Communication Architecture for Smart Services in Hospital Environments

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Abstract

Nowadays many hospitals and other healthcare institutions are using communications systems to optimize resources and adding a new kind of smart services offered to patients. However, some services and technological resources are restricted by the flexibility, availability and compatibility of the communication infrastructure. Therefore, we proposed a Communication Architecture for Smart Services in Hospital Environments based in SIP and focused on improving the way the services are offered. In addition, our proposal ensures interoperability with the standard HL7 and keeps the development open for a new kind of smart services using an OSGi platform.

1. Introduction

Traditionally, hospitals and other sanitary locations have environments that are in constant change and have a dynamic behavior. This behavior is caused by several reasons: patients, medical staff, urgencies and random facts that may affect the proper function and the service they have to offer. In addition, many of these environments have a very critical and important communication system, which has special requirements, as well as the important information it carries. However, many advances in network architecture, protocols, and services have been used in modern systems. On the other hand, these advantages have not been applied because lack of initiatives to adapt them to many restrictive medical constrains. Furthermore, it is clear that Internet-oriented systems and some of their characteristics, such as mobility, quality of service, standardization, self-adaptation and self-organizations can offer interesting upgrades for health environments.

Several organizations such as Health Level 7 (HL7) [1]have developed initiatives to integrate electronic health information in the application level in order to ensure the efficient communication between different equipments and; at the same time keep standardization. It is understandable that for extending the advantages of some technologies and exploiting them in health environments it is necessary to study and analyze the integration with different communication layers.

It is true that nowadays hospitals have many technologies that fulfill many requirements, and these requirements impact the way AAL is offered to patients. In addition hospitals have had messaging, HL7 devices and wireless communication. However, it is clear that with the upcoming tendency of smart medical sensors [2], smart rooms [3] and smart services, it is needed an adapted hospital communication architecture in order to support a new generation of medical services.

It has to be considered that wireless communication is the future of healthcare [4] so it will not be related only to connectivity. Some studies [5] had analyzed how to take advantage of it, and offer new mobile services, consequently other characteristics such as presence; messaging and media negotiation will also enrich a future AAL environment.

In this paper we introduce a flexible communication architecture that extends the capabilities of medical environments for allocating new kinds of smart services [6][7] and opening the possibility for potential integrations with health legacy systems and wireless systems. The architecture uses the Session Initiation Protocol (SIP)[8] to support session management and Open Service Gateway Initiative (OSGi) [9] as the based framework to interact with upper layers and create services. We also discuss different ways to manage hospital communication systems as well as its requirements to support different sort of medical data.

The following section surveys relate technologies to hospital service and communication management, highlighting the solutions of the architecture.

Subsequently we introduce some architecture design principles focused on the hospital scenario we have been analyzing. This is followed by the communication architecture proposed and ends with conclusions and future planned activities.

2. Related Technologies

There are some initiatives that try to enhance an Ambient Assisted Living (AAL) environment, from different points of view. Consequently, there are different conditions depending on the situation; a technology can be useful for the deploying of medical services. For example, in a hospital it is critical to have backup systems in some locations, and in that case a wireless network can be useful because it does not require a fixed infrastructure in order to operate. As a result, technologies such as Wireless Body Area Network (WBAN) [10] have tried to deal with some issues regarding sensor networks and the interaction with the patients. Other solutions [11][12] propose wireless medical architectures to communicate different devices and supporting different services, so it is comprehensible that a helpful advantage can be taken for extending and filling the gap of hospital communication management in wireless environments.

On the other hand, SIP is a signaling protocol used to create, modify and transmit messages over the Internet. SIP is the core protocol of some Next Generation Networks Architectures such as IP-Multimedia Subsystem (IMS)[13] and it is one of the efficient ways to provide different characteristics such as mobility, quality of services, session management, without affecting the concept of isolated layers and services. Another advantage of SIP is the flexibility of the implementation and the capability of ensuring reliability between different nodes using Proxys[14]. Nowadays there are some approaches [15][16] that suggest outlines to integrate this protocol into the health environment. In our scenario two important detected advantages are the mobile communication support, and the integration with sensor networks. Finally in this context, it is a valid approach to use SIP as the base protocol for hospital communication architecture in conjunction with other health technologies.

Another technology that has sustained flexibility by adapting itself in different medical scenarios is OSGi. OSGi is a well-known industry consortium and aims to create open specifications for managing and delivering multiple services and applications. The main concept of the OSGi Framework is to deliver a standardized environment in which applications called bundles can interact between them. Thus, OSGi has been proven [17][18] as a valid approach to address some issues with network architectures deployment in healthcare environments.

3. Overall Architecture Design Principles

There are scenarios that we have previously detected and analyzed in a project called CARDEA [19], which had the aims of integrating health services, extending drug's traceability, managing alerts and indentifying medical staff. With the purpose of address these requirements we proposed a basic platform for medical environments. As a continuation of this work, and the detection of several weaknesses, we propose an upgraded hospital communication architecture that fulfills those weaknesses and also identify many other items and scenarios that can be addressed such as: personal security in dangerous areas, patients' vital signs monitoring, emergency situation and efficient control of medical systems.

