Real-Time Cardiac Monitoring over a Regional Health Network: Preliminary Results from Initial Field Testing

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Abstract

To meet the need for detailed diagnostic data in the follow-up of cardiac patients residing in remote areas we have developed an extensible platform that allows the plug-in operation and remote control of multi-vendor medical devices, including an electrocardiograph and an electronic stethoscope. The doctor has remote control of all the medical devices installed at the patient's site.

Following satisfactory internal tests using a local area network with a bandwidth of 100 Mbps, we set out to test the platform in a 'real world' situation to assess its practical use. The real-time transmission was satisfactory over a dedicated channel of 128 kbps. However, problems occurred when the channel was shared, in which case the speed, latency and capacity of the network were the bottleneck. These early results suggest that a real-time tele-visit over a regional network is feasible and could help to bring health care closer to the patient, provided that sufficient bandwidth is secured.

1. Introduction

Our two-year experience with a tele-consultation service over the regional health care network of Crete [1,2] has revealed a further need for detailed diagnostic data in the follow-up of cardiac patients residing in remote areas. In an attempt to fill this need, we have developed of an extensible platform [3] that allows the plug-in operation and remote control of multi-vendor medical devices. The platform can be used both in home care delivery, even without the assistance of a nurse, and in rural Primary Health Care Centres (PHCC), enabling a tele-visit service and thus reducing the need for a patient to travel to the hospital. Following satisfactory internal tests using a local area network with a bandwidth of 100 Mbps, we set out to test the platform in a 'real world' situation to assess its practical use.

2. Methods

The platform is able to work with a variety of plug-in medical devices for different clinical domains. The medical devices focused on the cardiology domain are a 12-lead electrocardiograph and an electronic stethoscope that were designed to provide a cardiologist with the most basic tools for the performance of remote tele-visits with special attention to the possibility of short-term continuous monitoring. The data are acquired at the patient's site and transmitted through the regional health network to the doctor's site, where a specialist can inspect the biosignals through visual/audio output devices for the signal display/playback. The doctor's site is configured automatically at connection time, with the appearance of a medical device bar giving the doctor remote control of all the medical devices currently installed at the patient's site. The 12-lead ECG front-end allows short-term cardiac monitoring, while the electronic stethoscope permits the simultaneous transfer of heart sounds in real time to the doctor's site. An integrated videoconference module provides an audiovisual channel that allows the specialist to: a) guide or check the positioning of the stethoscope and ECG electrodes, b) view the physical condition of the patient and ask for additional information, c) have a communication channel open with a nurse or a GP, whenever the service is delivered either as alternate site care (i.e. in a PHCC) assisted by a GP or as home care but with a nurse's assistance.

2.1. Videoconference

The videoconference, when enabled, is automatically started at the establishment of the connection. Both the audio channel and the video channel are enabled and the communication is realized according to the standard H.323. The graphical user interface (GUI) displays the remote and the local video on the left side of the monitor and through a set of earphones/speakers and microphone the user can easily communicate remotely. The

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possibility of freezing the remote image is provided in the user interface in such a way as to save bandwidth for more significant clinical data whenever necessary. Additional tools, such as chat and whiteboard, are provided at both ends to facilitate the exchange of annotations, including written notes and drawings.

2.2. Stethoscope

The vital sounds are collected through a chestpiece built in with both a bell and a diaphragm for the acquisition of the low frequencies (Bell mode) and the high frequencies (Diaphragm Mode). The heart sound runs through the rubber tube to a microphone that is connected to a battery-powered electronic amplifier and amplitude limiter. The amplified sound is sampled by a soundboard and the software module compresses the samples and sends them through the network to the remote end.

On the doctor's site, the heart sound is decompressed and sent for playback to the soundboard. Special earphones with good acoustic insulation from the external environment allow the doctor to listen to the heart sound. In his user interface the doctor can adjust the remote and the local volume and can apply different filters for different ranges of frequencies.

2.3. 12-Lead ECG

Two different ECG front-ends have been considered to set up a multi-vendor solution. The two different devices, both using a 10-electrode patient cable, are connected to the patient station using different technologies.

