A Telemedicine WiFi Network Optimized for Long Distances in the Amazonian Jungle of Peru

Carlos Rey-Moreno
Rey Juan Carlos University
Camino del Molino s/n
Fuenlabrada, Spain
carlos.rey@urjc.es

Ines Bebea-Gonzalez
EHAS Foundation
Ciudad Universitaria s/n
Madrid, Spain
ines.bebea@ehas.org

Ignacio Foche-Perez
Rey Juan Carlos University
Camino del Molino s/n
Fuenlabrada, Spain
ignacio.foche@urjc.es

River Quispe-Tacas
P. Universidad Católica Perú
Av. Universitaria 1801
San Miguel, Lima, Peru
riquispe@pucp.edu.pe

Leopoldo Liñán-Benitez
P. Universidad Católica Perú
Av. Universitaria 1801
San Miguel, Lima, Peru
linan.el@pucp.edu.pe

Javier Simo-Reigadas
Rey Juan Carlos University
Camino del Molino s/n
Fuenlabrada, Spain
javier.simo@urjc.es

ABSTRACT

Isolated rural areas of developing countries often lack of any kind of communications infrastructure. There are some WiFi for Long Distances (WiLD) networks that have been deployed successfully in forests and mountainous regions of countries such as India, Colombia and Peru, for providing Voice over IP and Internet support to health centers. In this work a real telemedicine WiFi network deployed in the Amazonian jungle of Peru is introduced. Technical and social considerations taken into account and devices used for its deployment in such a difficult context are described together with the services provided. Furthermore, performance of this multihop network is analyzed in order to provide a better insight of its behavior. As a conclusion, we describe future and present works related to the improvement of the network.

Keywords

Developing countries, multihop interference, Rural areas, WiLD.

1. INTRODUCTION

Health care centers in developing countries are not equally accessible to people living in cities and those living in less developed and distant areas. Professionals are concentrated mainly in urban areas, where all levels of health care assistance are also located [6]. At the same time, in geographically isolated areas, where a bigger portion of the vulnerable population is located, care is provided through health posts scarcely equipped, which depend hierarchically of either higher-level health care facilities or rural hospitals. These posts are usually attended by health technicians who are barely trained and are responsible for taking care of several villages [5]. In this context, health technicians often need to communicate with their reference centers for consultation or coordination of medical emergencies that they can not handle by themselves [6]. However, due to isolation and lack of resources, these tasks turn to be extremely complicated to be carried out, thus, enlarging the social disparity in the access to high quality health care systems in developing countries.

Some experiences have suggested that WiFi networks composed of long distance point-to-point links and medium distance point-to-multipoint infrastructures allow an easy deployment of low-cost wireless broadband networks in rural areas [7, 3]. This may help to overcome the communications problems cited above and, hence, to improve health care systems in rural areas of developing countries.

Following this principle, several networks have been deployed successfully in rural areas of India, Colombia and Peru [12, 8, 15]. These projects are located in mountainous regions where presence of high peaks makes easier to establish WiFi links, since they require line of sight among stations. In this work, we will present a network installed along the Napo river in the Amazonian jungle of Peru. This network is believed to be the longest permanent WiFi network in the world, covering an end-to-end distance of around 450 Km through sixteen hops since March 2007.

The network was designed and deployed jointly by the EHAS Foundation and GTR-PUCP (Group for rural telecommunications from the Pontificia Universidad Católica del Perú)[1]. The main purpose of this project is to allow voice and data communications (Internet, Email, ...) for improving health management process and technical quality of health care workers in the area. Although the network has been running smoothly during long periods, social issues around

ExtremeCom '11, September 26-30, 2011, Manaus, Brazil.

[1]The network introduced in this paper was the result of two projects. The first one was entitled "*Malaria Control in Border Areas of the Andean Countries: A community Approach* (Pamafro)", ordered and financed by ORAS (Andean Health Organization). The second one, "EHAS-MADRID project: Improvement of the health conditions of the maternal and child population through the appropiated use of ICTs in health care posts and health care centers along the Napo River", was financed by the City Council of Madrid

Figure 1: Napo Region

the network continuously constrained both its performance and its maintenance, and there has been unavailability times too.

