Wireless Data Transmission in the Andes: Networking Merida State

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Abstract

The city of Merida, in the northern Andes, is home to a 200-year-old university that has shown a strong commitment to networking, as witnessed by the deployment of a 100 Mbps TDM fiber optic data and voice network, with a 155 Mbps ATM (asynchronous transfer mode) overlay and by the organization of three Latin American Networking Schools over the past six years.

The desire to extend the benefits of Internet access to the surrounding communities was curtailed by the difficult terrain and limitations of the telephony infrastructure. These challenges were met by means of radio technologies, beginning with packet radio in the VHF (very high frequency) and UHF (ultra high frequency) bands, that was soon made obsolete by the bandwidth requirements of Web access, and venturing into higher speeds made feasible by microwaves, using both spread spectrum and narrowband solutions.

The state-of-the-art network currently being deployed allows for 10 Mbps full duplex data transmission and spans a mountainous region some 200 by 100 km, from sea level to 5000 m. Innovative multisectorial antennas make for efficient use of the 6 MHz per channel spectrum, while allowing video conference and IP (Internet protocol) telephony applications.

Schools, hospitals, libraries, and community centers are the main target for connectivity, but several government agencies are now able to interact with citizens with unheard-of efficiency, prompting for profound social changes.

This paper addresses the technical and cultural hurdles that had to be overcome to bring the project to fruition.

Contents

Introduction

Merida is one of the three mountainous states of Venezuela, where the Andes reach 5000 m. (fig. 1).

Figure 1

The city with the same name lies at the foot of the highest mountain on a plateau at about 1600 m. It is the capital of the state, 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.

Nevertheless, many places in the city, not to mention the surrounding villages, are out of reach of the fiber optic ring. The university operates a communication server with telephonic lines to provide remote access to its network, but local calls are charged by the minute and many villages lack phone lines altogether.

For the above-mentioned reasons, efforts to develop wireless access to RedULA, the university's network, were undertaken from the very beginning. The first attempts took advantage of the existing packet network operated by radio amateurs who, as early as 1987, had a gateway with a HF (high frequency) station working at 300 bps for contacts overseas and several VHF (very high frequency) stations linked at 1200 bps that crisscrossed the country.

The rugged mountains of the region, while proving a big obstacle for laying cables and building roads, 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 with a 4765 m peak. On its way to the peak, the cable car passes by an intermediate station La Aguada, which is 3450 m high and has an astounding view of the city of Merida and other villages at distances up to 50 km (fig. 2).

Figure 2

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 (PC) by means of a terminal node controller (TNC). The TNC does the interface between the analog radio and the digital signals handled by the PC. It 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 Merida 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 [1], an amateur with a strong background in computer networks, wrote the KA9Q program that implements TCP/IP (transmission control protocol/Internet protocol) 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. Also in Merida, 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 wired network operated by the University of Los Andes, RedULA. The limit on the radio bandwidth available on the VHF band puts a cap on the speed attainable. To increase that speed, one has to move to higher frequency carriers. In UHF (ultra-high frequency), amateurs are allowed to use 100 kHz wide channels. Digital radios coupled with 19.2 kbps modems allowed the doubling transmission bandwidths. Using this technology, with antennas built in the communications laboratory of ULA, LabCom (fig. 3), a project was developed to link the House of Science in the city of El Vigia, to Merida and the Internet.

