Fig. 1. Server and battery loader at the health center (HC) of Shucushyacu.

Rural Telemedicine for Primary Healthcare in Developing Countries

ANDRÉS MARTÍNEZ, VALENTÍN VILLARROEL,
JOAQUÍN SEOANE, AND FRANCISCO DEL POZO

The Biomedical Engineering and Telemedicine Group of the Technical University of Madrid (GBT-UPM in Spanish) and the non-governmental organization Engineering Without Frontiers (ISF in Spanish) are leading the "Hispano-American Health Link" program (EHAS in Spanish), to develop low-cost telecommunication systems and information services specially designed for rural primary healthcare personnel from isolated areas in developing countries. The EHAS program has five lines of action: 1) research on the communication and information needs of rural health personnel in developing countries, 2) R&D on voice and data communication systems designed according to conditions of rural areas, 3) R&D on information services systems suited to the needs of health personnel, 4) deployment of those services and systems through pilot projects, and 5) evaluation of the impact of these telemedicine systems on health services. This article examines the results of each line of work, with emphasis on the pilot scheme deployed in 39 rural sites of the Alto Amazonas province, in the center of the Peruvian Amazon region.

Great Promise of Telemedicine

A great promise of telemedicine has been to help isolated or scattered populations gain access to health services [1]. In industrialized countries, telemedicine has proven to be a good tool for enabling access to knowledge and allowing information exchange, and showing that it is possible to bring good quality
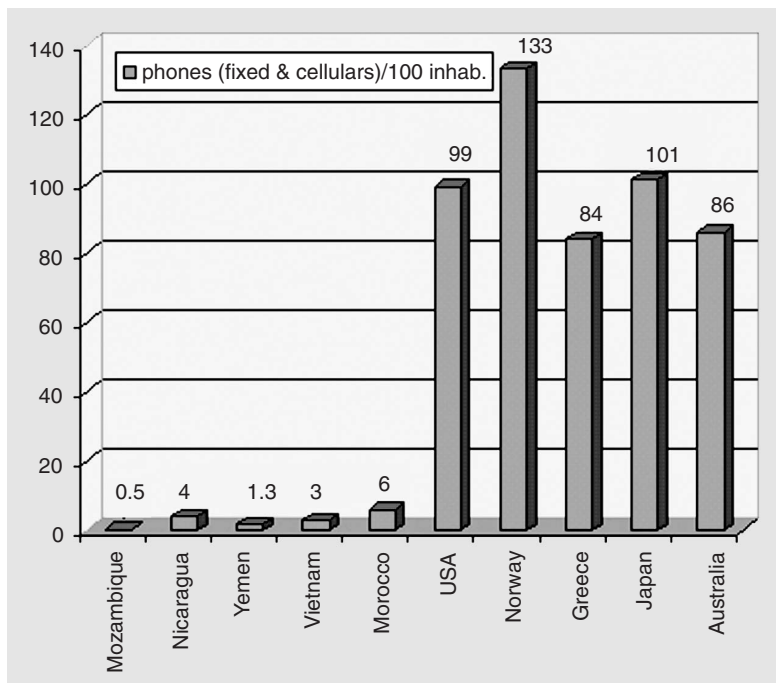
Fig. 2. Number of telephones (fixed and cellular) per 100 inhabitants.

healthcare to isolated communities [2].

Telemedicine can also (and must) be used to deliver healthcare to poor areas in countries with scarce infrastructure and to developing countries [3], [4]. But while information and communication technologies have tremendous potential for improving healthcare, we have to bear in mind that in rural areas of many develop-

ing countries, telephone networks and computers are scarce (Fig. 2). This is especially true in the health sector [5].