In this article, firstly, we are going to introduce the socio-political context in which the network has been deployed and its main implications. Then, the network will be described and performance results will be shown, focusing on the impact of multihop infrastructure. Finally, applications currently used and other to be used in the future will also be presented, together with the strategies proposed to solve inefficiencies caused by the social and technical issues mentioned above.

2. DESCRIPTION OF THE CONTEXT

The network is located in the department of Loreto, in the border region between Peru and Ecuador, along the Napo and Curaray riversides, see Fig. 1. The first network node is located at the Regional Hospital in Iquitos city. Travelling times from Iquitos to Cabo Pantoja (end node) or Santa Clotilde (reference rural health center) vary from 14 and 6 hours respectively within expensive fast boats, to one week and 3 days within cheaper slow ferries, used by most of the rural population. The description of the region included below does not consider Iquitos and Mazán, where many more services and opportunities can be found, including mobile telephony and electricity and much better heath care services [2].

Dozens of communities have been living in this area for hundreds of years. Riverside dwellers are both mixed race and indigenous people. They constitute a young population threathened by the high indicence of preventable diseases such as acute respiratory and diarrheal infections. Furthermore, although birthrates are high, infant mortality rate is one of the highest in Peru due to interrupted monitoring during pregnancy, prevalence of home births and scarce of resources for an appropriate birth attendance and response to emergencies.

Many of these communities are composed by a few houses spread over a relatively vast area, hence, its density is very low. In the inhabited areas, trees, bushes and undergrowths have been cut, leaving the community as an island surrounded by jungle with trees that can reach 40 meters tall, as it can be seen in Fig. 2.

People in these communities are very poor; their main economic activities are agriculture and cattle farming, which are carried out in a subsistence economy fashion. Some people are also starting trading beverages or bread brought from bigger villages.

Figure 2: Village of Tempestad

The isolation of these comunities is agravated by a difficult access to transportation and communications.. Only Santa Clotilde, where the reference health center is located, has a satellite connection in the city hall as external gateway. Most of the health care posts also dispose of High Frequency (HF) radios for communicating among them. However, the quality of this mean of communication is very low and depends heavily on the atmospheric conditions. Energy supply is also a challenge. Santa Clotilde town is powered from 6 pm to 11 pm, and its health center has an additional fuel engine used to power vaccines refrigerator, computers and radio autonomy for short periods. Smaller villages along Napo river may have one half of Santa Clotilde's energy resources.

Health care resources in the area vary greatly. Santa Clotilde and Mazan are more complex centers: they have at least a midwife and a couple of doctors and nurses, they allow hospitalization and include laboratory and operating theater, and they accomplish with administrative registration and logistics. Other health posts including Tacsha Curaray, Angoteros or Cabo Pantoja are relatively well equipped, with a doctor, a laboratory technician for blood tests and a couple of beds for hospitalization. The rest may have only one health technician and no diagnostic devices.

Moreover, it is worth mentioning the presence of a Canadian medical catholic mission in the village of Santa Clotilde. They have been helping with resource management and health care system advising for many years. Many of the equipments installed in the health care center at Santa Clotilde have been acquired thanks to the donations to the mission. Hence, the mission constitutes a great donor for the development in the area.

3. DESIGN OF A WIFI NETWORK IN THE AMAZONIAN JUNGLE OF PERU

3.1 Considerations for a jungle design

The network is comprised by seventeen stations along the Napo and Curaray rivers. This area of the jungle is characterized by very high trees and extreme weather conditions that need to be taken into account in the network design.

