GATEWAY BLUETOOTH–GPRS FOR ECG SIGNAL TRANSMISSION: IMPLEMENTATION IN MOBILE PHONES

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Abstract: This article describes the implementation of a Gateway device in a mobile phone for ECG Signal transmission between an acquisition device and a Data Reception Centre (DRC). The Gateway device is embedded in an ECG monitoring system called Holtin (Intelligent Holter) that includes three basic devices: Front-End, Gateway and DRC; and two wireless technologies: Bluetooth and GPRS. The implementation is done in a Nokia 3650 mobile, which has all the functionalities needed for the application. The system works as follows: The Front-end acquires the ECG signal and sends it, using Bluetooth, to the Gateway, who encapsulates and sends it to the DRC through Internet (TCP/IP protocol) over GPRS wireless technology. The system can be configured to acquire one or three ECG leads and to work in two possible operation modes: continuous monitoring or by events. The application has been developed in separate modules in order to achieve design simplicity, easiness in the exploitation and reusability.

Introduction

Nowadays, chronic diseases are the first cause of mortality on the planet according to OMS, and these kinds of diseases require continuous treatment. The patients are interested in their health state, not only after a critic episode, but also desire warnings for developing conditions. In the case of cardiac diseases, monitoring ECG signals during a long time period (more than 24 hours) gives a better knowledge of the disease making possible to improve the treatment and gain effectiveness [1]. However, this long time monitoring is not easy to carry out and involves a heavy load/burden for the hospitals due to the always limited number of beds and the high economic costs that it implies. The evolution of technology has developed solutions to alleviate the congestion at the medical centres using diagnose and tele-care techniques making possible a better quality of life for the patients. These solutions are grouped by the term telemedicine that can be defined as the use of information and communication technologies to give medical assistance to patients that are located in remote areas. The patients can be then monitored at home in an efficient and handy way using these techniques.

In any Tele-Care application it is important for the devices implied to be portable. Portability will favour the system to be accepted in a better way by the patients, especially in the case of cardiac telemetry, where the patients require long time monitoring of their heart and vital signs and also want to continue with their normal life if it is. They can have normal life activities such as walking or working outside.

The Public University of Navarra has developed a complete ECG signals telemonitoring system, which is called Holtin (Intelligent Holter) [2]. The system allows monitoring non-critic cardiac patients in two ways: continuous or eventual registering just the interesting events that the patient may suffer.

This system embeds the Gateway and it comprises three different devices:

- Data Acquisition System Holter: which is a wearable Front-End for the patient. It acquires and transmits the ECG signals via Bluetooth
- Gateway: that works as a configuration interface, receives the data acquired by the Holter using Bluetooth, allows visualization, transmits to a long distance DRC using GPRS technology, etc.
- Data Reception Centre (DRC): Central Station that manages a database with every patient's clinical history and its monitoring registers that are received from the Gateway via GPRS.

In Figure 1 it can be seen how these three devices fit in the whole system:

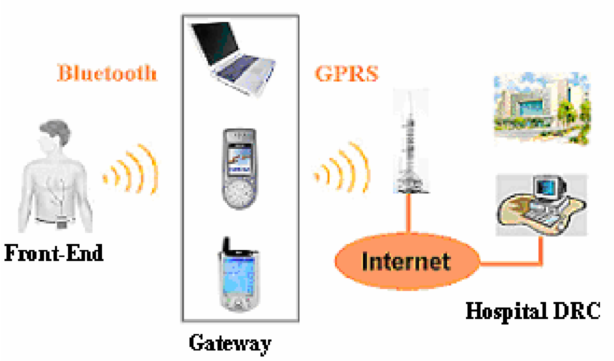

Figure 1: ECG Signals Telemetry System

The users are non-risk cardiovascular patients and mainly belong to an aged sector usually not familiarized with technologies. Taking this into account the application has been designed to maintain minimum interaction with the patient. This implies that almost every functionality will be automatic. This is the

 ISSN: 1727-1983

Gateway's duty: a wireless device between the Holter and the DRC that allows the Holter to have minimum size and easiness of configuration for the patient. However the user can interact with the application having the possibility to request information in every moment thus, knowing the monitoring status. The Gateway has been implemented and tested in a laptop, a PDA and a mobile phone as it can be seen in the above figure. The purpose of this document is to show how the Gateway works and how it was implemented in a mobile phone for transmission of ECG signals between the Holter and the Data Reception Centre, using a Nokia 3650 mobile phone and development software for Symbian OS. The rest of the system is not within the scope of this paper.