Another barrier to the implementation of telemedicine in rural areas of developing countries is limited access to electricity (Fig. 3) [6]. Yet another important factor is the deficient transportation infra-
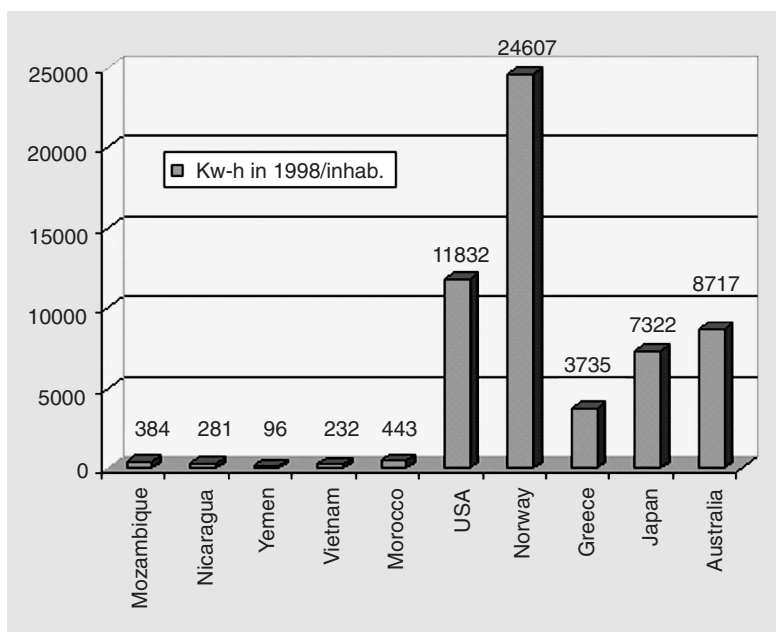
structure (Fig. 4) resulting in a lack of appropriate maintenance and control systems, limited ability to afford expensive telecommunication infrastructure, and poorly trained health personnel. Due to these restrictions, the rural populations of developing countries (already a highly underserved group) are far from enjoying the advantages of the so-called "Global Information Society." Information and communication technologies and services can improve the work conditions of isolated health staff only if those technologies are selected, developed, adapted, and carefully deployed to suit the population's real needs in their real environment [7].

These facts highlight important differences between developed and developing countries that condition any telemedicine project. Moreover, there is a technology gap between urban and rural zones within developing countries themselves. While in the main towns of developing countries most modern communication networks are accessible (ISDN; xDSL; Frame Relay, etc.), there are many rural areas without even a basic telephone network. Therefore, while the telemedicine experiences of urban areas, mostly interhospital projects, are very similar anywhere, rural telemedicine projects seeking to improve the efficiency of primary care result in quite different implementations, depending on whether we are dealing with rural areas of industrialized countries or isolated rural areas of developing countries. The needs and priorities are completely different [8]. Most importantly, the lack of communication infrastructure and financial limitations condition enormously both the appropriate technology and the services required.

The Enlace Hispano Americano de Salud (EHAS) initiative is a viable proposal to deploy telemedicine systems and services in rural areas of developing countries.

Fig. 3. Electricity consumption per capita.

Rural Health Establishments in Developing Countries

Many developing countries organize primary healthcare around two types of care centers. At the most basic level are Health Posts (HP), in other countries called surgeries. HPs are the way most citizens gain access to the healthcare system. At the higher level are Health Centers (HC), also referred to as either basic polyclinics or ambulatory care centers, depending on the country.

HPs and HCs are usually organized into networks, with the HC the reference point for several HPs that depend clinically and administratively on the HC. This network is a "health micronet," the basic unit of the primary health system.

It is important to highlight the common characteristics of these centers throughout developing countries. HPs are mainly located in small towns of no more than a thousand inhabitants, have no telephone lines, and have a poor road networks. HPs rarely have more than one health worker (two in exceptional cases), normally an infirmary technician or recently graduated physician with limited training. HPs depend on HCs for severe case referral, pharmaceutical deliveries, epidemiological management, and coordination of the general activities within the micronet. As a result of the widespread absence of communication systems, when health personnel need to exchange information they have to travel on foot or by land or river vehicles, taking hours or even days to do so.

HCs are above HPs in the health system hierarchy. The towns where HCs are located usually have access to the telephone network. HCs are always headed by physicians, have equipment for diagnostic tests, and sometimes have hospitalization facilities. As mentioned, the HC serves as the reference establishment for several HPs.

