated, which should be avoided. Although this is consumer grade equipment and quite inexpensive, after years of using it, we felt confident that it could serve our purpose. Of course, we kept a spare set handy just in case.

By setting the output power to 100 mW (20 dBm), we could obtain a 5dB advantage compared with the Orinoco card. Therefore, we settled for a pair of WRT54Gs.

Pico del Águila site survey

On January 15, 2006, I went to Pico Águila to check out the site that Radio Mobile had reported as suitable. The azimuth towards El Baúl is 86°, but since the magnetic declination is 8° 16’, our antenna should be pointed to a magnetic bearing of 94°.

Unfortunately, when I looked towards 94°, I found the line of sight obstructed by an obstacle that had not been shown by the software, due to the limited resolution of the digital elevation maps that are freely available.

I rode my mountain bike for several hours examining the surrounding area looking for a clear path towards the East. Several promising spots were identified, and for each of them I took photos and recorded the coordinates with a GPS for later processing with the Radio Mobile software. This led me to refine my path selection, resulting in the one depicted in **Figure 11.26** using Google Earth:

Figure 11.26: View of the 280 km link. Maracaibo's Lake is to the West, and the Peninsula of Paraguaná is to the North.

The radio profile obtained with Radio Mobile is shown in **Figure 11.27**:

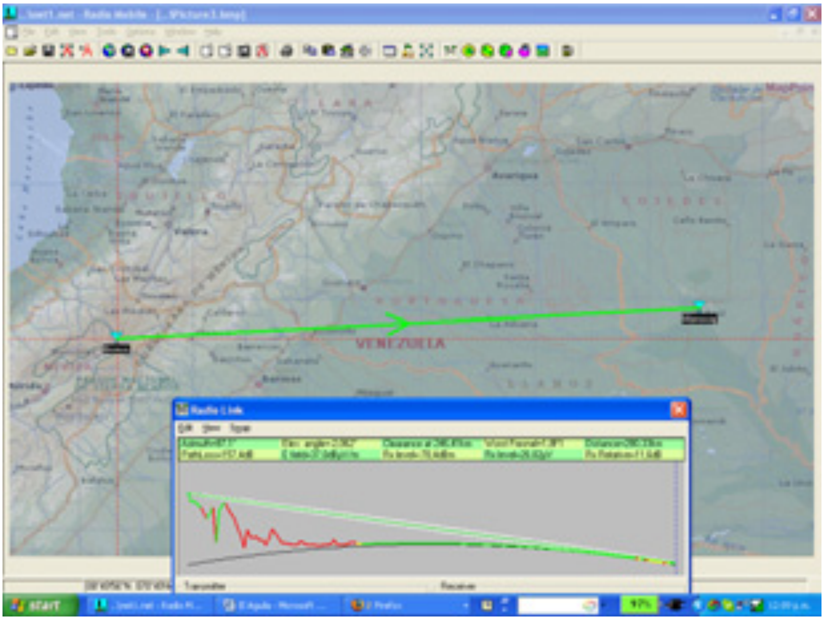

Figure 11.27: Map and profile of the proposed path between Pico Aguila, and Morrocoy hill, near the town of El Baúl.

The details of the wireless link are displayed in **Figure 11.28**:

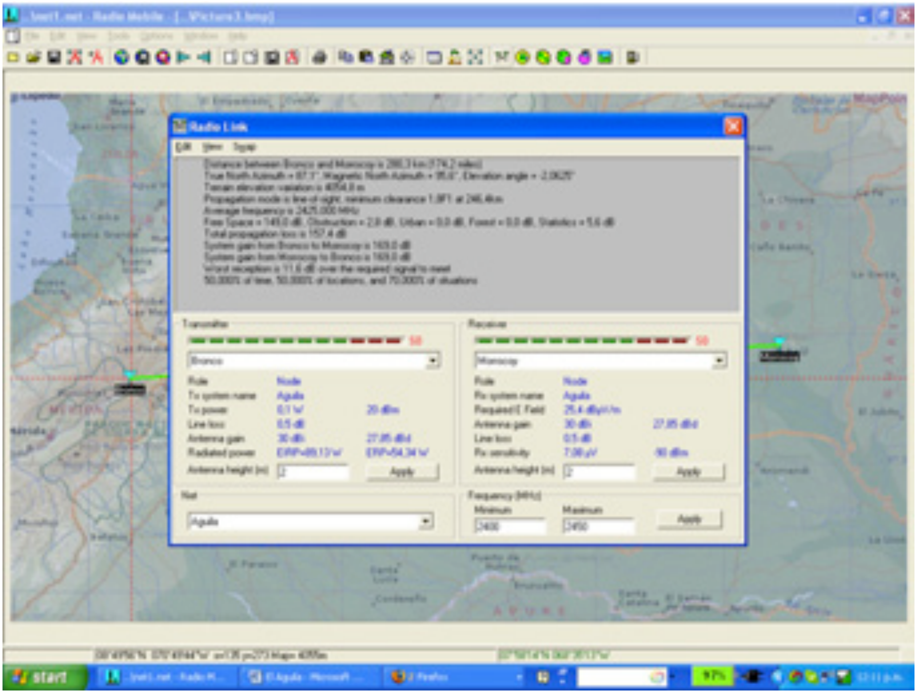

Figure 11.28: Propagation details of the 280 km link.

In order to achieve a reasonable margin of some 12 dB for the link, we needed antennas with at least 30 dBi gain at each end.

Antennas

High gain antennas for the 2.4 GHz band are not available in Venezuela. The importation costs are considerable, so we decided instead to recycle parabolic reflectors (formerly used for satellite service) and replaced the feed with one designed for 2.4 GHz. We proved the concept with an 80 cm dish. The gain was way too low, so we tried an offset fed 2.4 m reflector. This offered ample gain, albeit with some difficulties in the aiming of the 3.5° beam. The 22.5° offset meant that the dish appeared to be pointing downwards when it was horizontally aligned.

Several tests were performed using various cantennas and a 12 dBi Yagi as a feed. We pointed the antenna at a base station of the university wireless network that was located 11 km away on a 3500 m mountain. The test site sits at 2000 m and therefore the elevation angle is 8°. Because of the offset feed, we pointed the dish 14° downward, as can be seen in the following picture:

Figure 11.29: 2.4 m offset fed reflector with a 12 dBi antenna at its focus, looking 14° down. The actual elevation is 8° 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.

For a meaningful measurement of the gain, we needed a signal generator and spectrum analyzer. These instruments were 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, and also a pointing system better suited to the narrow radio beam.

In February 2006, I traveled to Trieste to partake in the annual wireless training event that 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 Theoretical Physics*** (***ICTP***) goes back to 1992, when the first Networking School was held in Mérida with ICTP support. Since then, members of both institutions have collaborated in several activities. Some of these include an annual training school on wireless networking (organized by ICTP) and another on computer networks (organized by EsLaRed) that are hosted in several countries throughout Latin America. Accordingly, it was not difficult to persuade Dr. Sandro Radicella, 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 in the experiment.

Back at 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.

Figure 11.30 shows the disassembly of the mesh reflector.

Figure 11.30: Carlo and Ermanno disassembling the satellite dish supplied by Mr. Ismael Santos.

We exchanged the feed for a 2.4 GHz one, and aimed the antenna at a signal generator that was located on top of a ladder some 30 m away. With a spectrum analyzer, we measured the maximum of the signal and located the focus. We also pinpointed the boresight for both the central fed and the offset antennas. This is shown in **Figure 11.31**:

Figure 11.31: 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. This showed a difference of 8 dB, which led us to believe that the overall gain of our antenna was about 32 dBi. Of course, there is some uncertainty about this value. We were receiving reflected signals, but the value agreed with the calculation from the antenna dimension.

El Baúl Site Survey

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

Performing the experiment

On Wednesday April 12th, Javier Triviño and Ermanno Pietrosemoli traveled towards Baúl with the offset antenna loaded on top of a four-wheel drive truck. Early the morning of April 13th, we installed the antenna and pointed it at a compass bearing of 276°, given that the declination is 8° and therefore the true Azimuth is 268°.