As it was mentioned in the introduction, line of sight is required to establish long WiFi links. However, line of sight is defined differently for microwaves than for visible light. Since the wavelength of a microwave beam is much longer

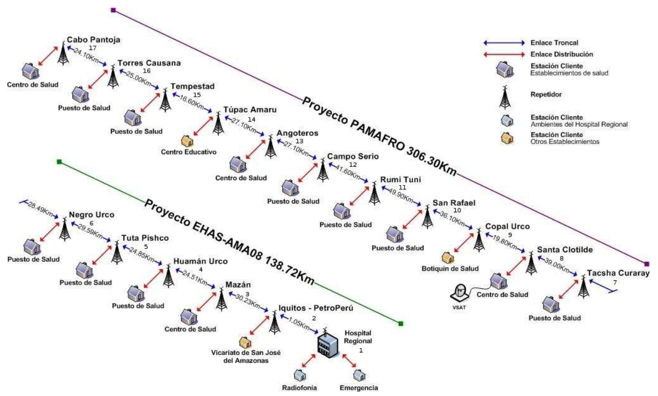

Figure 3: Diagram of the network

Table 1: Distances between stations

Link	From	To	Distance (km)
1	Iquitos	Iquitos-Petro Perú	1,05
2	Iquitos-Petro Perú	Mazán	30,23
3	Mazán	Huaman Urco	24,51
4	Huaman Urco	Tuta Pishco	24,85
5	Tuta Pishco	Negro Urco	29,59
6	Negro Urco	Tacsha Curaray	28,49
7	Tacsha Curaray	Santa Clotilde	39
8	Santa Clotilde	Copal Urco	19,8
9	Copal Urco	San Rafael	36,1
10	San Rafael	Rumi Tuni	49,9
11	Rumi Tuni	Campo Serio	41,6
12	Campo Serio	Angoteros	27,1
13	Angoteros	Tupac Amaru	27,1
14	Tupac Amaru	Tempestad	16,6
15	Tempestad	Torres Causana	25
16	Torres Causana	Cabo Pantoja	24,1

than a visible light beam, a clearance of 60% in the first Fresnel zone is needed to get such a line of sight. In our case, this has been translated in leaving at least 20 m from the top of the trees to the visual line of sight. As the area is very flat, and trees are very high, around 40 m, some towers need to be as high as 90 m to solve this issue.

In addition to this, the Amazonian jungle registers a high number of storms, which have to be considered when designing the network, since the increment of the attenuation due to intense rains can not be neglected in long links. When calculating the link budget, 20 dBs margin is left to assure connectivity under the worst possible wheather conditions. The height of towers and the link budgets are calculated using a Radio Frequency (RF) planning software called Radio Mobile.

Electronic equipments need to be protected from rain and moisture, which may cause them irreparable damages. Therefore, devices have been installed inside waterproof enclosures which protect them from degradation.

Context described in section 2 also influences the design of the network. As it was mentioned, no power supply is available in thirteen of the fourteen communities, while the remaining one, only has few hours of electricity. This fact constrains the deployment of the network, since devices require autonomous powering systems. The solution chosen was solar power, and details on the infrastructure used will be provided in section 3.2. This factor, together with the low economic resources available in the communities, also constrain the election of the communication devices, which need to have a high cost-effectiveness ratio, and be very low power consuming. Due to its different features, such as using non-licensed frequencies, and its worldwide acceptance, WiFi devices comply with these requirements.

However, due to the lack of qualified technical professionals in the area, sustainability of the network is seriously constrained. Several training courses have been carried out in order to teach locals how to maintain and repair the network. Although these courses can be considered highly successful, it is difficult that somebody without any technical basic knowledge, learns how to do so in the short term.

3.2 Technical Description of the Network

The network deployed consists of two different segments, as shown in Fig. 3. The backbone carries the signal from the gateways located in Santa Clotilde and in the Iquitos Regional hospital to the top of all towers, whereas the access network connects final users to the backbone. In the first one, distances between stations are shown in Table 1, while in the second one they are no longer than 1 km.

