Application of IEEE 802.11 technology for health isolated rural environments

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Abstract

Isolated rural areas often lack for any terrestrial telecommunication networks, especially in developing countries, which supposes an important obstacle for offering health assistance of acceptable quality. On the other hand, low density and low concentration of population, lack of electricity in many points and accessibility problems make it difficult to propose realistic solutions based on conventional technologies. This work shows the research on the adaptation of the IEEE 802.11technology for these kind of scenarios, stressing the case of long distance links. Based on this technology we have designed and installed a WiFi Mesh network in Cuzco (Peru) providing to 12 rural health centres with Internet access and VoIP services. Some results obtained from this network and future improvements related to them are also shown in this work.

Keywords: Rural telemedicine, Mesh networks, WiFi, IEEE 802.11, VoIP, Developing countries.

1. Introduction

More than half of the world population lives in isolated rural areas out of the scope of any terrestrial telecommunication networks. This is particularly true in developing countries, where rural areas very often lack of any access to the public telephone network or even to electricity. Low density and low concentration of population make difficult to afford the installation of permanent infrastructures that would be expensive due to typical restrictions in power service, accessibility, maintainability and security. Additionally, in developing countries rural communities are usually extremely poor and can not afford the cost of services if this is too high [1].

In our group – EHAS program [1,2] - we are very concerned about isolated rural environments in developing countries, and specifically with health facilities and their communication to hospitals. Previous advances in rural telemedicine for developing countries proved that providing voice and data communications in small rural health spots gives great benefits such as a drastic reduction in the average evacuation time of critical patients, improvement of diagnostics' reliability, and decrease of travels needed by the staff.

In this work we propose to use IEEE 802.11 mesh networks supporting voice and data communications as the most appropriate technology that makes it possible to use telemedicine applications and public health information systems in rural areas at developing countries. Mesh networks do not require any previous communication infrastructure. Nodes connect to neighbours as they discover them, and can communicate with non-contiguous nodes or with other networks using other nodes as routers. The extremely low price of IEEE 802.11 components, the use of the license-free 2.4GHz/5.8GHz ISM bands and our previous experience with WiFi-based wide area networks allow us to propose this technology as an appropriated solution for these scenarios.

It is important to remark that IEEE 802.11 technology has been designed for indoor environments. Very few experiences like [3,4] have reported formally the use of WiFi for long distance links. Besides that, existing research about performance models of IEEE 802.11 can not be applied directly to long-distance WiFi links because of the universal asumption that a node can listen to another transmiting node within a slot time.

In this paper we show some important guidelines to use Wi-Fi for long distance links. Based on these principles we have deployed a Wi-Fi Mesh network in an isolated area of Cuzco (Peru) for providing VoIP telephony and Internet services to 15 nodes with point to point links up to 42km long and point to multipoint links up to 20km for the furthest client. Some first results and conclusions about the performance of this network are shown in this work. In the last section of the paper we present the work in progress to improve the functionality of our design. We are especially focused on three points: mesh network's autoconfiguration, a very low-powered design and the management of QoS (Quality of Service) at the IP level for assuring a good quality to voice communications.

2. Limits For Using IEEE 802.11 For Long Distances

2.1 Limits at the physical layer

IEEE 802.11 uses 2.4/5.8 Ghz ISM bands which are license-free but with restricted maximum transmission power levels. The restrictions are fixed on a per-country basis and determine the maximum achievable distance. In many developing countries the North American FCC's reglamentation for these bands is applied, so that realistic PtMP (point to multipoint) links can be implemented with up to 28dBm of transmitting power plus 12dBi of antenna gain, and PtP (point to point) links may use 24dBi antennas by lowering th transmitting power to 24dBm. Other countries have much more restrictive limits, as is the case for all European contries. These limits mark the first clear limit of WiFi for achieving long distances.

The second aspect that must be taken into account is the propagation. For achieving long distances at those frequencies, LOS (line of sight) is a must. The exact propagation loss for a link can be estimated by using appropiated models, which are different for urban or rural areas. In isolated areas, an irregular terrain model like Longley-Rice's must be used in order to take into account the terrain profile.

The third important aspect regards the signal reception. In all three standards IEEE 802.11a/b/g there are several speeds corresponding to different modulations, all with different receiver sensitivity, which results in different maximum distances for the different speeds. Longer links will be obtained with lower speeds.