Primary Care System of the Alto Amazonas Province of Peru

We shall now explain in more detail the situation of the primary health establishments of the Peruvian Ministry of Health (MINSA) in the province of Alto Amazonas, Loreto region, where the first deployment experience of EHAS technologies and services is taking place. Alto Amazonas is a province with twice the surface area of Belgium and 116 200 inhabitants located in the Peruvian rain forest (Fig. 5). Its capital is Yurimaguas and the province is divided into 11 districts.

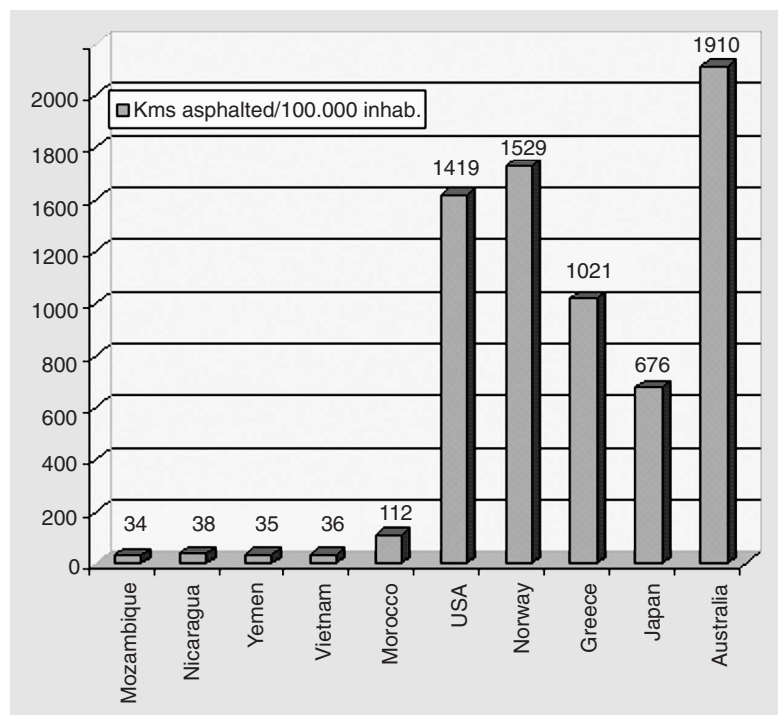According to the Peruvian Ministry of Health (MINSA), Alto Amazonas province forms a unique

Fig. 4. Paved roads per 100 000 inhabitants.

"health net" with 93 health establishments: 1 provincial Hospital in Yurimaguas, 11 HCs and 81 HPs. The pilot project of the EHAS program in Peru was carried out in the southern part of the province (referred to as "Huallaga health subnet") (Fig. 6) and deployed telecommunication systems in 40 establishments (the urban Hospital, 6 rural

HCs and 33 rural HPs). Alto Amazonas province has only one nonasphalt road, which links the capital with the rest of the country. All other surface transport within the province has to be carried out by riverboat. Only 8 out of the 93 health establishments in the province are accessible by road.

On December 1, 2000, we found the following scenario in Alto Amazonas:

- Only the Hospital and two other HCs (one of them in the capital) had a telephone. Seventy one percent of the establishments did not have any communication system. The remaining 29% had a HF radio or a public telephone in the town.
- Only one HP out of 32 had a physician in charge. Infirmary technicians headed the rest. The average age of physicians heading HCs was 32 years. They had 2 years' experience and only one year working in their current establishment.

- The average time taken to travel from an HP to its reference HC is about 11 hours. In case of urgent patient transfer, the mean is reduced to 8.6 hours, with a maximum of 72 hours.
- Only a quarter of the HPs had some transport vehicle (boat or speedboat) to evacuate patients.

Information and Communication Needs in Alto Amazonas

Up until now, the EHAS program has carried out three studies on the information and communication needs of the rural health personnel of Latin America. In December 1997, the GBT-UPM and the Peruvian MINSA carried out a study on 41 rural health establishments randomly selected from three provinces (Morropón, Moyobamba, and Islay), representing the main geographical areas of Peru: coastal desert, mountain, and rain forest. This study was used to facilitate developments in technologies and services within the EHAS program.

In December 1998 the same kind of study was carried out in 17 rural establishments within the province of Chinandega, Nicaragua. The objective was to compare the situation in a South American country with the situation in a Central America country, to identify potential geographical dependencies. The results were very similar.