In one case a PCMCIA card is used to collect the 12-lead ECG signal coming from the ECG acquisition device, either through a cable or through a wireless connection. In the PCMCIA board the preprocessing of the signal is done and the ECG is made accessible through a specific device driver. The ICS-FORTH software module is able to interface the 12-lead ECG device driver and to acquire the samples for their display and for their dispatch through the network.

In the second case a fibre optic with a USB adapter is used to collect the samples coming from the ECG acquisition device. The USB device driver is still used for the ECG signal preprocessing. The ICS-FORTH module is able to interface with the vendor device driver for the acquisition of the samples, their display and their dispatch through the network.

The ICS-FORTH 12-lead ECG module can be configured to work with one of these devices and on its activation it sends the device type to the remote end, so that the doctor's site can be configured with a different sampling frequency, a different LSB and other specific device parameters. The ECG front-end used for the 12-lead monitoring will appear in the doctor station's GUI, making the doctor aware of it.

2.4. Real-time monitoring session

When a session is opened the videoconference is started automatically and the doctor has available the toolbar showing the medical devices that he can activate. The doctor can activate the 12-lead ECG and the stethoscope simultaneously and start their operations. In this case, the appearance of the whole system, when the display of the ECG is enabled also at the patient's site, is as shown in figure 1.

Figure 1. Patient and doctor stations' GUIs.

3. Results

The platform was designed and developed to work as a modular system in many different IP based network infrastructures.

After accurate internal tests using switched Ethernet links of 100 Mbps between the two ends, the system was brought outside in the real world for a thorough test of the platform functionality and of all the provided services.

First we tested the platform in a private wireless network, IEEE 802.11, installed in a metropolitan area [4,5].

The network, as shown in figure 2, consisted of many clients, a central Access Point (AP), and a Bridge Connection (BC) that connected the AP with the backbone network of ICS-FORTH.

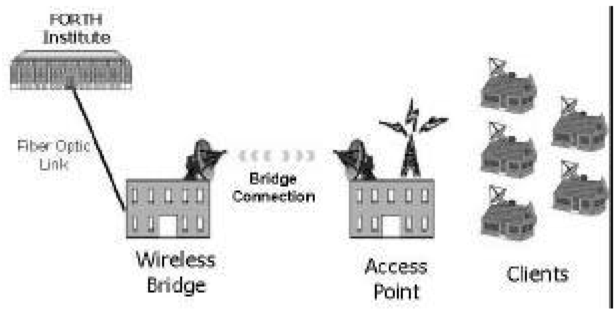

Figure 2. Architecture of the private wireless network.

Using this network architecture, all clients had to follow a two wireless hop path in order to reach the backbone network, the hop between the client and the AP and the hop through the BC. At the other end of the BC there was a fiber optic channel connecting the backbone network. All the wireless links worked in the Institutional Scientific Medical (ISM) frequency band with communication channels of 11 Mbps throughput.

Although in this kind of network infrastructure, at first glance, the bandwidth limitation seems to be the main difference compared to a common wired local area network, the actual problem is the latency variations of the packet propagation time, and the delivery time of a single packet, either TCP or UDP. The consequent degradation in network performance demands the implementation of special software modules that monitor the network status and are able to overcome any problems that can occur because of the wireless lossy links, the random propagation and the delay time of all packets. Thus, when a packet was lost, we had to be able to recover and resynchronize the reception with the next valid one in order to continue using it. Also a proper notification had to be delivered to the doctor's site.

Thus, for each device it was necessary to tune the asynchronous reception of the network messages and special attention was paid to the possibility of resynchronizing the network message reception after the lost of a single packet or of a series of them.

After exhaustive tests we were able to adapt the platform to work very satisfactorily within the wireless infrastructure for hours, either when the network was working with no problems or in cases where we experienced low performance in the wireless links, for instance because of bad weather conditions. The result was a robust platform able to work in a real-world network, with the ability to recover when necessary from a number of difficult situations.

After this first step, the system was ready to be tested in a clinical environment connected to ICS-FORTH through a "digital leased line" network of 128 Kbps with frame relay provided by a commercial telephone company. During tests between our laboratory configured as a call centre and a rural primary healthcare centre (PHCC), the real-time transmission was done over the dedicated channel described above and the network traffic is shown in figure 3 in the right part of the graph around the value of 12 for the abscissa (from 11.00 am to 12.00 am).