In Table 1 we can see an approximation of the achievable distance for each speed in IEEE 802.11b; propagation in free space has been considered, with FCC transmission restrictions and typical sensitivity values for Engenius Senao SL2511 cards. Point to point links are supposed to use 24dBm transmitters and 24dBi antennas in both sides, having 2dB of loss in connectors and pigtails. A guard band of 25dB has been respected between the minimum received power leved admited and the sensitivity, so that the BER (bit error rate) stays under 10^{-5} even if the imperfect alignment of antennas, the rain or other factors introduce an extra loss of up to 10dB.

	1 Mbps	*2 Mbps*	*5.5 Mbps*	*11 Mbps*
PtP	80	63	50	39
PtMP	19	15	12	10
MPtMP	5	4	3	2

Table 1. Achievable distances (in Km) for IEEE 802.11b

Those three aspects are considered in the link budget, which basically calculates the received signal power as the difference between the transmitted power and the total propagation loss.

2.2 Limits at the MAC layer

The first important limit is related to the slot time in the IEEE 802.11 MAC. All stations that are not hidden are supposed to listen to each other's begin of transmission within an slot time, implying that the propagation time must be lower than that parameter. For the most used PHY layer in IEEE 802.11, the DSSS (direct sequence spread spectrum), the slot time lasts 20µs, so distances of more than 5.9 Km violate the previous assumption.

An absolute upper limit is the value of the ACKTimeout, which is the time a station waits for the ACK of each transmitted packet before considering that it is lost and retransmitting. This value is not clearly stated in the standard and different implementations can vary. However, there are several IEEE 802.11 products that permit to assign the desired value to this parameter, letting us to fix the limit imposed by the PHY as the upper limit.

The performance of WiFi for distances between those two limits (slot time and PHY) diminishes with the distance due to an excess of collisions, specially for PtMP links. We are working on a model that permits to analyse this but the details go beyond the scope of this work.

3. Development of a WiFi Network in a Rural Area Of Cuzco (Peru) For Internet Access and VoIP

Figure 1 shows the design of the Cuzco network in a schematic way. There are seven Repeater Stations (actually they are wireless routers) that connect twelve End User Stations. The northern area is Quispicanchis Province (4 End User Stations and 3 Repeater Stations) and the southern one is Acomayo Province (7 End User Stations and 3 repeatears). There are two main radio links that connect this provinces to Cusco City: the first one is a 39Km radio link from Cusco Hospital Repeater to Josjojojahuarina1 Repeater, and the second one is a 42 Km radio link from Josjojahuarina1 Repeater to Don Juan Repeater. These two radio links are the main part of the backbone. The Cusco Hospital Repeater is linked to a gateway that connects this network to the Internet and to the PSTN.