Finally, in December 2000, a third study was carried out in the Alto Amazonas province in Peru, where GBT-UPM and ISF had

> # A great promise of telemedicine has been to help isolated or scattered populations gain access to health services.

deployed the first field pilot project to use EHAS systems. The latter study was used to compare the initial situation with the final conditions once the pilot scheme was implemented. Thirty-two managers of the 39 health project sites were interviewed.[1] A guided questionnaire was used to achieve an in-depth interview. The main results of the initial study were:

Fig. 5. Alto Amazonas province, Peru.

- The health personnel spent 28 hours a month traveling in order to send administrative and epidemiological reports. Sixty-five percent of the people interviewed said that reports had been lost at some time.
- Eighty percent declared that they had never or had hardly ever received feedback information on epidemiological topics.
- The drug acquisition system is slow. The roundtrip to get the drugs took an average of 4.3 days.
- Ninety-seven percent affirmed they had insufficient training.
- Fifty percent never received a health magazine and only one was in the process of carrying out some kind of research.
- Workers made an average of 1.83 trips a month for coordination purposes. Seventy-five percent asserted that, even traveling personally, it is difficult to make contact with the target person.
- Only one monthly trip is made to consult over doubts and it is the same trip they make for the monthly coordination meeting of the health micronet. In the event of doubts or emergencies specific consultations are rarely made.
- The first priority for 40.5% of interviewed people was the improvement in the infrastructure of the establishment, followed closely by the acquisition of a communication system (32.4%), and the increase in personnel (16%). However, taking into account only personnel working in establishments without any communication system, their first priority, 43%, was to have some communication link, followed by improving the infrastructure (28%).
- About one patient transfer was made a month. Its average cost was $47. Taking into account the rest of the trips, there was a monthly average cost of $218 per worker. There were 1.45 monthly trips to the HC (taking three days each), and 1.47 monthly trips to the hospital (taking 4 days each).
- If electronic mail were used, 94.6% agreed that epidemiological surveillance would improve. With an adequate

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[1] The remaining sites could not be visited due to security considerations or adverse climatic conditions.

communication system, 91.7% affirmed that sharing vehicles would be more efficient. 88.9% considered decreasing the number of trips desirable.

We can conclude that communication deficiencies seriously affect successful coordination of activities, sharing of information, and ongoing education/training of health professionals, thereby diminishing the efficiency of the healthcare system.

Restrictions Imposed by the Situation in Alto Amazonas

The use of a communication system seems an obvious solution for the situation described, but in order to achieve long-term viability, the situation in rural areas of developing countries has to be considered:

- There is no access to electricity in most rural villages (in rural areas of Alto Amazonas six towns have electricity, and those only 4 hours a day).
- Rural areas have limited or no public telecommunication infrastructure and they are not included in the midterm expansion plans of the operator companies.
- Rural health establishments have limited financial resources to fund expensive infrastructure and, more importantly, the operating costs.
- Maintenance costs of any system are very high due to the long distances between establishments.
- There are few well-trained candidates for the management, maintenance, and repair of computer and telecommunication systems.
- The cost of current telecommunication systems on the market is too high to become a systematic solution for all the rural areas of a country (e.g., the Peruvian MINSA has more than 5500 primary health establishments without a telecommunication system).

- No information systems suited to the real needs and capabilities of rural health personnel in Latin America are currently available on the market.

The EHAS Proposal

Considering all the previous constraints, the EHAS program works on research and development of appropriate telecommunication systems and telemedicine services designed to solve the needs of rural health personnel in developing countries. The partners of the program in Spain are the GBT-UPM and ISF, and their counterparts in Peru are the Catholic University

and the Electronic and Electricity Section of the PUCP centered their work on developing an access system to electronic mail for towns without a telephone. The developed system's main feature was: low infrastructure cost and especially low operating cost. The rest of the specifications are:

- VHF transceivers are used for voice and data (email) communications within a health micronet. This system has no operating cost.
- HPs are endowed with VHF transceiver, laptop, lighting system, and solar powered system with a minimum of
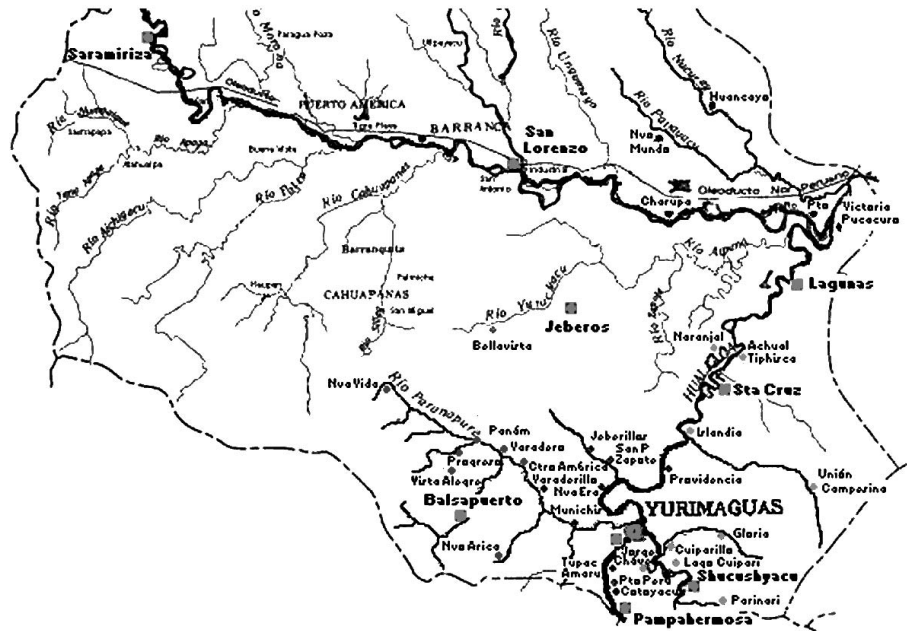

Fig. 6. Map of the health network of Huallaga (Alto Amazonas province, Peru).

(PUCP) and the Cayetano Heredia University (UPCH). This multidisciplinary team works in two main lines of action: development and deployment of "EHAS technology," and development and deployment of "EHAS services."

Accessing Electronic Mail through VHF Radio

The Biomedical Engineering and Telemedicine Group of the UPM

five days' autonomy. (Fig. 7 and Fig. 8).
- The low consumption email server (located at the HC) stores the email messages of the health micronet and forwards them to the Internet through five telephone calls every day (Fig. 8) optimizing telephone costs, which are shared by all the sites belonging to the micronet. In order to

Fig. 7. Infirmary technician using the VHF system for voice and data (email) communication.

simplify the network topology, the Peruvian government collaborated with the project by installing 7 telephone lines.

- Server main power is provided through a battery charger (Fig. 1 and Fig. 9), taking advantage of the four hours of electricity in the capital district and optimizing the battery load.
- A central server in Lima (permanently connected to the

Fig. 8. Solar modules and communication tower in the HP of Lago Cuipari.

Internet) is the connection between the EHAS network and the Internet. When an email comes from the Internet, the central server stores it temporally until the following telephone connection with the server at the HC. To increase the robustness of the whole system, a second server, located at the MINSA headquarters, is used.

To be able to use the traditional e-mail protocols (POP-3 and SMTP) and in order to use standard email software clients, an open-source based application has been designed. This software is a local proxy of the server services, so that the email clients must be configured as having local servers. The proxy multiplexes the connections, compresses and encrypts them, and tunnels them through the AX.25 connection.[2] Using 9600 bps modems and a standard 12.5 kHz channel, it is capable of transferring email messages at an average rate of 17 Kbps of real data.

The server at the HC is a robust, compact and low consumption embedded computer with hard disk, telephone and radio modems, Ethernet, VHF transceiver, and control circuits. It has neither keyboard nor screen and works with a Linux based operating system (GNU/ Debian distribution). Any number of local computers can be connected to it through an Ethernet network, and other remote ones by radio links.

This server has a system to orderly shut down services and the hard disk when an imminent power failure is detected, automatically rebooting all the system when energy returns. Even so, to prevent possible uncontrolled failures, a transactional files system has been installed (ReiserFS).

