EXPERIENCES IN REMOTE MONITORING OF PATIENTS WITH CHRONIC DISEASES USING MOBILE TECHNOLOGIES

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Abstract: During recent years the number of patients who suffer from chronic diseases has noticeably increased in developed countries. This implies an increase both in costs and resource allocation of the health system and in the commuting frequency to health centers by patients as well. These costs can be reduced by using mobile communication technologies. In addition, these technologies can also be used to improve the patients´ quality of life who suffer from chronic diseases, their relatives and caregivers. However, wireless communications can be affected by interferences generated in the patient's domestic environment. The work presented in this paper describes an architecture which aims to improve assistance quality using health monitoring services and remote monitoring of patients that suffer from chronic diseases.

1 INTRODUCTION

Medical care for chronic patients is becoming a priority problem in developed countries, although there is also a notable increase in developing countries. It is estimated that chronic pathologies will represent more than 60% of worldwide illness in 2023. Heart failure is a chronic disease under constant growing, mainly due to the ageing of population and survival of patients with a heart condition. This illness has a great impact over cardiovascular problems, like diabetes and high blood pressure.

Another emerging point is the cost for the health system caused by the increase of hospital admissions due to chronic heart failure. Consequently, it is crucial to find steps that would improve their quality of life. In this way, it is possible to improve both the diagnosis of cardiac events and to avoid or delay an admission to the hospital and treatment compliance.

Current developments of mobile communications technologies allow the creation of solutions for health services and online monitoring not available in the past. These solutions aim at reaching final users who do not possess specific technological knowledge.

The diagnosis of a chronic disease means to a greater or lesser extent a decrease in both patient and caregivers' quality of life. The nature of the chronic pathology usually implies regular monitoring with continuous trips to health centers. Minimizing commuting by patients to centers could increase reaction time in potential complications. In some cases, patients can be trained for making monitoring tests in their own houses. However, this approach can only be applied to a set of simple tests and therefore raise uncertainty on obtained results. Alternative solutions have been considered to make homemonitoring more effective and efficient.

In the last few years, there has been considerable research activity in wireless body area networks (WBAN) (van Dam et al., 2001). MobiHealth project (Van Halteren et al., 2004) has developed and trialed a highly customizable vital signs monitoring system based on a body area network and a mobile-health service platform utilizing next generation public wireless networks. For example, (Jovanov et al., 2005) focus on computer assisted physical rehabilitation by designing a WBAN based on intelligent motion sensors. Other approaches like (Latré, 2004) aim at developing energy efficient network protocols for this kind of networks.

However, the use of different mobile and wireless technologies can entail some problems related to the effects produced if all of them operate at once in the same environment: the interferences they cause to each other. The simultaneous use of

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technologies and the way they transmit to the medium in a reduced environment can generate interferences that affect the performance of the networks they make up. This results from the free use of the industrial, scientific and medical bands, which are internationally reserved, not intended for commercial use and open to everyone who wants to use them.

This work proposes the application of mobile communications to track chronic disease patients who need frequent trips to medical centers. The technological infrastructure developed in this work allows a selected group of patients to not modify significant aspects of their daily life. This infrastructure is composed by a network of biomedical sensors and mobile devices. Biomedical devices collect individual biomedical data, which is sent through mobile devices to centralized information systems from the infrastructure. Data is directly obtained by patients who take their measurements from their own houses by using mobile communications. Thus, mobile communication technologies minimize the number of visits to health centers from patients and enhance their quality of life as well as their relatives and caregivers. The system provides information to medical staff for managing different services associated to medical monitoring, treatment compliance control and alert receipt.

Thus, this document focuses on technical aspects of the proposed architecture for a set of specific pathologies and parameters in remote tracking as well as on the deployment problems caused by the existing interferences in patients' home.

Following on from this Introduction, Section Two focuses on pathologies, biomedical parameters and monitoring devices. Section Three shows the full system architecture whereas Section Four includes information related to the deployment and evaluation methodologies. Section Five shows a study of the influence over mobile devices caused by radio interferences. Finally, Section Six offers some conclusions and future pathways for research.

2 PATHOLOGIES, PARAMETERS AND BIOMEDICAL DEVICES

This work focuses on cardiology health service. Our aim is controlling heart failures from hypertensive patients older than 50 years and prone to weight increase. In collaboration with (GRIMEX, 2010), some meetings took place to identify pathologies and biomedical parameters to track:

Weight Control. Liquid Retention. Patients' daily weight is controlled due to potential anomalies related to liquid retention. Weight thresholds have already been considered regarding the actual health state of chronic patients. A daily weight tracking should be done to obtain a trend about these variations. In case of rapid weight increasing, alarms for medical staff are sent. We used a Bluetooth weight control device model (A&D Medical Precision Health Scale, 2010).