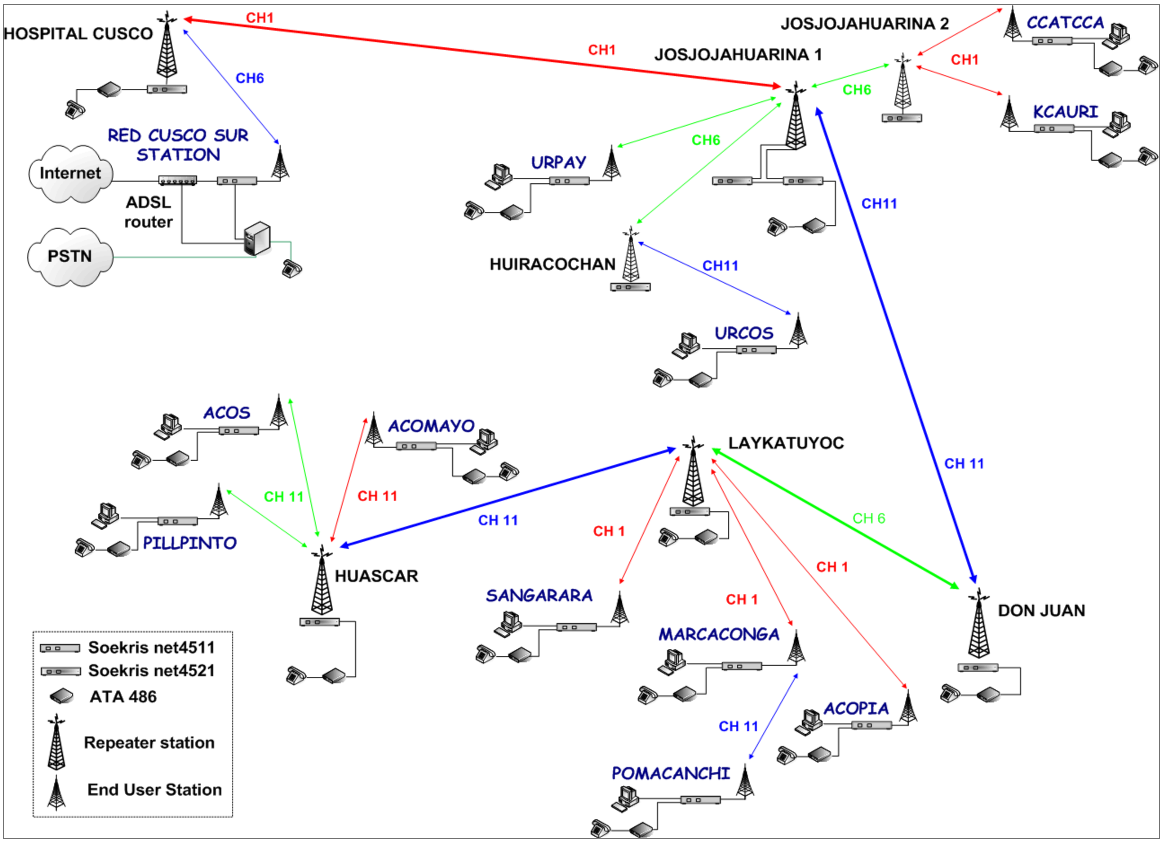

Figure 1. CuzcoSur WiFi Network

3.1 Design aspects

The network was firstly designed with the aid of the software RadioMobile, which uses the Longley-Rice model and Digital Elevation Maps for giving a realistic prediction of radio links behavior. Once the end users were positioned in the map, the repeaters where placed in order to assure LOS and reasonable distances in all the hops.
The received signal is kept 25dB over the sensibility of receivers for all the links. Non overlapping channels (1, 6 and 11) are used in the 2.4GHz band, and PtMP links involving distances longer than 6Km are limited to 4 stations. When necessary, two or more routers are installed in the same place and connected through an ethernet cable in order to guarantee this. The height of the antennas is calculated for assuring that the first Fresnel zone is clear.

3.2 Network architecture

The design of Cuzco network architecture is based in three kind of network stations: repeaters, end-user stations and one gateway. The core of all these stations is the same: a router consisting of a Soekris board, an embedded computer optimized following consumption and size requirements. It has low cost design, availability of wireless interfaces, robustness against bad weather conditions and hardware watchdog. It incorporates an operating system, Pebble-EHAS, developed by our Group and based in Pebble-minidistro, which size is around 77MB. It has all the networking tools necessary for routing and a watchdog software. Also the software PBX Asterisk is included.
Below we briefly describe these three kinds of station:

3.2.1 End User Station

It corresponds with a Primary Health Center or Health Post (see Fig. 2). It can be divided in three subsystems:

– Telecommunications Subsystem. Responsible of the communication with the rest of the network. It consists of one directional 24 dBi antenna pointing to the closest repeater, a Soekris Board with a wireless card (leaving some slots free for future expansion) and cabling.
– Facility Ground Subsystem. Responsible of the ground and lightning protection.
– End User Subsystem. It has two elements: the VoIP system, consisting of a analog phone and an Analogical Telephone Adapter (ATA486), and the computer, running applications like Web browsing, electronic mail, office suite, e-health programs, etc. All of these applications are open-source ones and run under Ubuntu Linux systems.