In addition to the standard email

services (POP-3 and SMTP), a complementary program to that used in the clients' is running in the server, demultiplexing, decrypting, and decompressing the radio connections. Email exchange with the outside through the telephone line uses the UUCP protocol, appropriate for intermittent connections. It uses the TCP transport through an Internet Service Provider at the cost of a local phone call.

The Linux kernel within the server has been modified to allow Demand Assigned Multiple Access (DAMA) instead of CSMA, used by standard AX.25. Thanks to that, each station does not need to see the others, allowing smaller towers and less power, reducing the costs of the whole system.

Special attention has been paid to maintenance through local security backups for all hard disks and a remote maintenance system to access all the computers by radio links.

Telemedicine Services for Rural Health Personnel

The Alexander Von Humbolt Institute of Tropical Medicine from the UPCH works along with ISF in the development and deployment of services centered on the needs detected: distance training and remote access to health information. Services that have been structured in three categories of "EHAS services":

- **Distance training.** Based on an education constructivist model,[3] and taking into account the principal training deficiencies of health personnel, we have developed twelve eight-credit courses, designed with local MINSA managers responsible of continuous training and centered on the prevalent diseases of rural areas: childhood and maternal health, diarrhea, infectious dis-

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[2]AX.25 is a data communication protocol designed for semi-duplex radio communications.
[3]This model assumes that the education program will be successful only if it deals with contents that can be integrated in the daily work.

eases, nutrition, etc. Courses, sent through email, are developed in HTML with JavaScript to allow offline interaction with the trainees. They also have a system for self-examination and remote assessment. Other comple-mentary training units are also provided, such as "the question of the day": a clinically focused question whose answer is provided the following day.

- ▪ **Electronic publications.** "Sanicho" magazine is edited by UPCH to provide an informal forum for the Alto Amazonas health personnel. It includes relevant news and events to reduce the feeling of isolation experienced by the rural health professionals.

- ▪ **Access to experts and health information.** This kind of service allows a mediated access to remote data bases and magazines related to health. The EHAS program uses the idea of "information access facilitators." Health personnel send an email to EHAS requesting information, documents or magazines. Facilitators look for material in local and remote databases, in magazines or from experts at the UPCH. Finally, they prepare the information to be sent back to rural personnel via email.

First EHAS Pilot Experience in the Field

The first pilot experience has taken place in the health network of Huallaga in Alto Amazonas, Peru. Thirtynine EHAS telecommunication systems have been deployed. It consists of 7 email servers and 32 client systems. There is one server in the provincial Hospital at Yurimaguas and six in the HCs of Shucushyacu, Lagunas, Santa Cruz, Pampahermosa, Jeberos, and Balsapuerto. Clients are distributed over these

seven health micronets as follows: eight depending on Yurimaguas, five on Shucushyacu, seven on Balsapuerto, five on Lagunas, four on Sta. Cruz, two on Pampahermosa and one on Jeberos.

The provincial Hospital of Yurimaguas had a significant participation on the selection of the HC and HP involved as well as on the design of the hierarchical features of the communication network. To

Fig. 9. Battery pack in the HC of Shucushyacu.

encourage local appropriation, or a feeling of ownership, many institutions (province government, local authorities and the recipients communities) were involved in the project through active contributions on some deployment activities, such as transportation of experts, equipment, and materials, construction of the tower foundation, etc.

Users were trained on preventive maintenance, operation of the communication system, and use of the computer (hardware and software). An adult training method was used in the two 50-hour courses each user received. During the project two local technicians were trained in network maintenance and the province Hospital received support on how to develop a maintenance system: procedures, equipment replacement, and economic provisions. Finally, managers of each

department at the province Hospital received support on how to change their traditional procedures to new ones in order to better benefit from the new communication system.

In order to make the technology useful for the organizations, we have to adapt the organization to the technology, and also adapt the technology to the organization. The actions we took on the social level (local participation, users and technician training, maintenance procedures and organizational change) gave those results, better matching the technology and organization in both directions: from technology to organization, and from organization to technology.