At the same time, the other team (composed by Carlo Fonda and Gaya Fior from ICTP, with assistance of Franco Bellarosa, Lourdes Pietrosemoli and José Triviño) rode to the previously surveyed area at Pico del Aguila in a Bronco truck that carried the 2.7 m mesh antenna.

Figure 11.32: Pico del Águila and surrounds map with Bronco truck.

Poor weather is common at altitudes of 4100 m above sea level. The Aguila team was able to install and point the mesh antenna before the fog and sleet began. **Figure 11.33** shows the antenna and the rope used for aiming the 3° radio beam.

Power for the signal generator was supplied from the truck by means of a 12 VDC to 120 VAC inverter. At 11 A.M in El Baúl, we were able to observe a -82 dBm signal at the agreed upon 2450 MHz frequency using the spectrum analyzer. To be sure we had found the proper source, we asked Carlo to switch off the signal. Indeed, the trace on the spectrum analyzer showed only noise. This confirmed that we were really seeing the signal that originated some 280 km away.

After turning the signal generator on again, we performed a fine tuning in elevation and azimuth at both ends. Once we were satisfied that we 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. Javier substituted the spectrum analyzer on our end for another WRT54G configured as a client.

Figure 11.33: Aiming the antenna at el Águila.

At once, we started receiving "beacons" but ping packets did not get through.

This was expected, since the propagation time of the radio wave over a 300 km link is 1 ms. It takes at least 2 ms for an acknowledgment to reach the transmitter.

Fortunately, the OpenWRT firmware allows for adjusting the ACK timing. 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 a delay of about 5 ms.

Figure 11.34: El Baúl antenna installation. Actual elevation was 1° upward, since the antenna has an offset of 22.5°.

We proceeded to transfer several PDF files between Carlo's and Javier's laptops. The results are shown in **Figure 11.35**.

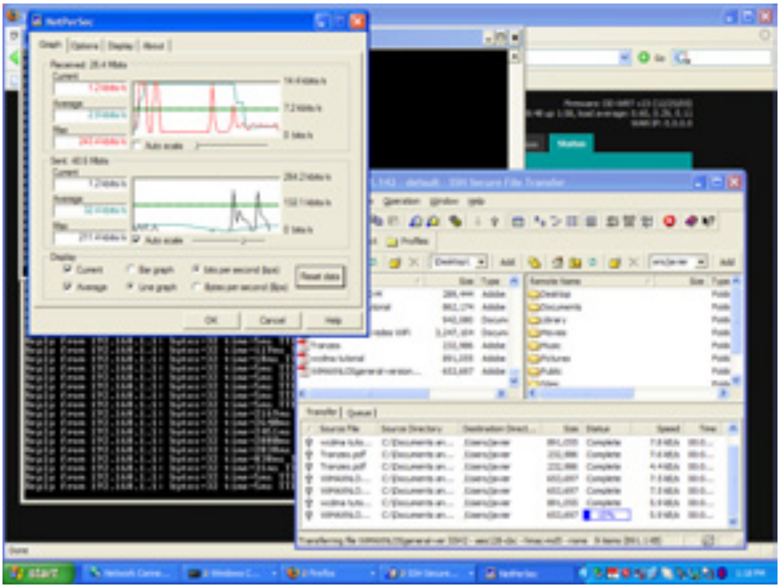

Figure 11.35: Screenshot of Javier's laptop showing details of PDF file transfer from Carlo's laptop 280 km away, using two WRT54G wireless routers, no amplifiers.

Note the ping time of a few milliseconds.

Figure 11.36: Javier Triviño (right) and Ermanno Pietrosemoli beaming from the El Baúl antenna

Figure 11.37: Carlo Fonda at the Aguila Site

Mérida, Venezuela, 17 April 2006.

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 led by Dr. Eric Brewer of Berkeley University.

The purpose of the modification of the standard WiFi MAC is to make it suitable for long distance applications by replacing the CSMA Media Access Control with TDMA. The latter is better suited for long distance point-to-point links since it does not require the reception of ACKs. This eliminates the need to wait for the 2 ms round trip propagation time on a 300 km path.