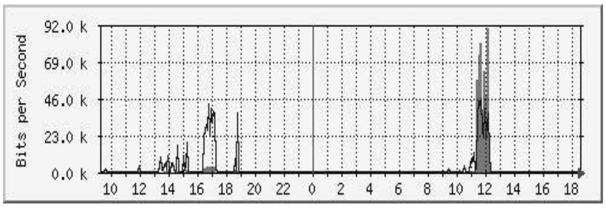

Figure 3. Network traffic during some tests between a Primary Health Centre and ICS-FORTH.

The quality of the video and audio channels of the videoconference was judged very satisfactory by the GPs at the PHCC. The ECG quality was excellent and some sessions of short-term monitoring were performed with success. The peak of the channel occupation was due to the simultaneous use of videoconference, 12-lead ECG and stethoscope but, as expected, the channel capacity was large enough for the successful transmission of all the data.

Further tests were done between a regional hospital configured as a call centre and our laboratory and in this case we experienced some more difficulties due to the large network traffic caused by the simultaneous use of the network by many users. However we found that, even without any changes in the network configuration, the video and audio channels for the videoconference could be used simultaneously with either the 12-lead ECG or the stethoscope, with good quality. The simultaneous real-time use of stethoscope and 12-lead ECG was hampered by the limited bandwidth available for this service, as shown in figure 4 in the right part of the histogram between 12 and 14 (from 12.30 till 14.00 o'clock).

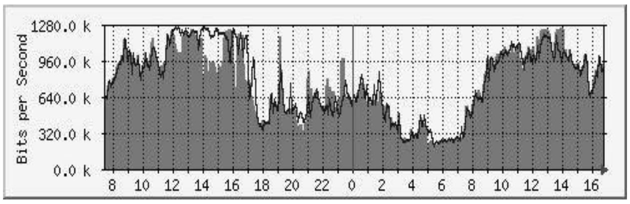

Figure 4. Network traffic during some tests between a Regional Hospital and ICS-FORTH.

Other applications/services were using the communication channel, consequently reducing the amount of bandwidth instantaneously dedicated to the real-time monitoring. This sharing of the communication channel with other users reduced the available bandwidth below a critical threshold and hampered the proper operation of the real-time monitoring. The observance of the real-time requirements necessitates a guaranteed minimal bandwidth assigned to the service for the whole duration of a monitoring session, otherwise problems will occur when the channel is shared, in which case the speed, latency and capacity of the network were the bottleneck.

The assignment of a higher priority to the service so that enough bandwidth was guaranteed improved the quality of service (QoS) and made possible the simultaneous transmission of the heart sound and the 12 lead ECG with satisfactory performances.

Thus, subsequent tests in the clinical setting between the rural PHCC and the ICU of a regional hospital showed good performances and these results suggest that a real-time tele-visit over a regional network is feasible and could help to bring health care closer to the patient, provided that sufficient bandwidth is secured.

Consequently the GPs at the PHCC with the cardiologists at the ICU have planned to use the system for some clinical studies on the remote monitoring of cardiac patients.

4. Discussion

Further developments are planned in an attempt to enhance the quality of service in an IP network, to reduce the protocol overhead, and to take advantage of 2.5G/3G mobile telephony to allow deployment in mobile settings.

Although mobility seems to be a challenge in the future development of new age personal and mobile communication systems, we must take into account that high data rate channels are still delivered only in low mobility or fixed settings. The visionary perspective, in order to meet the future needs of society in real-time and remote monitoring of patients, is to go towards an increase of both user mobility and network capacity. This will be the future direction of the technology and telemedicine applications will benefit from a larger amount of bandwidth in affordable networks with higher quality of service and good coverage in regional areas.

With the current technology, of course, the addition of the mobility requirements to the features of this service will necessitate taking into account the significant probability of broken links due to the limited coverage in a regional area.

So in these cases, where the coverage of an area cannot be guaranteed, the only realistic and affordable solution is to ensure the data delivery in a postponed time whenever the real-time functionality cannot be provided.

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