The network came into operation in September 2001 and two impact evaluations were programmed at medium and long term (9 and 24 months, respectively). These studies are centered on measuring the impact of EHAS systems (technology and services) on the health of the community, as well as the health personnel and health system. The evaluation was made over four main lines of inquiry [9]: the impact on the health of patients, the impact on the health attention process, the economic impact on the various participants, and the impact on the accessibility to a quality health service.
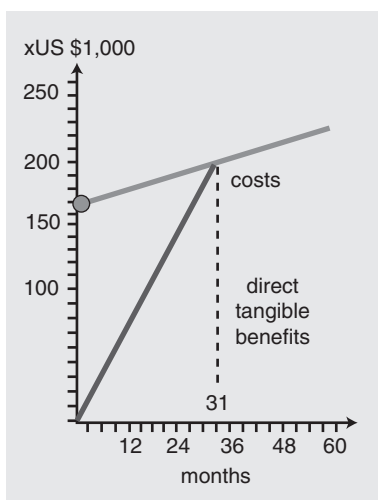
Fig. 10. Cost-benefit analysis using only the direct tangible benefits.

Impact of the Pilot Project (Medium Term)

Starting in May 2002, technical feasibility was evaluated by means of 81 precisely defined indicators. Relevant information was compiled by documental review, direct observation, focus groups and, most importantly, questionnaire-driven interviews of the 32 managers of the 39 sites in the Alto Amazonas.

We present the main results grouped into five categories: quality of the system, improvement in urgent evacuation of patients, improvement in diagnosis and treatment capacity, improvement in epidemiological surveillance, and cost-benefit study.

- **Quality of the system.** The system is highly used (100% frequently used the radio, 71.4% the email, and 86.7% used the PC) and has a good usability (radio system is easy to use for 100%, PC for 77%, and email for 93%). The voice system has a reliability of 97% and email 90%. The system has a good acceptability among users and managers: 100% think the system allows better coordination, 93% think the system allows them to better do their work and 80%

think the task load has decreased.

- **Improvement in emergency evacuation of patients.** The first and main impact was produced in this area. In 9 months, 237 urgent evacuations were carried out in the 39 establishments covered in the project. In 100% of the evacuations the communication system was used to communicate the patients' evacuation in order to prepare their reception, hitherto impossible to achieve. In 64% of the cases the communication system enabled the use of vehicles from other establishments, reducing the mean time employed for evacuation from 8.61 hours to 5.17 hours (60% reduction). The use of the communication system has been crucial in saving 60 patients' lives (25.3% of the cases).
- **Improvement in diagnosis and treatment capacity.** At present, 93.3% of the health staff covered by the project consider it fast and easy to make consultations. Before the project, 93.8% of the people thought it was impossible or very difficult. There have been 391 diagnosis-related questions (10.06 per establishment) and 254 about treatment (6.52 per establishment). 96.7% of those questions were satisfactorily answered. In 90% of the cases, questions were asked while the patient was in the establishment. In most of the cases, questions are asked in real time over the radio, instead of using email.

The EHAS system has been useful for distance training; 5 courses have been imparted (malaria, dengue, tuberculosis, breast breeding, and first aid) and the participants evaluated them with a score of 16.95 / 20. 95.2% of interviewed people declared that the EHAS system was appro-

priate for training rural health personnel.

- **Improvement in epidemiological surveillance.** The EHAS system has proved to be effective in improving the epidemiological surveillance system in the Balsapuerto health micronet (one of the most isolated areas in Alto Amazonas), by reducing by a quarter the number of trips made to send reports. Twice the number of health establishments are now reporting weekly, compared to before the EHAS system. In 60% of the cases the PC has been useful in filling in reports, allowing a reduction in the monthly time devoted to preparing reports from 20 hours to 13 hours (35% reduction). Malaria detection time was reduced by half.
- **Cost-benefit study.** The infrastructure and set-up costs per establishment come to US$4195, and the estimated cost of the telephone bill (seven telephone lines shared by the 39 establishments) plus the system's maintenance and repair is US$704 / month for the entire communication system. The total cost of the system will be recovered by the savings generated in 2.5 years (Fig. 10). In this forecast, we are only considering the savings on travel (US$1718 monthly) and on patient evacuation (US$4230 monthly). However, if we also consider the indirect benefits, breakeven will be reached in 13 months. The indirect benefits include the increased productivity of health staff due to reduction in travel and office tasks, and the productivity increase of patients and relatives due to the reduction in patient evacuations.