Materials and Methods

The Gateway application was then implemented in a mobile phone and, after a study of its appropriate implementation, it was clear that the following functionalities were needed: It has to work as a gateway between two technologies: Bluetooth and GPRS. The mobile phone should offer triband GSM coverage (GSM 900/1800/1900) so it can be used world wide. It is interesting for the mobile phone to have high speed GPRS connection in the up-link and the same for the down-link. This feature can be measured by the number of slots in every link; the bigger the number of slots is the better the device will work for the application. It is also interesting that the mobile phone can manage GSM and GPRS simultaneously in order to make possible to receive a call while it is transmitting the data. The mobile phone needs enough memory to manage the amount of information, giving a margin that allows the correct operation. The information managed is estimated to be 1MByte, 1MByte more for the Operating System, 1MByte for other user applications, and 1MByte for extra space. Then, the requirements are 4MBytes. A good battery response is a need in the application. The battery is measured in two ways: standby time (the time that the device can be active without using it) and talk time (the time that the device can keep on when making a call). The second parameter is decisive because it limits the length for extreme conditions (continuous transmission of ECG samples via GPRS). This is the more limiting feature for the system. It would also be convenient for the device to be light and small sized.

The second step was to choose the Operating System to be used. There are several options, Microsoft's Windows Mobile, Palm Os by Palm Inc and Symbian OS by Symbian. The Symbian Company, that has its head office in England, was established in 1998 as a private enterprise. This company can be considered as one of the mobile phone market leaders with an extraordinary growth since its very beginning. The leading Nokia, Ericsson, Psion and Motorola are part of the Symbian Company. Recently, some new associates had joined the consortium and all of them develop mobile phones and applications for the open standard Symbian OS. The first mobile phones with Symbian OS were announced by the year 2000, at this moment Symbian OS is the global industry standard operating system for smart phones, and is licensed to the world's leading handset manufacturers, which account for over 85 per cent of annual worldwide mobile phone sales [3]. Symbian is committed to open standards and is actively working with emerging standards, such as J2ME, Bluetooth, MMS, SyncML, IPv6 and WCDMA [4]. Symbian is an operating system targeted at mobile phones that offers a high-level of integration with communication and personal information management functionality. Symbian OS combines middleware with wireless communications through an integrated mailbox and the integration of Java and personal information management functionality (agenda and contacts). The Symbian OS is open for third-party development by independent software vendors, enterprise IT departments, network operators and Symbian OS licensees [5]. For the OS version the more conservative option was taken: Symbian OS v6.1. is one of the oldest versions but it was more than enough for the application development needs. Moreover, it has all the software tools for developing and a lot of documentation can be found. This election was also influenced by the decision of the mobile phone model, and it was taken at the same time. Symbian have attempted to maintain backward compatibility so that developers can write code that runs on multiple versions of Symbian OS. Backward *source* compatibility means that code written for older versions can be made to run on newer versions by simply rebuilding it [6], what may be convenient for the application's future extension.