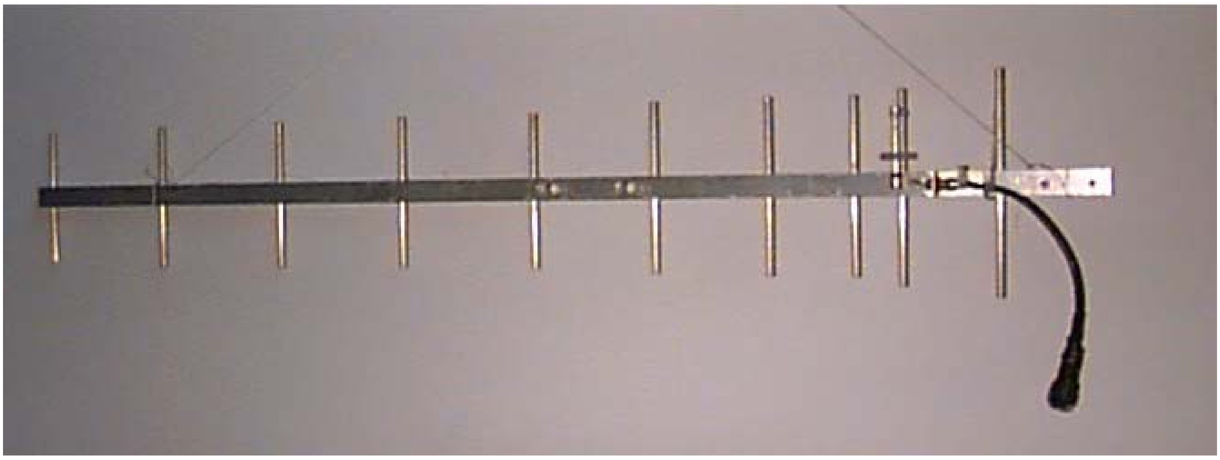


Figure 3

Although El Vigia is only 100 km from Merida by road, the mountainous terrain calls for the use of two repeaters, one 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 poll of 56 kbps telephonic modems to provide Internet access for institutions and individuals. The need for two repeater stations underscores the limitations imposed by using carriers of higher frequencies that require line of sight to establish a reliable transmission, whereas in the VHF band the signals are easily reflected and reach beyond hills. Sometimes it is possible to use passive repeaters built by connecting two directional antennas back to back with a coaxial cable, without any radio. This scheme was tested to connect my residence to LacCom, which is only 11 km from the LabCom, but with a hill in between that blocks radio signals, by reflecting off La Aguada, with the two antennas pointing 40 degrees apart.

While this was very exciting and certainly much cheaper than access through the telephone modems that provided roughly the same bandwidth at that time, when faced with the task of building a wireless backbone to connect remote villages a faster medium was called for.

We therefore explored the use of the 56 kbps modems developed by Dale Heatherington[2], housed in a PI2 card built by Ottawa amateurs connected directly in the PC bus and 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 in 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 civilian applications as a short-reach wireless local area network (LAN), 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 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 in effect 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 Merida in 1992, we were able to demonstrate this technique and establish some trial networks making use of external antennas built at the LabCom, which allowed transmission at several kilometers.

In 1993 [3] 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 ERP (effective 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 that satisfied the new requirements imposed by the surge in World Wide Web activity. Stemming from the LabCom, where the connection to RedULA was provided, an in-house-built Yagi antenna pointing toward Aguada was complemented at that location by a corner reflector, which, with a 90 degree beamwidth, illuminated most of the city of Merida. 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 bilateral amplifiers.

These encouraging results were reported to a group set up at the International Centre for Theoretical Physics (ICTP) in Trieste, Italy, in 1995, aimed at providing connectivity among the Computer Center, the Physical Sciences Building, and the Technology Building, three facilities separated about 1 km 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[4].

Back in Merida, meanwhile, as the number of sites increased, the observed throughput per user was declining, so we started looking at the 2.4 GHz band to provide a new venue for the added traffic. This band can carry three simultaneously independent 2 Mbps streams, but the distance that can be spanned is lower than that allowed on the 900 MHz band. We were very busy planning the extension of the backbone using this band 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 deliver system

After visiting the Nashua, New Hampshire, facilities of Spike Technologies [5], 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 (fig. 4) antenna, with 20 dBi gain that allows up to 22 independent sectors, each transmitting and receiving on independent channels at 10 Mbps, full duplex, for an aggregate throughput of 440 MHz. Frequency reuse on interleaved sectors makes for a spectrally efficient system.