Heart Rate Control. Tracking of heart rate in patients is conducted using individual electrocardiography monitors. Measurements are done on a daily basis and in case the patient is feeling unwell. Similarly to weight control, alarms that detect anomalies notify medical staff, who are the ultimate responsible of patient care. The device used for heart rate control is (Card Guard PMP[4] SelfCheck ECG, 2010), with Bluetooth capabilities.

Blood Pressure Control. Blood pressure is another factor that would anticipate heart failure. The patient conducts blood pressure measurements on a daily basis using a blood pressure monitor. If measurements are beyond a predetermined threshold, an alarm to the medical staff is generated. Similarly to weight control, there is a trend analysis that shows variations of systole, diastole, and arterial pulse in time. The Bluetooth blood pressure monitor model used is (A&D Medical Digital Blood Pressure Monitor, 2010).

3 GENERAL SYSTEM ARCHITECTURE

This section presents the architecture developed for this work, which is depicted in Figure 1. It is composed of a communications infrastructure that incorporates a set of biomedical sensors for chronic patients distance monitoring.

The architecture components are:

- Biomedical Devices (three each patient): they obtain patients' biomedical data (weight, heart rate and blood pressure).
- Mobile Devices (one each patient): Data from biomedical devices is received and sent to a central server.
- Central Server: Stores and processes all data that comes from measurements of the monitoring processes.

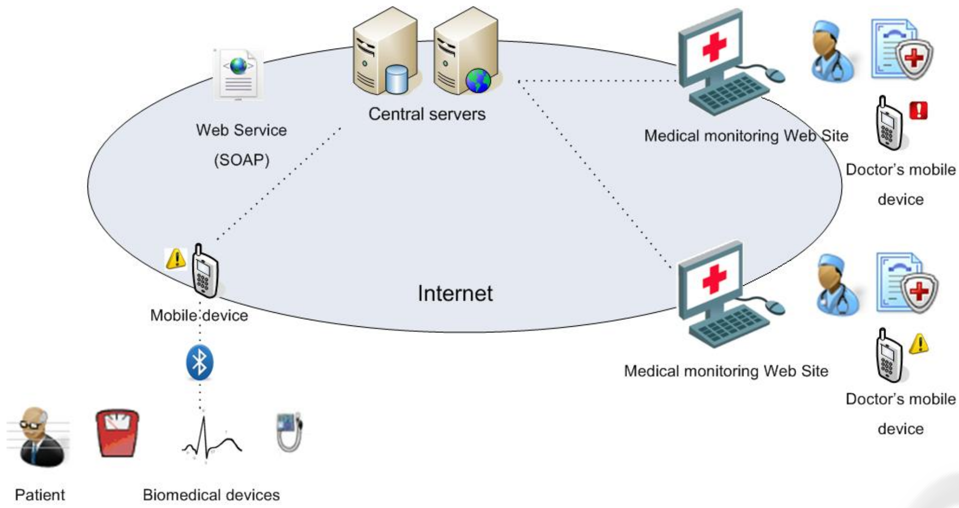

Figure 1: Scheme of the general system architecture.

- Medical monitoring Web site: Provides remote access to medical information for each patient so health parameters can be controlled. Access is only available for doctors.

Once a patient is diagnosed with a chronic pathology (e.g. heart disease), a decision has to be made about including the patient in the remote tracking program. If the patient is finally included, medical staff provides the patient with both equipment and training. Equipment consists of a set of biomedical devices described in section 2 and a smartphone mobile device. Training consists on explaining the patient how to use all those devices.

Biomedical devices conform to the European Directive 93/42 EEC for Medical Products (Council Directive 93/42/EEC, 1993). These devices are designed to send information to mobile device using Bluetooth technology. J2ME technology has been used to develop the application created for the mobile device. Besides, several Bluetooth modules have been developed to get measurement data from biomedical devices.

The process followed to get a measurement is shown in Figure 2 and described next: The user chooses the kind of test to carry out and the mobile device starts a search to find the corresponding biomedical device. If it is found, a Bluetooth pairing is created. Once both devices are paired, data obtained from biomedical device is transferred to mobile device. Then, measurements data appears on the mobile device display and the patient is asked about sending it to central server so that the information about his health conditions is updated.

Doctors observe their patients through the medical monitoring Web site, an application where several different graphs specific to each patient are provided. Struts Framework and JBoss Application Server have been used in its development. We have also developed a Web Service implementation to send data from mobile device to central server using 3G network. For this purpose, kSoap2 library for Java has been used. Using this tool, doctors are able to know the evolution of the monitored parameters and to act accordingly. In addition, doctors also have mobile devices with network connectivity in the system. An alert system has been designed to allow alert reception when a potential health anomaly is detected for a patient. These anomalies indicate that there is a value or a set of values obtained during monitoring tests that exceed a threshold previously set by medical staff. Figure 3 (a) shows an example of an alert reception after a monitoring test.