Except the links 1 and 2, the rest of the links in the backbone have been established alternately in channels 6 and 11 of the 2.4Ghz band. The devices used are embedded computers WRAP E1 with Ubiquity Super Range 2 wireless cards, and highly directed Hyperlink 2424G grid antennas of 24 dBi. All of them are placed inside the enclosures close to the top of the towers. The computer runs a self-desgined version of Voyage, an embedded operating system based on Debian GNU/Linux. The modifications made to the operating system include the reduction in the number of packages, which allows fitting it in a 128/256 MB Compact Flash, and the addition of some extra components to allow specific configuration. Among the packages added, it is worth mentioning the MadWiFi drivers, which allow tuning the wireless cards for optimizing their performance for long range links; Asterisk, a digital Private Branch eXchange (PBX) for handling VoIP traffic; and our own network management agents. For more details regarding these packages consult [11]. In links 1 and 2, the 5.8 GHz band was used to avoid the pontential congestion of the 2.4GHz band in a city like Iquitos. These links are established using Mikrotik RouterBoard 333 with R52H radios and highly directed Hyperlink HG5829D antennas. The decission of using Mikrotik is that by the time of the instalation Madwifi drivers were having inconsistencies when stablishing long range links in the 5 GHz band.

As it can be seen in Fig. 4, in the stations located in the middle of the network two enclosures are needed. One is used for the link with both the previous station and with the health center, and the other one is used for the link with the next station. For the link with the health center, PC Engines CM9 wireless cards are used. In the whole network, wireless cards have been configured for working at 6 Mbps and optimized for long distances through tweaking of SlotTime and ACKTimeout parameters following recommendations from [14].

In the health center, link is established through a Linksys WRT54GL router, which allows working with OpenWRT, a GNU/Linux operating system, and a Hyperlink HG2409Y yagi antenna of 9dBi.

The client stations are equipped with a PC, a printer, and

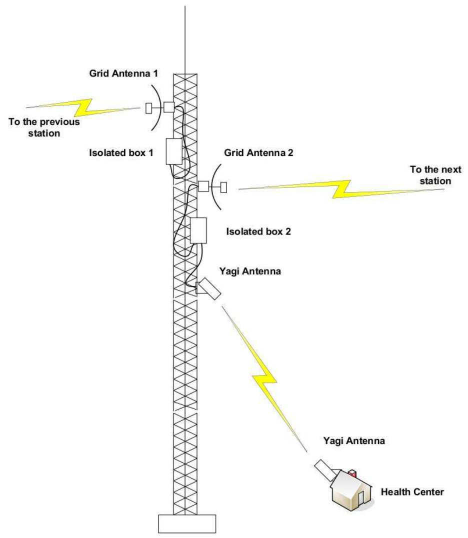

Figure 4: Devices in a tower

Figure 5: Health care professional making use of VoIP services in Copal Urco

an analog telephone. The PCs are adapted in order to be powered from a solar infrastructure. Furthermore, its CPU was changed for a laptop model in order to reduce its power consumption. For using the telephone, an Analog Telephone Adapter (ATA) was required to communicate with the digital PBX.

All health care centres are solar powered. 75 W solar panels, are installed both in the tower and in the health care facility. Depending on the number of embedded computers, wireless cards and light bulbs to supply, the number of panels vary. A typical configuration includes two panels for the tower and two more for the final user.

Energy captured by the panels is taken to the batteries in order to power all the devices. However, in the middle of the way a solar power controller is installed for protecting batteries both from overcharge and discharge. Two different types of batteries have been used: gel batteries, which do not need any maintenance, supply power to devices installed on the top of the towers; and traditional ones, which are simpler, for the client stations.

In addition to this, an electrical protection system has been installed, comprising a Franklin lightning conductor and a grounding well. In addition to this, coaxial line protectors are installed to prevent electronic devices being damaged by electromagnetic fields caused by lightnings.

3.3 Services provided by the network

According to different studies voice communication is the most important service in rural areas of developing countries [10]. Unlike HF systems, WiFi networks are in essence data IP networks that were not devised initially to support voice services. In this scenario, Voice over IP (VoIP) turns up as a technological solution to provide voice connectivity on WiFi networks. In our network we choose for an open-source software PBX named Asterisk that supports VoIP-to-PSTN (Public Switch Telephone Network) switching.