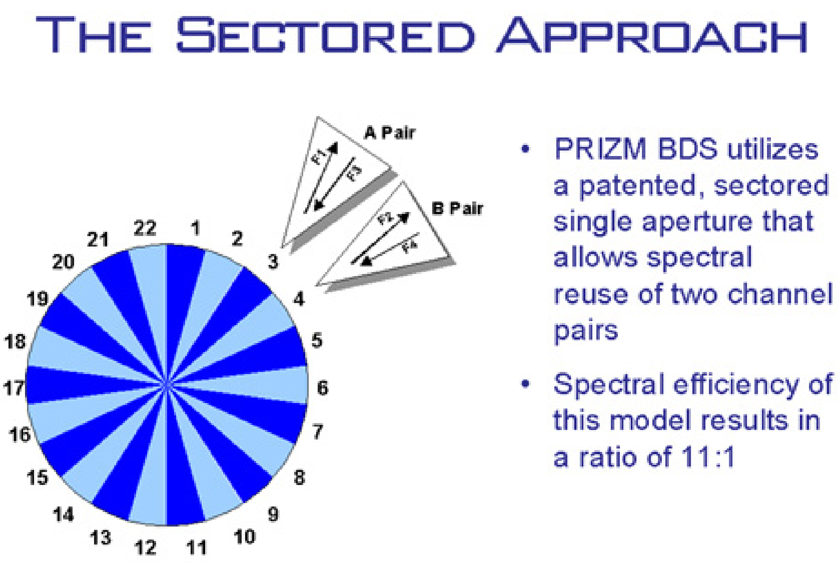
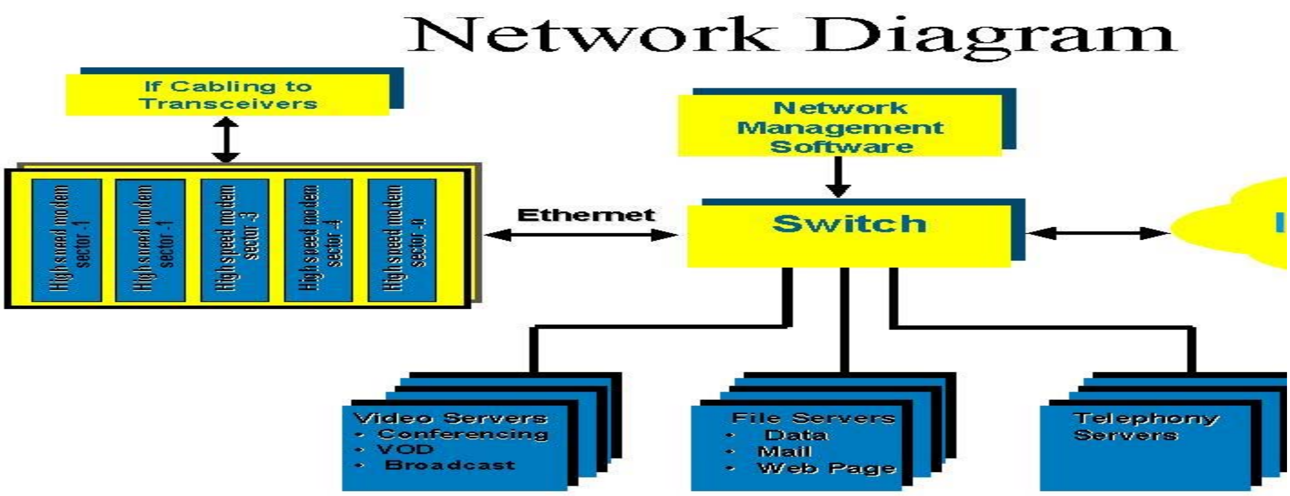


Figure 4

The narrowband digital radios can operate anywhere from 1 to 10 GHz, with a coverage of up to 50 km. The radios can work with a variety of cable TV modems, delivering to the subscriber a standard 10Base-T connection for the LAN. At the base station, the different sectors are interconnected with a high-speed switch with a very small latency (fig. 5), supporting streaming video applications, up to 30 frames/s. Each sector acts as an independent Ethernet LAN.