In an illustrated scenario, an emergency situation such as an earthquake has occurred. A patient, who is in a temporary bed, because there are no more available at that time, has some medical sensors that generate data that has to be sent and analyzed. If the vital signs reach a critical state he needs to be transferred to the surgery room and the proper medical staff needs to know it immediately in order to save his life. This scenario has special requirements that have to be accomplished by communication architecture. First, the mobility, because the patient is using a temporal bed there was no enough time to attach and adapt a communication infrastructure to it. Secondly, efficient network resource management, since there is an emergency situation and the primary network infrastructure has failed, the backup infrastructure does not have resources and the connectivity is limited. Therefore the alert messages have to be integrated and rapidly delivered to the destination, so different data priorities have to be categorized.

In another more specific hospital scenario the information flow would start when a patient needs attention. For achieving it the first step will be to assign him or her a hospital bed. This bed will contain several bio-sensors that will monitor the patient's activity and will use some kind of Hl7 messaging to transmit the vital information. Additionally the patient will probably move with a nurse around dangerous areas such as: X-ray rooms, laboratories and radioactivity rooms and at the same time, the information taken by the sensors has to be transmitted to the health monitorization desk for continuously verifying vital signs. Another important item will be when the medical treatment is applied to the patient; this drug will be manually taken and supplied by the medical staff. However, we have identified some upgrades for example; The amount of drugs administered could be tracked, so the traceability will be kept from the pharmacy who expend it to the patients; the system can inform the medical staff about the time they spent in dangerous places using Radio Frequency Identification (RFID) tags[20]; the generated data can be showed to the medical staff in a user-friendly way, and they also could have the possibility of configure their own services and alerts. These upgrades introduce similar requirements to the communication architecture as the previous scenario and add others such as: intelligent processing, interaction between different technologies and context aware.

There are essential technologies that are used in the scenarios above. As we mentioned before Hl7 has proposed a number of standards to guarantee the communication between different computer systems used in hospitals and healthcare providers. As a result there is a complete open-source integration engine called Mirth[21]. Mirth is based in some libraries that can handle properly Hl7 message standards, which are used for medical devices. However there are detectable weaknesses in some Hl7 integrations, from the whole system's point of view such as: not complete stack standardization and dependability on underlying protocols. Consequently, those characteristics can be especially important in environments in which a flexible and efficient deploying of medical services is needed. On the other hand, including mobility in telemedicine applications is a valid approach[22][23] so in order to overcome the disadvantages of fixed network infrastructure, SIP native features such as mobility and tracking could be used.

4. Architecture Design

The architecture we propose in this paper is focused on resolving the scenario above, and taking special attention in the hospital communication architecture needed. One of the problems is how to improve a hospital network infrastructure to unify the medical services offered by bio-sensors into a single platform. This system also has to support mobile messaging in order to keep the medical staff informed about the patients' state and in case of emergency be capable to prioritize the data that has to be sent over the communication channels. Another goal is to support an upper intelligent level called OCP (Open Context Platform) that will process the contextual information generated by bio-sensors and extract behavioral patterns.

The overall system architecture we propose depends on the hospital's characteristics and the number of floors and beds. The figure number 1 depicts the global architecture. In each room there is a device called iBed. Connected to this there are several bio-sensors that are in charge of taking the

patients' vital signs, there is also a RFID antenna to detect the patients' location. The iBed is in charge of transmitting all the information to an intermediate server using SIP as the signaling protocol and using other protocols depending of the transmitted data type. The physical connection of the iBed node and Intermediate Server is done by Ethernet links but there is a backup Wi-Fi connection to ensure the reliability of the system.
The aim of an intermediate server is to support multiple nodes per room and to do a message pre-processing at the application and routing layers if it is needed. In addition, the intermediate server can be used for the medical staff to check the status of the nodes. The intermediate servers also contribute to prevent overloading of the central ones and to add a decentralization level for the general system. This new functionality adds a hierarchic style network management that can be useful for the hospital communication management. Another feature of the intermediate server is to be capable of sending and receiving alarms that can be generated in every room and give them the correct priority.

The physical communication between floors and the central server is done by using optic fiber to maintain electric decoupling. However, even if a problem occurs with the central server, the intermediate servers can be capable of keeping controlling the nodes and informing the staff about the critical events. This characteristic is considered unavoidable for the medical communication system we examine.