The application has been programmed using the Series 60 platform. The Series 60 Platform is a complete package of applications, user interface and development tools built upon Symbian OS technology. It has been designed to run on various models of different manufacturer's devices. In other words, an application developed for the Series 60 Platform will run smoothly on all devices that support the same platform [7]. That is also important for the application's possibilities because it will be possible to run it on different models. The version of the Symbian SDK (Software Development Kit) used was: "Series 60 SDK 1.2 for Symbian OS Nokia Edition", a group of tools for developing applications for Series 60 platform 1.0 (Symbian OS v6.1) that includes the APIs and programs needed. Nokia is committed to maintaining compatibility between the different series of the developer platforms wherever possible. Where compatibility is not achieved Nokia will maintain and publish a record of any issues, such as minor differences in API implementations or problems with technology implementations [7]. The programming languages that can be used to program applications in this OS and the platform selected (Symbian OS Series 60) are C++ and Java. Most of the commercial applications use Java but using this language some of the OS functionalities are not accessible. This language is normally used for developing user applications (especially games) that are usually downloaded from an operator network and

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access to some features is restricted because of security reasons. Thus, as there was a need of a total control of the OS possibilities was, the programming language chosen was C++.

Finally, after all the analysis, the implementation was done in a Nokia 3650 mobile, which has all the functionalities mentioned above: Wireless technologies: Bluetooth and GPRS, enough memory and battery, Symbian OS v6.1 and triband operation. In table 1 the selected mobile phone features can be seen:

Table 1: Nokia 3650 features

FEATURES		Nokia 3650
Band GSM		900/1800/1900
Symbian OS		v6.1
Bluetooth		√
GPRS	**Slots**	3 + 1
	Class	Class B
Standby time (h)		150 - 200
Talk time (h)		2 - 4
Memory (Mb)	**Intern**	4
	Extern	16, 64
Size (mm)		130x57x26
weigh (g)		130
Wap		1.2.1
Infrared		√
Java		√
Camera		√

As a development environment C++ Builder XMobile was selected. It is a program from Borland Company with great advantages as: integration of different SDKs for application development, debugging in the simulator and in the phone, application development menus, etc.

The architecture of the developed application can be seen in Figure 2, with all the different parts that compose the Gateway.

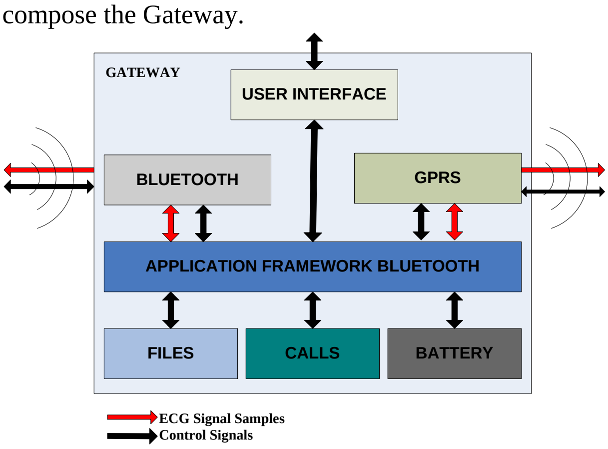

Figure 2: Gateway (Bluetooth – GPRS)

Bluetooth is the wireless technology chosen for the communication between the Front-end and the Gateway. The reason is that Bluetooth offers advantages in speed, costs, operation range (10-100m), power consumption and standardization [8]. It also provides scatter-net modality (master/slave hierarchy) and the ability to recognize nearby Bluetooth devices and establish connections with those devices. All this makes Bluetooth the ideal technology for wearable reconfigurable systems. The Bluetooth connectivity block manages the Bluetooth connection and the communication protocol with the acquisition device Holtin. The basic structure of this block is composed of three Symbian classes that control the connection status, the data reception, bytes sending and the execution of the protocol.

For the long distance transmission GPRS is used, mainly for its implementation simplicity (TCP/IP). GPRS connectivity allows the mobile device to establish TCP/IP connections. A TCP/IP connection is established between the Gateway and the Data Reception Centre in order to send the ECG monitored signal from the patient environment to the Hospital Module. This connection is controlled by the GPRS block that has a similar to the Bluetooth structure.

It was also needed to develop personal communication protocols over the Bluetooth and GPRS connections established between the devices.

One of the advantages of using a Gateway between the Holter and the DRC is the possibility to provide the system with a User Interface. The User Interface has two different functions: to configure the system and to inform about the monitoring status every moment. The Series 60 platform allows a great variety of possibilities for the implementation of visual interfaces with colours, panels, windows, images and video, etc. Then, an easy and friendly User Interface could be achieved. This was a need due to the type of patient that is going to use the application.