Solving Efficacy and Efficiency Problems

To the best of our knowledge, this study is the first feasibility and impact analysis of a rural telemedicine project for a developing country that includes a large sample of isolated communities (39 in the same province) using radio-based voice and data (electronic mail) communication technologies.

This project has clearly demonstrated, supported by convincing statistical evidence (to higher than a 95% degree of statistical significance in all cases), that the use of technologies appropriate to the available local resources (easy to use, robust, and with low operating costs) solves some of the important efficacy and efficiency problems at the rural primary healthcare level. It does so by improving the speed of resolution and diagnostic capacity of the health sites, by speeding up the patient evacuation system, by enhancing the efficiency of epidemiological surveillance mechanisms, by facilitating pharmaceutical deliveries, and by reducing the widespread sense of isolation, both professional and personal, felt by the rural health personnel. The feasibility and sustainability of the VHF radio communication solutions provided to implement rural telemedicine systems in developing countries has also been proved, this being a conclusion that has not been demonstrated with other satellite-based solutions. The working methodology used in the project has also confirmed the hypothesis that only with participative implementation programs, using solutions derived from the needs and constraints of the target communities, and not technology-driven, is it possible to achieve the global acceptance of all users involved: administrators, health professionals, and patients, as well as the integration of a rural telemedicine system within the local health institutions.

Results obtained are intended to demonstrate to the Health Ministries of the region that the solution proposed, and its systems and services, is within the reach of most health rural centers. There are more powerful alternative technologies, but they do not respond to the priorities of the rural sector demands and, more critically, they can never provide sustainable solutions, taking into account the limitations of the developing countries' health systems.

Companies, Public Administrations, and R+D centers have to understand that the massive implantation of telemedicine and telecommunications in isolated rural areas requires a "two-way" approach. In one way, the technology has to be adequate to the user context: local economic resources, human factors and knowledge, cultural considerations, and energy considerations. In the other way, a natural interface must be provided between technology and the institutions: adequate training of the users and of maintenance personnel, and appropriate levels of motivation and tools so the administrative bodies may successfully achieve the organizational changes required.

The EHAS experience demonstrates to health program funding bodies that it is possible to improve the efficiency of the isolated rural systems by means of systems and services such as those we propose here, based on low complexity and low cost technology, as well as appropriate methodologies to support the technological transfer.

Expansion of the EHAS Program

Following the initial results of the impact evaluation of Alto Ama-zonas, the EHAS program is considering five other pilot projects: two new areas in Peru (Marañón network in the Loreto region and Quispi-canchi-Acomayo health network in the Cusco region); two more in Colombia (the indigenous government of Guambía and the Municipalities of Silvia, Jambaló, Almaguer, Piamonte, Santa Rosa, and San Sebastián, all in the department of Cauca); and one more in Cuba, in the province of Guantánamo.

One of the most important results of this program is the significant North-South and South-South

> # There is almost no access to electricity in most rural villages.

collaboration in the telecommunications and health sectors between universities, research centers, and a nongovernmental organization with the aim of developing solutions for rural health systems.

The new projects will test new tools created in EHAS laboratories, such as an electronic mail system over HF radio, or a low orbit satellite mail gateway, both suited to zones with complicated orography, or a rural telemedicine system using IEEE 802.11b for carrying media-rich data.

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Author Information
Andrés Martínez was with the Grupo de Bioingeniería y Telemedicina, Universidad Politécnica de Madrid, Madrid, Spain, currently on leave at the Universidad Carlos III de Madrid. Email: andresmf@gbt.tfo.upm.es. Valentín Villarroel and Francisco del Pozo are with the Grupo de Bioingeniería y Telemedicina, Universidad Politécnica de Madrid, Madrid, Spain. Email: valentin@gbt.tfo.upm.es and fpozo@gbt.tfo.upm.es. Joaquín Seoane is with the Dpto de Ingeniería Telemática, Universidad Politécnica de Madrid, Madrid, Spain. Email: joaquin@dit.upm.es.

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