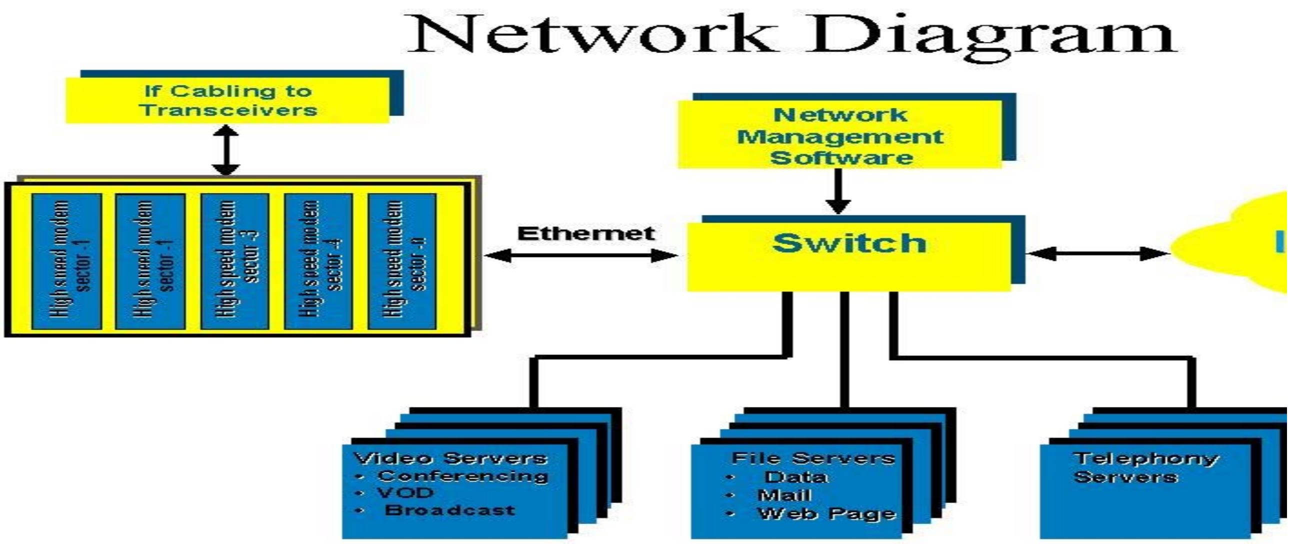
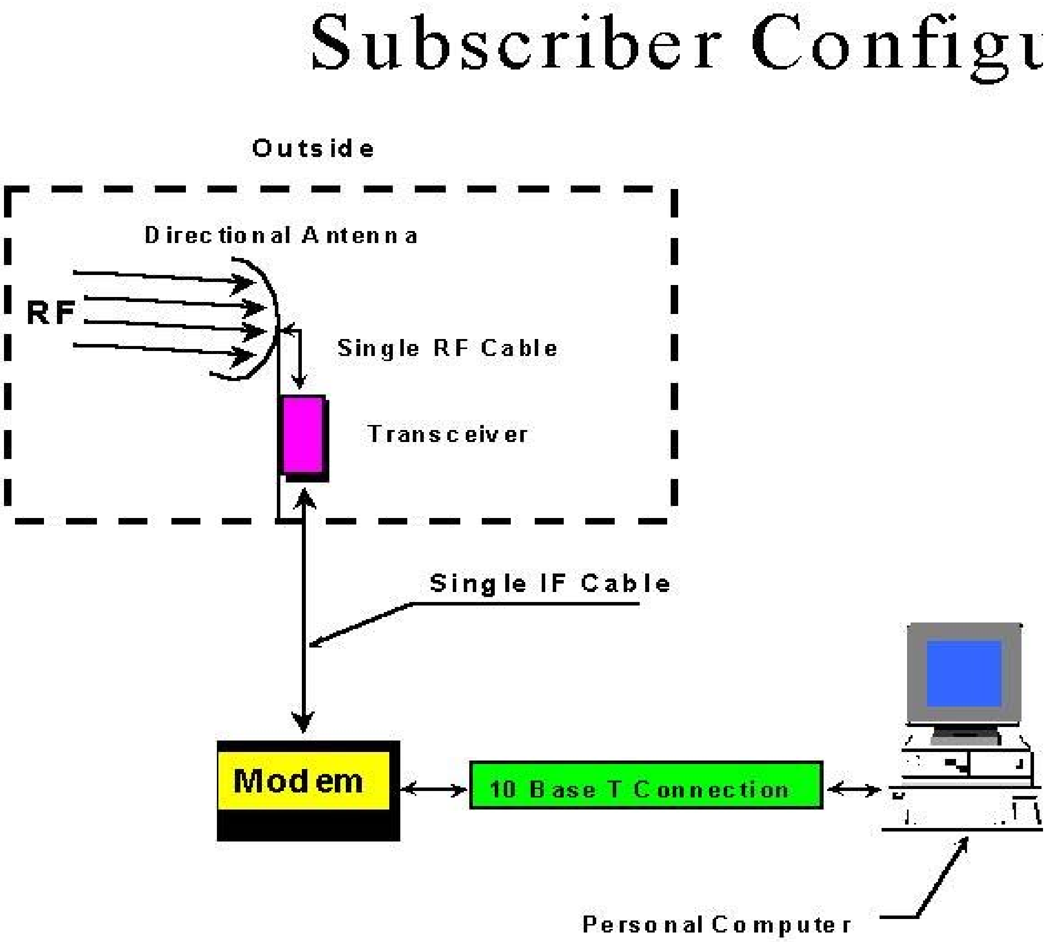