Some of the VoIP services provided to final users are: free voice communication (Fig 5 shows a user making a phone call), voice mail, and communication to/from PSTN with prepaid cards. All VoIP terminals in the network use SIP (Session Initiation Protocol) to communicate with each other, whereas Asterisk PBXs communicate with their peers using the proprietary IAX2 (Inter-Asterisk eXchange) protocol. Asterisk PBXs are installed in each repeater and are responsible for the calls of their respective clients in a kind of distributed VoIP system. This allows making calls inside different subparts of the network, even if, for any reason, a repeater between that subpart and the gateway stops working.

At the beginning of the project, the satellite gateway in Santa Clotilde city hall was shared and used as a gateway for this network. However, this gateway depended on an intermittent local energy supply. Nowadays, and thanks to fund obtained from another project, the network has its own satellite gateway in Santa Clotilte. In addition, it has an ADSL connection at the Iquitos Regional Hospital. This way the networks has two gateways for connecting to the PSTN and the Internet.

In addition to this, the network has Intenet and internal email service. The latter works with two different servers: one installed in Santa Clotilde, in charge of the internal email; and another one in Lima, in charge of email exchange among all EHAS-GTR networks in Peru. For this service a Postfix MTA (Message Transfer Aggent) is used.

3.4 Quality of Service in layer 3

IEEE 802.11 networks can offer a strong, suitable and low-price solution to distribute voice and data communications. But real-time communications, such as VoIP need to ensure a quality of service (QoS) in certain conditions. This would be also interesting for the introduction of telemedicine and e-learning applications, among others.

Typical IP QoS architectures are IntServ and DiffServ. Both are standardized by the IETF, but the second one is preferred generally because it is simpler and it scales better. The QoS at the IP level in DiffServ implies that different traffic classes can be identified in each router and, therefore, treated separately with different priorities. An important handicap to this will be that throughput of wireless links

Table 2: Thoughput results by node

From/To	7	8	9	10	11	12	13
7		1.45	1.13	1.01	0.89	0.85	0.83
8	1.38		1.72	1.18	0.87	0.87	0.75
9	1.02	1.81		1.42	0.89	0.82	0.90
10	0.86	1.15	1.46		1.24	1.02	0.85
11	0.78	0.98	1.06	1.33		1.43	0.83
12	0.74	0.81	0.87	0.98	1.39		1.66
13	0.77	0.87	0.82	1.00	1.36	1.66	

must be estimated in order to perform bandwidth sharing in a fair way. This throughput may be variable in long wireless links due to the distance between nodes or to the presence of interferences. Some experiments made by our group with mesh chains have demonstrated that a differentiated QoS for voice, video and elastic traffic could be guaranteed if it is possible to delimit the performance of the link [13].

Based on these tests, and in order to assure a minimum quality to voice service, we have been successfully applied some Diffserv principles to the network. The QoS architecture developed consists mainly of the following elements: filtering packets to distinguish VoIP packets from the rest; marking them so that all routers recognize them; and using queuing disciplines that allows to assign different priorities according to the type of packet. From tests done in laboratory, we selected the PRIO queuing discipline as the one that suits our needs best.

3.5 Costs of the deployment

Finally, regarding the cost of a system including all the elements described, a whole node could cost about 15000 USD, including the cost of maintenance and training of technicians and health care workers during the first year. This price is much higher than others obtained when deploying other EHAS-GTR networks [11] due to different factors. Being an ORAS project all the purchases were subject of a licitation process, thus increasing the real prices of the devices. Furthermore, towers are very high, up to 90 m, which make them more expensive than those usually used, that are about 12 metres. In addition to this, due to the context where the network is deployed, transport of materials through the river increased hugely the budget.

4. RESULTS AND DISCUSSION

Performance results of a segment of the network in terms of throughput are shown in Table for 2. It was impossible to get data from the whole network since by the time this paper was written some maintenance tasks were taking place hindering the data collection process. The numbers in the first column and row correspond with the number assigned to each node in Figure 3. Results have been obtained during night hours, when nobody was using the network locally. Iperf has been used to generate saturation conditions by injecting bidirectional UDP traffic. UDP is used since it provides a more accurate estimation of real load in the network (there exist no retransmissions at the transport layer).