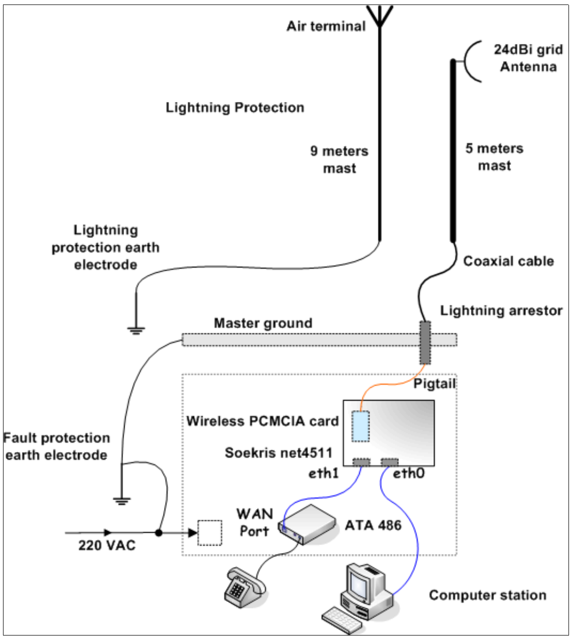

Figure 2. End User Station

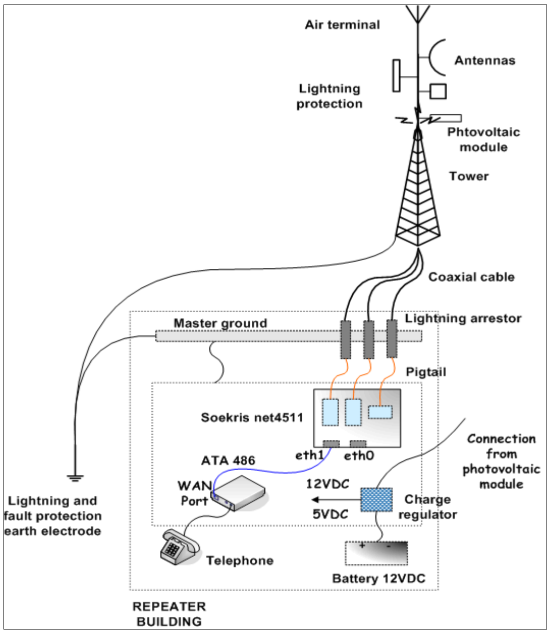

Figure 3. Repeater Station

3.2.2 Repeater Station,

It is normally placed at the top of high mountains in order to get the maximum coverage (see Fig. 3). Due to adverse weather conditions typical of these locations, all of the equipment is located inside a repeater building (3m^2 room).

– Telecommunications Subsystem. Responsible of the communication with the end user stations, mostly PtMP links with sectorial antennas, and with other repeaters, PtP links with directional antennas. It also has a Soekris board with more than one wireless card running at the same time.
– Facility Ground Subsystem.
– Solar subsystem. Normally in these kind of locations there are no power sources at all. So it is necessary to have a solar power subsystem to provide enough power in a continuous way. This subsystem consist of all necessary elements to feed in DC our communication system: solar panel, batteries, charger/regulator and cables.

3.2.3 Gateway

Figure 4 shows how Internet and PSTN are distributed in Cuzco network. Internet Access is provided through a ADSL leased line while PSTN is connected to our network through a internal server, SVCUSCO, using a TDM13B Digium card.

3.3 VoIP

VoIP service is provided by a software PBX called Asterisk. There are five Asterisk servers installed in Cuzco network: Cusco, Josjojahuarina(2), Laykatuyoc and Huascar. Only the first one has been installed in a PC, the others have been installed in Soekris boards. Each of these servers is responsible for the calls of a certain part of the network. First idea was to install only one server in Cuzco. But in case some points of the network lose the connectivity with Cuzco, it would not be possible to make calls until connection was restored again. Some of the VoIP services provided are: free voice communication among all the users, voicemail, conference and communication to/from PSTN with prepaid cards. SVCUSCO server is the responsible of voicemail and conference services for the whole network as Soekris net4521 does not support sound files. Codec ulaw is the one used in Cuzco network at the moment. All VoIP components in our network use SIP protocol to communicate each other, whereas Asterisk PBX communicates with peers using the proprietary IAX2 protocol.