The last feature of the developed architecture is related to treatment compliance. Depending on the physical characteristics of the pathology of each patient, medical staff can determine if it is necessary to notify the patient through his mobile device every time he has to take a step in treatment. Figure 3 (b) shows an example of a warning in the mobile device that reminds the patient about treatment compliance.

Due to its private nature, patients' data is only accessible by the doctors assigned to the monitoring. Data protection scheme is designed to satisfy all the legal and technical aspects to obey the current law related to the regulations for the protection of personal information.

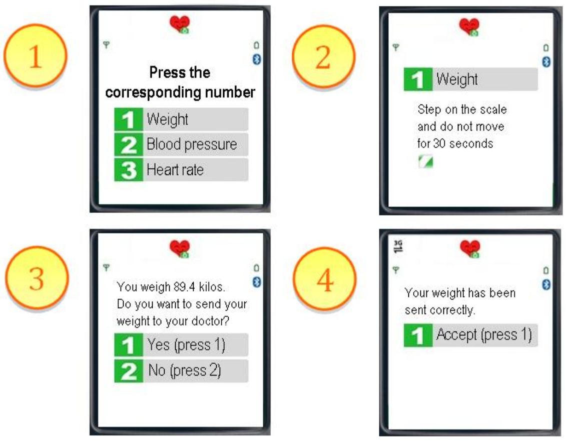

Figure 2: Example of weight monitoring and data sending.

4 DEPLOYMENT AND EVALUATION

The deployment of the experiment has been carried out with patients selected following a random process. All of them are members of groups of patients currently monitored in the Cardiology Unit in the Don Benito-Villanueva de la Serena Hospital of the province of Badajoz in Extremadura, Spain (Pérez et al., 2009).

Inclusion criteria are described below:

- Patients with diagnosis of chronic heart failure (HF).
- Recently hospitalized for this reason.
- Currently in situation of medical stability.
- Patients' home inside an UMTS coverage area (metropolitan areas of the region).

Exclusion criteria include:

- Psychophysical handicap to do the experiment or lack of assistance.
- Fail a test about how to use the devices.
- Refuse signing an informed consent.
- Lack of UMTS coverage in the place where patient lives.

A sample of 9 patients and duration of 6 weeks were estimated for the period of the experiment. With the aforementioned criteria, the study was carried out on men and women between 49 and 69 years of age, both experienced in the use of mobile communication technologies and without any previous experience.

(a) (b)

Figure 3: Monitoring and treatment compliance alerts.

Results allowed doing a division into two clearly distinct groups according to the age:

Group A (Aged 59-69): The five patients over 59 years old did not have any experience using mobile devices. Three of them used biomedical and mobile devices and carried out the tests with the help of any other people. The other two patients lived alone with their spouses and did not rely on the help of third parties to use the devices and carry out the measurements. The result of the experiment with the patients that received some support was optimum/satisfactory. However, in the case of patients with no help, the result was deficient/not satisfactory.

Group B (Aged 49-58): The four patients with diagnosis of heart failure over 50 years old had experience in the use of mobile devices and carried out the tests autonomously, without help of third parties. Result: optimum/satisfactory.

For those patients without experience in the use of these technologies, the help provided by third parties was fundamental. Problems arising from patients that could not carry out the measurements can be avoided with training both for the patient and his family environment. Ergonomics and usability both biomedical and mobile devices have been essential in this pilot experiment. The main problem detected when using biomedical devices was the electrocardiography monitor.

Several interviews have been held with some patients at the beginning, at mid-term and at the end of the pilot experiment. Moreover, there was a final survey for every participant, both doctors and patients. Patients seemed to be keen on participating within the experiments and admitted the validity of the approach. Participating doctors also admitted the validity of the system and the need of its integration in health services.

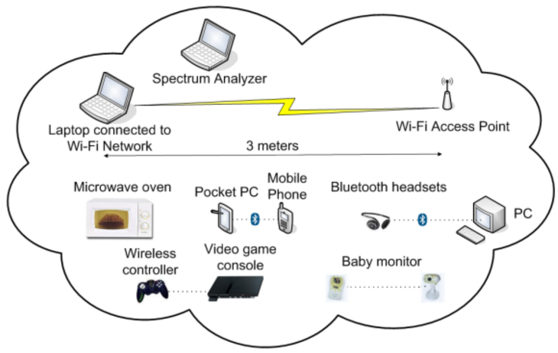

Figure 4: Test environment.