The sums of the values for both directions of each link are shown in Table 3, link numbers correspond with those in Table 1. As it can be seen, there is a drop in the performance of the end-to-end throughput of this segment. If there were no other loses this value should be equal to the least throughput value of the links the signal has to cross.

Table 3: Thoughput results by link

Link	Throughput (Mbps)
7	2.83
8	3.53
9	2.88
10	2.57
11	2,82
12	3.32
end-to-end	1.6

Table 4: Thoughput drop by node

Node	Throughput drop (Mbps)
8	0.25
9	0.21
10	0.26
11	0.21
12	0.2

In our network, this value corresponds to link 10, which is the longest, whose throughput is 2.57 Mbps. However, as it can be obtained from Table 3, the experimental value of the end-to-end throughput is 1.6 Mbps. Therefore, the network is "loosing" around 1 Mbps in this segment of the backbone. Although part of this drop can be attributed to the data processing in each router, other factors need to be taken into account for such a big drop. According to [4], this can be attributed to the existence of interferences between wireless cards and antennas in the tower due to their closeness.

In this network, packets have to go through many towers where, in some cases, three wireless cards and three antennas have been installed very close. Although no overlapping channels are used and antenna polarization alternates from link to link, some interferences among them may occur.

A more in-depth analysis of this factor can be carried out by analyzing closer Table 2. Steep drops in throughput occur when packets go through a particular node. This is the case when analysing performace "To" node 7 (seoncd column in Table 2): throughput "From" node 8 is 1.38 Mbps, and "From" node 9 is 1.02 Mbps. Since throughput "From" node 9 "To" node 8 is 1.81 Mbps, if there were no loses in node 8, throughput "From" 9 "To" node 7 should be 1.38 Mbps (the lesser of the the two hops). However, this values is 1.02 Mbps, entailing a drop of 0.36 Mbps when going through node 8.

At first glance, it seems that different drops occur in each node. Nevertheless, if the average throughput drop occurred in each intermediate node (those with two boxes) is calculated, results look different. To do so, we have considered every combination of two measurements regarding a node, as calculated above for one combination regarding node 8. Results of this calculation are shown in Table 4. As it can be seen drops remain approximately constant around 0,2 Mbps in each node.

In Table 5, distances and angles between backbone antennas, together with distances (both vertical and horizontal) between endorses installed in each intermediate tower are provided.

Distance and angle between antennas vary greatly in each node, so it is not possible to establish a relation between these two values and the constant drop shown in Table 5. Something similar happens with the distance between en-

Table 5: Possible causes for drop

Node	Distance between antennas	Angle between antennas	H distance between endorses	V distance between endorses
8	1.5 m	165°	0.75 m	1.5 m
9	1.3 m	125°	0.27 m	1.27 m
10	0 m	133°	1.125 m	0.2 m
11	1.7 m	180°	0.75 m	1.7 m
12	1.7 m	111°	0.53 m	1.27 m

dorses: the differences of distances in each node are so different, that cannot be related to the constant drop in each node. Therefore, research conducted in a more controlled scenario modifying one by one each of the parameters is needed in order to find the cause of the drop and, hence, avoid interference in a multihop network.

5. CONCLUSION AND FUTURE WORKS

Results show that more research needs to be done in identifying the details of the decrease on the performance shown in section 4. When the 16 hops are opertaing, the detected decrease would entail a drop in more than 2 Mbps in the end-to-end throughput. This is paramount since, in addition to the described services, many other applications are going to be included in the netork such as real time teleconsultaion through telestethoscopy, telemicroscopy, tele-EKG, and tele-ecography. In order to run these applications properly, a better througput is needed and QoS support is a must. In this sense, work is being done on the adaptation 802.11e, the standard that provides QoS at 802.11 MAC layer, to a long distance scenario [9]. This approach will be compatible with Diffserv solution presented here and would allow us to include QoS in MAC and IP layer.