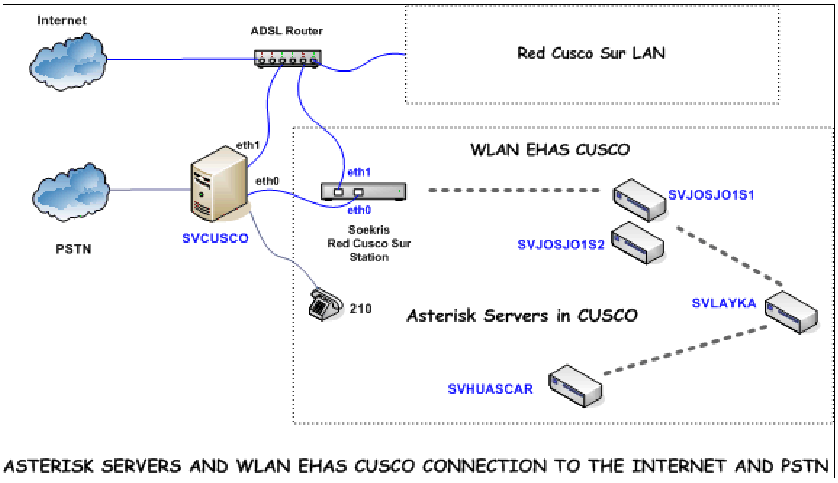

Figure 4. Software PBX

4. Results and Evaluation

In this section we present some practical results from the performance of the Wi-Fi network in Cusco. The first subsection refers to some tests done in long distance links previous to the building of the network. Next subsection refers to some performance evaluations done two months after the network was finished. Based on all of these results we can draw some conclusions to study in depth in further work.

4.1 Previous Tests in Long-Distance Wi-Fi Links

In order to get some experimental results based in our previous research we did some performance tests in 40km and 11km links. We have done all of the throughput measurements using Iperf software with TCP traffic.

– 40km links: Cusco – Josjojahuarina and Josjojahuarina – Don Juan. See Table 2. We did tests in these two links obtaining very similar results. The wireless card used was Ubiquity SR2 b/g 400mW, managed in Linux by Madwifi driver. This was the first time we use 802.11g and the results were quite promising. Although this mode presents worse sensitivities than 802.11b, it has turned out to be a very stable mode. We got these results after modifying some parameters in 802.11 MAC layer. Performance was quite poor without those modifications. Ad-Hoc mode is not working well with these wireless cards so all results showed here refer to infrastructure mode.

– 11km link: Josjojahuarina – Urpay. This time the wireless card used was Senao 2511CD PLUS EXT2 200mW, managed by Hostap driver. Table 3 shows results for Infrastructure, Ad-Hoc and Pseudo-IBSS. We can see very similar results in these three modes, slightly better than in infrastructure mode. Ad-Hoc mode showed a stable behaviour but it will be convenient to perform more tests in a longer period in order to get more reliable results.

Rate	Cusco - Josjojahuarina	Josjojahuarina - Don Juan
1M (b)	68.5	69.7
2M(b)	119	110
5.5M (b)	205	197
6M (g)	275	266
9M (g)	440	425
11M (b)	368	350
12M (g)	500	499
18M (g)	602	585
24M (g)	759	721
36M (g)	833	810
48M (g)	184	no link
54M (g)	no link	no link

Table 2. 802.11 b/g throughput (Kbytes/s) in 40km

Rate	Master - Managed	Ad-Hoc	Pseudo - IBSS
1M	79.5	74	80.1
2M	159	152	153
5.5M	360	334	331
11M	553	341	506

Table 3. 802.11b throughput (Kbytes/s) in 11km

Figure 5. Tests in Josjojahuarina

4.2 Later Performance Evaluation

In this section we present some evaluations carried out in the Cuzco network two months after the installation was completed.

4.2.1 Tests based on network performance

There are 15 links in total installed in the network. 13 of them are running 802.11b mode with 2M rate (effective throughputs go from 122 to 181 Kbytes/s) and the other 2 links are running in 802.11g with 6M rate (similar throughputs to shown before). Although signals received in the nodes are generally good enough to increase the rate to higher values, we prefer to fix a low value in order to assure the stability of the link. Ping times in low-load conditions in these links are 4.4 ms for 802.11b links and 2.2ms for 802.11g ones.

According to the type of link some evaluations and tests have been done:

- PtP: Figure 6 shows 4 nodes of the network, all of the them joined by PtP links (red straight arrows in the figure). Throughouts between different points are shown in Kbytes/s. Blue curved arrows show the effective throughout between two points separated by more than one hop. This throughput corresponds approximately to the most restrictive link in terms of bandwidth between the two points. If we inject TCP traffic to Don Juan from Acomayo, Huascar and Laykatuyoc at the same time we can observe that traffic is fairly divided among these links. In the test done for this purpose Acomayo had 40.2Kbytes/s, Huascar had 41.9Kbytes/s and Don Juan had 44.4 Kbytes/s. So PtP links appear to work as expected and just lack another performance issues due to collisions and distance considerations.
- PtMP: To evaluate these kind of links we refer to Laykatuyoc node, which is transmitting in PtMP link to Sangarara, Marcaconga and Acopia. See Figure 7. First thing we observe is that throughput between clients of Laykatuyoc is approximately half of the most restrictive one. This behaviour is normal as Wi-Fi is Half-Duplex. If we try to inject TCP traffic to Laykatuyoc or a further point from two clients at the same time we observe that most part of resources are kept by the best link. In our experiment we injected traffic to Laykatuyoc from Marcaconga and Sangarara at the same time obtaining 158Kbytes/s for Marcaconga link and 10.2Kbytes/s for Sangarara one. It is clear to state that PtMP lack PtP issues besides inherent problems in them, as it was explained in the second section of this paper. It will be necessary to modify the protocol in some way to consider this case.