The rest of the blocks that complete the application are related to File, Battery and Call management.

File management: The application uses Symbian files resources with two aims. The first one is to have a configuration file at its disposal. This file is created by the application in the Administrator mode and contains the information to execute the application. The second aim is to store the samples received by Bluetooth.

Battery management: As the battery life is limited it could happen that it ends when the application is in use and the mobile phone would switch off. The other system devices would detect the disconnection without knowing the reason. To avoid this discommoding situation the application is completed with a battery monitoring block that offers the user the possibility to stop it. If the patient can not recharge the mobile phone battery he has the possibility to close the application in a proper way, stopping the connections that could be active in that moment.

Call management: The mobile phone selected does not allow simultaneous GSM and GPRS connections. It may happen that a call is received while the application is in use; in this case, the application offers the user the possibility to answer or reject the call. If a GPRS connection is active and a call (GSM) is detected, the GPRS connection would stop. This means that it would stop receiving or sending data but the GPRS connection would be still active. After the connection stops, the

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possibility to answer it is shown to the user. After the call has finished, the mobile phone re-establishes automatically the GPRS connection. Thus, the call does not suppose but a pause in the transmission and does not affect the normal function of the application.

The data stored by the application in the mobile phone are protected by the Personal Data Protection Act that has the purpose of protecting the personal information recorded in data files. This privacy should be assured and this is done by encrypting the data. The Nokia SDK makes possible to encrypt the data by means of its Security API.

As it was said, the Gateway device is part of an entire system where different kind of users can be found: System Administrators, doctors, medical personnel and patients. In the case of the Gateway device it should be emphasized the fact that the users are going to be of two defined types:

- System administrator: The administrator can configure new patients as users of the system and new mobile phones as devices that belong to the system.
- Gateway users: This denomination includes all the system persons that may use the mobile phone for ECG signal transmission, doctors, nurses or patients. Generally the regular user will be the patient. However, every other person belonging to the system may be able to use it without changing the application operation.

Observing the different needs for the user and the administrator, two separate applications were developed instead of only one: “Administrator” and “Gateway”. To ensure that the only one user of the Administrator application is really the administrator, he is needed to introduce a security key. The Administrator application has two aims. The first one is the configuration of the Gateway application for a certain patient ECG signal transmission. This patient will be the only one who is allowed to use the Gateway application. The second aim is to configure the mobile phone so it can be used inside the Holtin system. A data number identifies the patient in a univocal manner inside the Holtin system. For the connection the identifier data are the IP address and the connection port. These data, that identify the patient and the mobile phone connection, are stored and encrypted with a key that is known by the Gateway application.

The Gateway application is the one in charge of monitoring the ECG patient’s signal. The application has been developed in separated modules in order to get design simplicity and reusability. It is desired for the device to be as much autonomous as possible, in order to make it easier the “living together” for the patient.

The system works as follows: The Front-end (Holter or acquisition device) acquires the ECG signal and sends it using Bluetooth to the Gateway, who encapsulates and sends it to the distant Data Reception Centre through the Internet (TCP/IP protocol) over GPRS wireless technology. The system can be configured to acquire one or three ECG leads for monitoring and to work in two possible functional modes that can be configured by the user: continuous monitoring or by events.

- Continuous monitoring: The ECG register is acquired and sent real-time during the system monitoring. Thus, the device needs both GPRS and Bluetooth continuous connection. For the configuration the user only needs to introduce the number of leads desired for the ECG monitoring.
- Events monitoring: In this operation mode the acquisition device is configured and stores the last ECG registered minutes. At the very moment that a sudden event occurs the user can press a button in the acquisition Holter. That event remains stored in the Holter. Through a communication protocol, the Gateway receives the event via Bluetooth. After it is stored the Gateway sends it over GPRS technology. As it can be seen, in this operation mode there is only one connection active (Bluetooth or GPRS) in every moment. The parameters that can be configured in this operation mode are the number of leads desired for monitoring and the ECG acquisition time in the Holter.