Futhermore, it needs to be noted that due to the linear disposal of the network, there is only one way for the data to reach the gateway. Therefore, each node is essential for the services to reach all the nodes behind it. In a context where electrical storms are very common, and come accompanied of heavy rains, if maintenance is not carried out properly devices will need frequently to be replaced. Thus, maintenance plans need to include a protocol against failures, assigning responsibilities for the revision and replacement of devices, a management of the spare parts, etc. This maintenance plan has not only been designed, budgeted and put in practice [1], but its cost has been asumed by regional health care authorities, thus guaranteeing the long term sustainability of the network.

Acknowledgment

The authors would like to thank GTR-PUCP for its great job in the field.

6. REFERENCES

[1] I. Bebea-González, L. Linnán, and C. Rey-Moreno. Design of a sustainability action plan for ehas-napo project: a rural e-health initiative. In *In Proceedings of the IPID PG at IEEE/ACM International Conference on ICTD2010*, London, United Kingdom, 2010.

[2] I. Bebea-González, J. Paco, L. Linán, J. Simó-Reigadas, and A. Martínez-Fernández. Management framework for sustainable e-healthcare provision. In *IADIS International Conference e-Society*, Avila, Spain, 2011.

[3] P. Bhagwat, B. Raman, and D. Sanghi. Turning 802.11 inside-out. *ACM SIGCOMM Computer Communication Review*, 34, January 2004.

[4] K. Chebrolu, B. Raman, and S. Sen. Long-distance 802.11b links: Performance measurements and experience. In *ACM MOBICOM*, 2006.

[5] A. Martinez, J. Seoane, V. Villarroel, and F. Del Pozo. A study of a rural telemedicine system in the amazon region of peru. *Journal of Telemedicine and Telecare*, 10(4):219–225, August 2004.

[6] A. Martinez, J. Seoane, V. Villarroel, and F. Del Pozo. Analysis of information and communication needs in rural primary healthcare in developing countries. *IEEE Transactions on Information Technology in Biomedicine*, 9(6):66–72, August 2005.

[7] E. Pietrosemoli. Wireless data transmission in the andes: Networking merida state. In *Inet'99*, San Francisco, Ca., U.S.A., 1999.

[8] A. Rendón, A. Martínez, M. Dulcey, J. Seoane, R. Shoemaker, and V. Villarroel. Rural telemedicine infrastructure and services in the Department of Cauca, Colombia. *Telemed J E Health*, 11(4):451–459, August 2005.

[9] S. Salmeron, J. Ramiro, A. Martinez, and J. Simo. Traffic engineering in rural wireless networks for developing countries using ieee 802.11 edca. In *Wireless Rural and Emergency Communications Conference (IEEE WRECOM)*, Rome, Italy, 2007.

[10] S. Sen, S. Kole, and B. Raman. Rural telephony: A socio-economic case study. In *International Conference on Information and Communication Technologies and Development (ICTD-2006)*, U.C.Berkeley, U.S.A., May 2006.

[11] J. Simo, A. Martinez, P. Osuna, S. Lafuente, and J. Seoane. The design of a wireless solar-powered router for rural environments isolated from health facilities. *IEEE Wireless Comunication Magazine*, 15(3):24–30, June 2008.

[12] J. Simo, P. Osuna, R. Quispe, and D. Espinoza. Application of ieee 802.11 technology for health isolated rural environments. In *Proc. of IFIP WCC-WCIT*, Santiago de Chile, Chile, 2006.

[13] J. Simo, J. Seoane, and R. Salazar. A qos-aware ad-hoc wireless network for isolated rural environments. In *EUNICE 2005*, 2005.

[14] J. Simo-Reigadas, A. Martinez-Fernandez, J. Ramos-Lopez, and J. Seoane-Pascual. Modeling and optimizing ieee 802.11 dcf for long-distance links. *Mobile Computing, IEEE Transactions on*, 9(6):881–896, August 2010.

[15] S. Surana, R. Patra, S. Nedevschi, and E. Brewer. Deploying a rural wireless telemedicine system: Experiences in sustainability. *Computer*, 41:48–56, 2008.