Figure 5

At the subscriber site (fig. 6) a similar radio and a modem provide a 10Base-T connection to the local Ethernet.



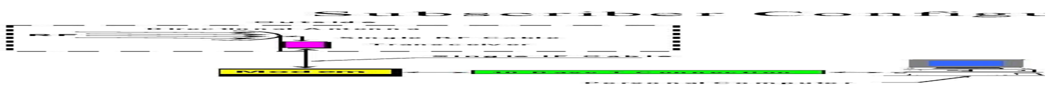


Figure 6

With funding from Fundacite, a trial system was soon installed in Merida, with the base station located just above the cable car station of La Aguada, at an altitude of 3600 m (fig. 7).

Figure 7

Initially only 5 sectors, each with a beamwidth of 16 degrees, were installed. The first subscriber site was in sector 1, at Fundacite premises, where a satellite system provides Internet access. Sector 2 served the Governors Palace; Sector 3 served FUNDEM**,** a relief organization of the local government; sector 4 served a penitentiary near the town of Lagunillas, some 35 km from Merida; sector 5 transmitted to a mountain top repeater close to the village of La Trampa (fig. 8), at 40 km from La Aguada. From La Trampa, another 41-km link extends the network to the House of Science in the town of Tovar.

Figure 8

Figure 9 shows a map of the state of Merida. The black lines show the initial backbone, while the red lines the extended one.