These two different operation modes can be re-configured in the device. At the beginning of the Gateway operation the user has the possibility to choose the operation mode. Furthermore he can stop the selected mode and change it or establish new parameters if desired at any moment during the ECG monitoring.

The system is also able to manage the ECG samples and to communicate/configure the rest of devices that complete the system: Holter Front-End and the Data Reception Centre at the hospital.

Principally, the application is intended to operate in a non-hospital environment (outdoor), because its main users are going to be patients non-hospitalized. However, it could be used by medical staff in a hospital environment (indoor) if it is considered appropriate for the system.

Results

The implementation has been perfectly viable in a mobile phone; all the requirements such as operation specifications, security, ease of use and minimum involvement of the patient have been fulfilled. After testing the application, it is seen that it runs smoothly in the mobile phone selected.

The mobile phone selected uses a standard battery (BL-5C 850 mAh Ion–Litio) that presents a standby time of more than 150 hours and a talk time of 2 ~ 4 hours. There is a compromise between the use of the device and the operating time: the higher the number of ECG registers the lower the operating time. Testing the two operation modes it was seen that the continuous monitoring mode is highly limited by the battery life. This limitation could be overcome to a certain extent by changing the battery with a compatible one (BL-5C 950 mAh Ion-Litio).

A moment when the application is running can be seen in figure 3.

Figure 3: Screenshot of the Gateway.

Discussion

As an additional feature it is considered to make a digital processing of the received data before sending it via GPRS. This processing would allow compression of the samples that form the ECG register and this compression should end in a volume reduction that would decrease the GPRS transmission costs. This possibility can be convenient for sending data in the events mode but, in the continuous mode, it is likely that the exigencies of synchronization with the acquisition system would not allow making the processing.

It could be considered the possibility to provide the Gateway device with GPS positioning abilities (Global Positioning System). In this case it should be considered the use of a mobile phone that includes this feature, or the use of a GPS device with mobile connectivity via Bluetooth, wire or infrared.

It should be considered the possibility to make the needed modifications to adapt the application to the Series 60 platform 2.0 (Symbian OS v7.0), v8.0 and the new v9.0. This adaptation should not be overly difficult as the main differences added to the new platforms refer to added functionalities. The use of Borland's C++BuilderX will make easy this adaptation process as it allows to have several SDK installed and develop applications for the different platforms.

The visualization capacity of the user interface for representation of the ECG signal received has not been considered, due mainly to two important factors. On one side it is obvious the limitation of the screen size for this use (176x208pixels, standard size of the Series 60 platform 1.0). On the other side, the user will not be part of the medical staff generally and the information presented would not be relevant for him. For these reasons the interface designed just show notifications. The user will interact with the interface basically using menus.

Conclusions

The implementation of a Gateway Bluetooth–GPRS device, using a mobile phone embedded in the Holtin (Intelligent Holter) patient telemonitoring system, is perfectly viable. The mobile phone sector offers a huge amount of electronic devices with enough hardware performance and software development possibilities to act as an intermediate device inside the system. All the expected design specifications had been satisfied.

The system Holtin, use two wireless technologies for connections between the devices that compose it. This implementation of the Gateway device in a mobile phone has achieved to manage these two connections and the communication between the both of them. The communication with other devices around the environment, over Bluetooth and GPRS connections established is possible with personalized communication protocols defined for the devices.

The need for security preservation of the managed data is totally satisfied by means of restricted access techniques (passwords, identifiers) and the encryption or the signals and personal data.

The application can be used in an easy way, with its friendly interface, and with a minimum involvement of the patient. The operation of the mobile phone as a Gateway turns out to be nearly autonomous.

Acknowledgements

This work was supported by:

- Government of Navarra. Department of Health, Teaching and Investigation. (Departamento de Salud, Docencia e Investigación).
- The project "New healthcare telemedicine-based services" from Red de Telemedicina and Fondos de Investigación Sanitaria (FIS) FISG03/117.

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