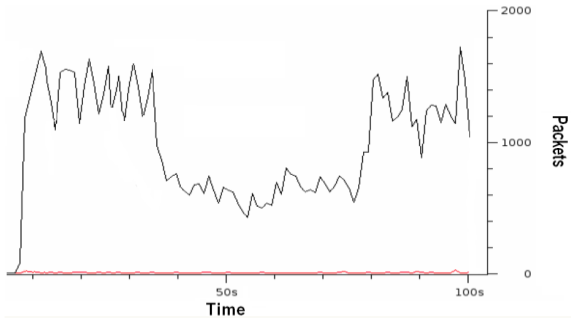

Figure 5: Performance graph of a HTTP download when the source of interferences is a Bluetooth transfer.

5 STUDY OF INTERFERENCES IN MOBILE MONITORING

Another topic investigated is the effect produced when mobile and wireless technologies are exposed to certain situations in some interference environments (Angrisani et al., 2008); (Mathew et al., 2009); (Theuang et al., 2009). The simultaneous use of these technologies and the way they transmit to the medium in a reduced environment can generate interferences which have negative effects to the performance of the networks they make up. This can cause a performance decrease during tests when transferring data through the communication established between biomedical devices and the mobile device. This performance decrease could also be evident when data is sent from mobile device to the central server if there are devices prone to generate interferences operating all at once in the same environment. As an example, there is some equipment inside hospitals that can cause deficient performance of WLANs (Jiang et al., 2009); (Subramanian et al., 2008).

In order to analyze interference among wireless technologies, the WildPackets OmniSpectrum Analyzer was used. We have also developed an application to obtain real data about the performance variation in these situations (Galán-Jiménez et al., 2008).

Three types of tests have been done in this study: 1) File download using FTP protocol. 2) Download of the same file using HTTP protocol. 3) A video file transmission using RTP protocol. The three aforementioned tests have been carried out for each of the following situations: file transfer via Bluetooth, microwave oven, Bluetooth headsets connected to PC, baby monitor and wireless video game controller. In other words, we have introduced a new source of interference to measure the variation of the wireless network performance caused by these specific devices. All of these devices can be found in any of the monitored patients' home. Figure 4 shows a scheme of the test environment.

To obtain reliable and consistent results, tests have been made following the same methodology:

1) With the spectrum analyzer we obtain the interference values that a specific device produces.
2) Next, we start a 100 seconds traffic capture and the transmission to test.
3) After a 30 seconds interval, we switch on the interference source to get the effect that it causes to the wireless network performance.
4) This interference source is active for 30 seconds. Then, we switch the device off.
5) Finally, the capture and transmission finish 100 seconds after start.

Figure 5 shows the chart provided by the developed software extension. It corresponds to the HTTP download when the situation which generates interferences is the file transfer via Bluetooth.

In Table 1, we can observe that the biggest performance decrease is produced when the baby monitor is switched on (100%), followed by the microwave oven in which case is around 80%. Otherwise, the test done with the Bluetooth headsets does not affect to the performance of the wireless communication. Test carried out with the wireless video game controller and the file transfer using Bluetooth technology affect to the test that involves TCP traffic (around 45% of performance decrease), but they do not affect to the multimedia transmission with RTP.

By means of the last table, we can assure that wireless technologies interact each other and their simultaneous use limits their performance depending on the type of traffic and on the devices which are active in the same environment.

Table 1: Percentage of performance decrease by test.

Transfer Device	FTP Download	HTTP Download	RTP Transmission
Microwave oven	79 %	88 %	75 %
Bluetooth transfer	40 %	50 %	0 %
Bluetooth headsets	0 %	0 %	0 %
Baby monitor	100 %	100 %	100 %
Game controller	41 %	50 %	0 %

6 CONCLUSIONS

One of the immediate consequences derived from the successful result of the work is the experience about remote monitoring of patients with chronic diseases. Among all of the technological innovations contributed to this work, we emphasize the use of biomedical sensor networks and their communication with mobile devices in environments where patients live. Besides obtaining biomedical information, we have studied different ways to send this information to central health care systems from both clinical and operative point of view. Third generation telephony has been taken in advance to remotely monitoring patients through the new developed medical Web site. We have analyzed the effect of interferences among mobile and wireless technologies over data transmissions in similar situations like the existing ones in this type of remote monitoring services.

Future research lines will allow identifying most suitable patients' profiles and pathologies to be monitored using this kind of technologies. Benefits and disadvantages of using them in communities' creation could also be studied. These communities are referred to both patients and people in their environments. An early identification of the problems in patients' health would be possible by using the information obtained by means of mobile communication technologies. It would be feasible to identify anomalies in treatment compliance as well.

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