On April 28th, 2007, a team formed by Javier Triviño, José Torres and Francisco Torres installed one of the antennas at El Aguila site. The other team, formed by Leonardo González V., Leonardo González G., Alejandro González and Ermanno Pietrosemoli, installed the other antenna at El Baúl.

A solid link was quickly established using the Linksys WRT54G routers. 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 the simulations done at Berkeley.

Can we do better?

Thrilled by these results, which pave the way for really inexpensive long distance broadband links, the second team moved to another location previously identified at 382 km from El Aguila, in a place called Platillón. Platillón is 1500 m above sea level and there is an unobstructed first Fresnel zone towards El Aguila (located at 4200 m above sea level). The proposed path is shown in **Figure 11.38**:

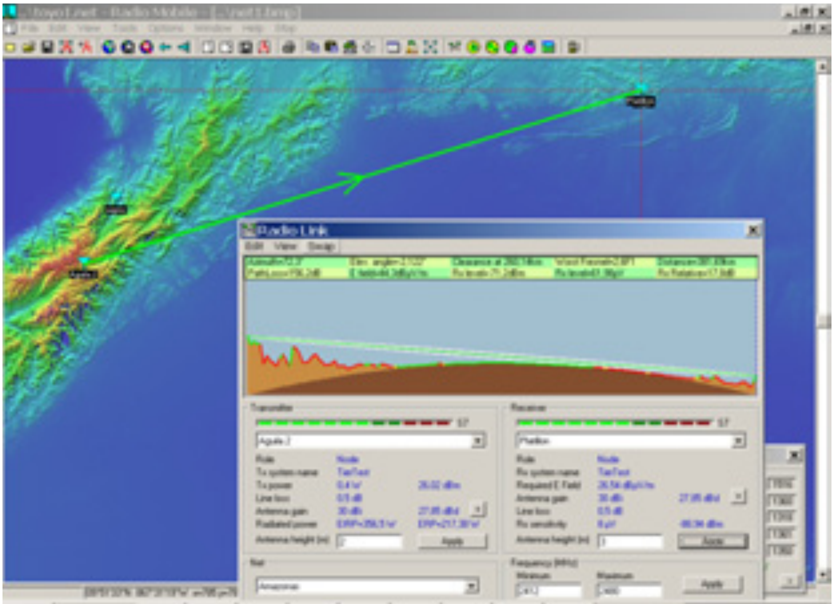

Figure 11.38: Map and profile of the 380 km path.

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, with propagation times below 1 ms. This allowed for video transmission, but the link was not stable. We noticed considerable signal fluctuations that often interrupted the communication.

However, when the received signal was about -78 dBm, the measured throughput was a total of 6 Mbps bidirectional with the TIER routers implementing TDMA.

Figure 11.39: The team at el Aguila, José Torres (left), Javier Triviño (center) and Francisco Torres (right)

Although further tests must be conducted to ascertain the limits for stable throughput, we are confident that Wi-Fi has a great potential for long distance broadband communication. It is particularly well suited for rural areas were the spectrum is still not crowded and interference is not a problem, provided there is good radio line of sight.

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.

We'd also like to thank the Abdus Salam International Centre of Theoretical Physics for supporting Carlo Fonda's trip from Italy to Venezuela.

Figure 11.40: The team at Platillon. From left to right: Leonardo González V., Leonardo González G., Ermanno Pietrosemoli and Alejandro González .

The 2006 experiment was performed by Ermanno Pietrosemoli, Javier Triviño from EsLaRed, Carlo Fonda, and Gaya Fior from ICTP. With the help of Franco Bellarosa, Lourdes Pietrosemoli, and José Triviño.

For the 2007 experiments, Dr. Eric Brewer from Berkeley University provided the wireless routers with the modified MAC for long distance, as well as enthusiastic support through his collaborator, Sonesh Surana. RedULA, CPTM, Dirección de Servicios ULA Universidad de los Andes and Fundacite Mérida contributed to this trial.

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--Ermanno Pietrosemoli