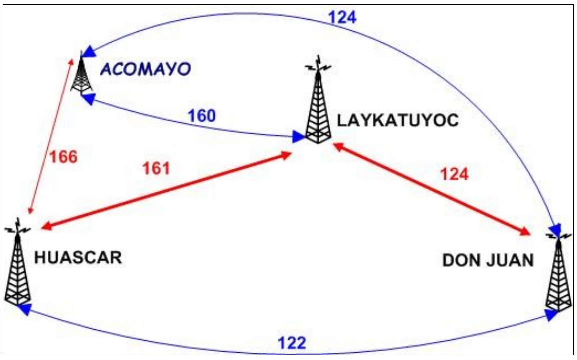

Figure 6. PtP links

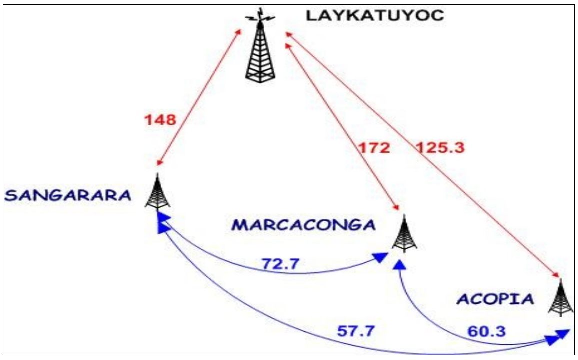

Figure 7. PtMP links

4.2.2 First subjective experiences from final users

We interviewed the network users (13 final users considering Cuzco Hospital) in order to do a first subjective evaluation of the network. We divide this evaluation according to Web browsing-electronic mail and VoIP service.

- Web browsing-electronic mail. All users are quite happy with the performance of Web browsing and electronic mail service. The average throughput a user gets from Internet is around 50Kbytes/s, enough for the needs of these communities.
- VoIP service. Each Health Post or Primary Health Centre makes on average 7 calls per day, meaning that the network carries approximately 91 calls daily. Most users agreed that the IP phone service is of a high quality, in some cases comparable to conventional phone service (PTN). However some users also stated that the service often falters and has some delay. This could be due to instances of high traffic on the network or adverse weather conditions that worsen the performance of the network links. We are currently working on the design and implementation of a QoS adaptive model that permits to solve most part of these incidents. Also final users connected to PtMP links (e.g Sangarara, Marcaconga, Acopia) experience similar problems when they try to communicate each other. This is mainly due to protocol issues typical of these links as explained before.

5. Functional Improvements Under Development

Isolated rural scenarios in developing countries usually have some common characteristics: long distances of several tens of kilometres among "controlled" points; lack of fast routes that make easy the movement between different points of the network; lack of an electric installation and, if it exists, it is often unstable; shortage and high cost of qualified technical staff; extremely low incomes of rural inhabitants. Those environmental characteristics determine the requirements that must be met by any telecommunication technology in order to be successful and sustainable in such scenarios. In the introduction of this paper we have presented some of the main characteristics of Mesh networks that make them a candidate solution.

Cuzco network could be partially considerate a Mesh network in terms of its architecture. On the one hand it is a decentralized architecture. On the other hand all of the nodes belonging to the network have mainly the same hardware, being the only difference the position and use of nodes. The fact that all nodes in mesh networks have the same functionality is also very positive for the extension and maintenance of the network. Although this architecture has been considered in the design of Cuzco Network, there are still some important features of Mesh networks that need to be taken into account in the specific case of isolated rural areas. Especially those which have to do with autoconfiguration aspects. We will go through them in this section. Also we will present another two research lines which we need to face in order to give a complete proper solution for this scenario: the reduction of power consumption and the design of a adaptive QoS model. All of this work is under development at the current time.