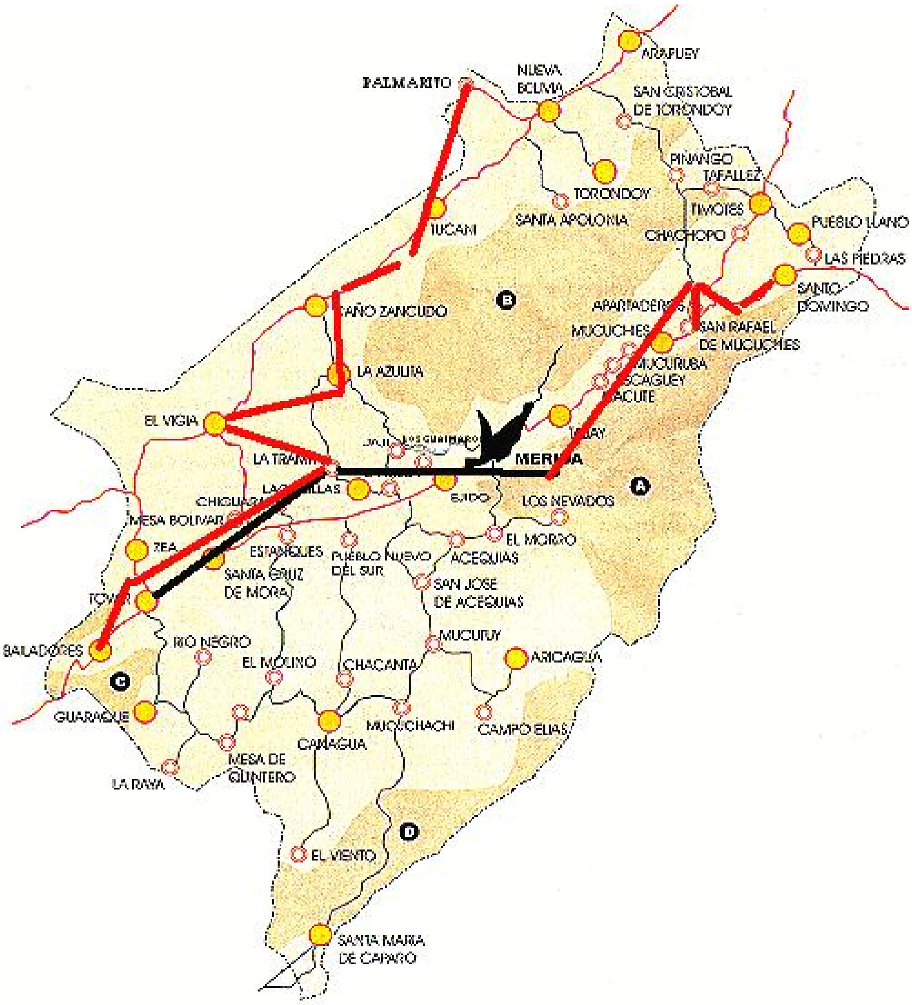


Figure 9

On January 31, 1998, a videoconference between the penitentiary and the Justice Palace in Merida proved that, besides Internet access, the system could also support streaming video, in this case 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. 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 station 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: Besides the university and Fundacite, 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 on line for the citizens. We expect this to have a profound impact on the relationship of citizens with the government. Relief agencies and police and law enforcement forces 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 to migrate 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 Merida broadband deliver 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 effort to establish a computer network, we realized that training for the people involved in the building, managing, and maintaining of it was of paramount importance for the success and survival of the project. Given our very limited budget, we decided that we had to poll our resources with that 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 Merida, 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 that organized there in 1992, where I was joined by my colleague Professor Edmundo Vitale. The rest of my sabbatical I spent 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, which 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 Merida [6], 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 Merida 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.

EsLaRed'99 will merge this year with walc'99, the second Internet workshop for Latin America and the Caribbean that will take place in June at our university.

Concluding remarks

This paper describes some of the efforts undertaken in the networking field in the state of Merida. The Internet in developing countries has even a more profound impact than elsewhere, owing to the high cost of international phone calls, faxes, magazines, and books, exacerbated by the lower average income of people. Some dwellers of 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 improve 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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