5.1 Autoconfiguration in network design

If we were able to obtain a highly self-configurable mesh architecture, nodes can be place at strategic positions by any non-qualified person whose only concern will be to assure the line-of-sight to neighbour nodes. As a node is powered on, it discovers its neighbours, attributes itself a unique IP address, and then establish the most appropriate routes to the rest of the network and to the world, taking into account the quality of the links. In order to get this functionality we will divide our research in two aspects: IP Autoconfiguration and Multihop Dynamic Routing Protocol.

5.1.1 IP Autoconfiguration

To be part of an IP network, each node needs to be set up with an IP address, whether it be manually or automatically through a DHCP server. In fact, this has been the approach taken in the Cuzco network. However, the dynamic and self-configuring character of a mesh network makes these procedures an unsuitable solution. In IPv6 there are several solutions [9,10,11] to obtain automatically an IP address in the scope of an unique multicast domain. This local character makes them useless for the nodes of a Mesh network whose addresses do not keep a fixed relation and therefore do not share the same domain. In IPv4 ZEROCONF workgroup has implemented a similar solution to IPv6 one. Using this implementation (zcip in Linux) a node is automatically set up with a 169.254/16 IPv4 address. As the case of IPv6 these addresses are only valid for the communication with nodes in the same physical link (or logical). The draft [8] shows an overview of the proposed solutions for autoconfiguration issue in MANETS. These solutions are being studied by AUTOCONF group, responsible of the standardization process of autoconfiguration. However, it will take a long time to have an implementation which complies with the standard. In the short-term these are some of the solutions studied and proposed by our group:

- In IPv4, although a node has a unique 48 bits MAC address, there are no means to obtain a unique 32 bits IPv4 address from it. One partial solution in order to get this uniqueness could be the use of wireless cards from the same manufacturer.
- PACMAN [9], NOA-OLSR[10], LUNARng[11] are multihop adhoc dynamic routing protocols offering a solution for the autoconfiguration issue. However, they suffer from other limitations: no QoS-aware, limited number of interfaces per node, instability.
- A DHCP centralized server would permit that a node could get its IP address making use of several DHCP relays or sending DHCP requests through routing packets.

5.1.2 Multihop Adhoc Dynamic Routing Protocol.

For the case of the Cuzco network we have chosen a static routing design. This solution is stable and does not add any routing control traffic among the nodes that compose the network. However this is not a self-configuring solution. In mesh networks, multihop ad-hoc dynamic routing protocols have been developed for routing packets among contiguous nodes or not contiguous of the network, or between any node of the network and the exterior through a gateway node. In these protocols the only requirement for an IP address in the network is its uniqueness. A lot of research articles analyse and compare the performance of different protocols, among them the most famous is [12]. A traditional classification of these protocols divides them in: 1) Reactives, a one node only exchanges control information when it wants to begin a communication with another node. AODV [13] y DSR [14] are the most extended in this category. 2) Proactives, nodes exchange information in a periodical way to learn the typology of the network. OLSR [15] and TBRFP are the most popular. Some of the critical aspects that make some of these protocols better than others are the quick convergence faced with changes in the network topology, the mechanisms to avoid loops, the right establishment of routes to the gateways and the efficiency to avoid loading the network with unnecessary control traffic. Most of these problems disappear in static networks and most of the protocols mentioned before are suitable from a stability point of view. Our work [16] mentions some lab tests that allowed us to use with success the AODV (implementation of the Upsala University) as well as OLSR (Qolyster version) in static ad-hoc chains.

Furthermore, there is a specific problem that only recently has been tackled by some research groups: a QoS-aware routing protocol. As an MIT group proved in [17], the protocols mentioned before stablish routes that are not always optimum because they use a number of hops as metric, not taking into account the relative quality of the links. De Couto et al. have suggested a metric called ETX [18] that considers the average number of retransmissions in every link. This breaks the independence rule between layers since it uses the information of the MAC layer to influence on IP level. The QOLSR [19] project has introduced QoS in OLSR. Its implementation, Qolyester, still finds itself on a first stage of development but it deserves to be followed closely in the future.

Our team has selected *olsrd*, Andreas Tonnesen's OLSR implementation, as the best current solution for our network. In contrast to other projects, it has achieved a remarkable maturity and stability and nowadays it continues to be supported by an extensive community. Recently this protocol has incorporated a ETX metric to its core. "olsrd" is a protocol structured in a modular way by plugins that easily allow to add external functionalities to the code. We could mention the following: Dynamic Internet Gateway, to add gateways to Internet dynamically; Security, to add signature messages to OLSR traffic; HTTP info, a small HTTP server that displays various information about the running olsrd daemon; and Dot Topology information, to generate graphics of the current net topology.

5.2 Low-powered system

Our router will be installed in isolated rural areas, typically high mountain or jungle, where often there are no power sources at all. So nodes need to have a solar power subsystem to provide enough power in a continuous way. The cost and size of the solar sub-system will be proportional to its power consumption, so it will be essential to design a very low-powered system. A first approach to reduce the consumption will be to migrate the hardware platform to a less-consuming one. According to measurements performed in our laboratory, Soekris board has an average consumption of 4W, a value still too high for our requirements. A second version of the node is under development, in which the power consumption will be reduced to 1W. For that purpose we are working now in a consumption comparison from different boards: ARM architecture (Peplink, Compulab, Inhand) and MIPS architecture (RouterBoard, MeshCube). Results from this comparison will be available in the short term. Another approach has to be with the wireless cards. According to measurements performed in our laboratory wireless cards are the most power-demanding elements. IEEE 802.11 specifications include a power-saving mode (PS). Linux drivers are using that mode, but it is more efficient in centralized networks than mesh ones. To improve this power-saving scheme our group is considering the design of a protocol which wakes the wireless interfaces up and sleeps them in period cycles while the network is idle. During certain periods, for example in the night, it could be allowed a delay of up to several minutes in the establishment of the communication in order to reduce power consumption while the solar subsystem is not supplying power.

5.3 QoS adaptative model

As we have already seen IEEE 802.11 networks can offer a strong, suitable and low-price solution to distribute voice and data communication. In our case telephony communications are essential, voice is the most demanded service to communicate isolated rural areas as it has been proved in the long-term evaluation of previous demonstrative projects of the EHAS group [1]. Additionally if we could propose other real-time services as video-conference, it could be also interesting to telemedicine and e-learning applications, among others. We have seen in a first evaluation of Cuzco network that some users are experiencing problems with faltering connections in the VoIP service. So if we want to propose real-time communications it is necessary to ensure a quality of service in certain conditions.

The QoS (Quality of Service) can be defined as a guarantee assured by the network of respecting certain maximal or minimal values to certain parameters when switching a packet throughout the network. The main problem associated to the QoS in a protocol stack is that all protocols must be QoS aware, which is not the case of 802.11b; any wireless network using this technology will never support QoS completely. However, the use of certain technical procedures at the IP level will permit at least that different kinds of traffic could be differentiated and treated as needed. 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. None of them can be directly applied to ad hoc networks because they make some important functional differences between edge nodes and core nodes while in ad hoc networks all nodes have the same functionality; so any of these solutions will have to be adapted.

The QoS at the IP level implies that different communications (in IntServ) or different traffic classes (in DiffServ) can be identified in each router and be treated separately, with different priorities. An important handicap will be that the throughput of wireless links must be estimated in order to perform bandwidth sharing in a fair way, though the throughput may be variable due to the distance between nodes or to the presence of interferences. We have also mentioned that the WiFi technology is not QoS-aware. However, a partial support for QoS may be obtained at the IP level applying QoS aware IP switching, which permits us to give different priorities to different traffic classes. The parameters that can be adjusted for each traffic class are mainly the following ones: throughput, delay and packet-dropping probability. Additionally, traffic shaping functions give us a way to avoid network overload, which permits us to guarantee that the network performance will approach what is expected.

Some experiments made by our group with mesh nodes chains have permitted us to demonstrate that a differentiated quality of service of voice, video and elastic data could be guaranteed if it is possible to restrict the performance of the link [16]. It would also be very interesting to future works the dynamic estimation of the available resources so that they could be adapted according to changes, presenting even control adaptive admission.

6. Discussion and Future Work

In this work we have presented a wireless mesh network design using IEEE 802.11, and adapted for long distance links. This scheme provides a voice and data communication infrastructure adapted to the requirements of isolated rural areas in developing countries. It has been seen that the provision of VoIP telephony, access to public health information systems and e-learning in these scenarios has a very positive impact in the quality of health assistance in deprived areas. We have shown a real network installed in Cuzco as an example of proper solution to this scenario. Although several aspects have already been successfully tested, we have encountered some problems that will need to be faced in future work, among these:

- Research of a IEEE 802.11 model for long distance links.
- Optimization of PtMP case.
- Selection of a low-powered hardware for the second prototype of Mesh router.
- Implementation of an autoconfigurable solution.
- Adaptive QoS support at the IP level to assure a good quality for the VoIP service.

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