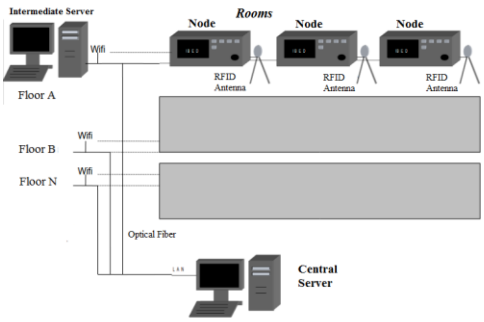

Figure 1. General Architecture

4.1. Node Model

The node model is divided in several layers. The First Layer is the Access Network which depends on the situation (we already explained in previous paragraphs); Ethernet or Wi-fi access will be used. The Communication Interface is formed by two elements: the SIP User Agent[8] and the Mirth Module. The SIP User Agent (UA) will register the IP and the sip address of the iBed in a Proxy Server located in the intermediate servers to support the mobility, and session control. The Mirth Module has to process all the communication between the encoded data in Hl7 format obtained by the sensors and transmitted to the destination. These two modules are bundles of the OSGi framework and are managed by a control application that has all the logic. In this way when a data is captured by a bio-sensor and has to be sent, the Control Application orders the SIP User Agent to create a session based in predefine attributes we will explain later. Secondly, the Mirth Module constructs a bearer channel with the optimal parameters at TCP level for the Hl7 messaging that includes the sensor data. As a result the node architecture keeps the modularity to implement different kinds of protocols, sensors, data format without affecting the interoperability with other possible platforms or components' upgrades. Another iBed's task is to detect if the patient is in the correct room, so it is overcome using a RFID module that is included in the OSGi framework, this module is capable to identify the correct RFID tag detected using an antenna connected physically to the device. The RFID data is sent using the same criteria as the sensor-data messaging.

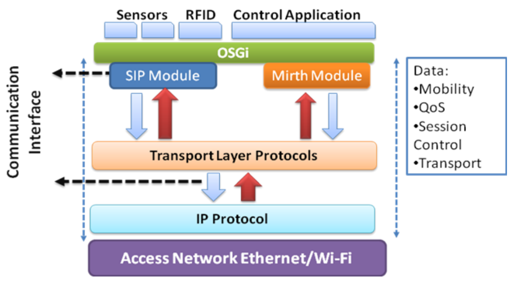

Figure 2. Node Model Architecture

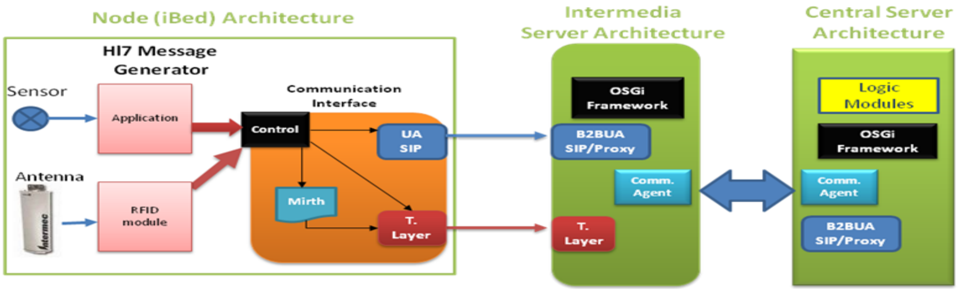

Figure 3. Global Architecture

4.2. Server Model

The Server model has the same stack of the node's model and is applied to the intermediate and central server. At the communication level, there is a SIP Back-2-Back User Agent (B2BUA)[8] Module that has more capability to process SIP messages. There is also a Proxy Module that registers the SIP UA, keeps the established sessions and tracks the availability of network resources. The OCP on the top of the communication layers is in charge of the information's logic processing, it is based on an Enterprise Service Bus that we will not approach in this article.

4.3. Network Model

The Network Model is depicted in figure 3. The three main components listed based their messaging in the same communication interface, but there is a slight difference between intermediate and central server communication. In some way there is not a need of a central node to know every node connected in each floor and all the information and sessions that are generated. These data could be very considerable in a hospital environment with multiples nodes; as a result, the central server checks the availability of the intermediate servers with heartbeat messages. If the intermediate server fails, the nodes have a mechanism to detect that there is a failure in the system so they redirect the packets to the central server and renegotiate the proper sessions using SIP. This control mechanism is managed for upper layers that we will not discuss in this paper.

4.4. Data Model

The data model has a direct relationship with the bio-information regarding the patients. This information has to be registered in the servers' platform and be available for processing. Defining a data model permits a secure, reliable and quick way to transmit the data over the hospital communication system we propose. Every sort of data needs a specific quality of service. Indeed, we differentiate between tolerant-traffic and non-tolerant traffic, the first one can be adapted to the network quality while the second cannot.

In the medical data we focus on real-time data and non-real time data. The first one is defined as non-tolerant traffic and has to fulfill some requirements such as: low jitter, low latency, low redundancy in upper layers, fast processing and efficient acknowledge in packets. Depending on the message's weight network resources are allocated or not. In our architecture we define four kinds of traffic: urgent traffic, important traffic, and best effort traffic. Another general classification can be done by differentiating the data sent in a single message or a stream. The stream data has special requirements in order to keep a sustainable packet level per unit time but not exceptionally reliability.

In table number 1 we classify the data type transmitted over the network and the related QoS needed. This table facilitates the linking with the information provided by the bio-sensors.

Traffic Type	QoS			
	Delay	Jitter	Bandwidth	Reliability
Urgent traffic (non-tolerant)	Very low	Low	High	High
Important traffic (non-tolerant)	Low	Low	High	Medium
Important traffic (tolerant)	Medium	High	Medium	High
Best Effort (tolerant)	High	High	Low	High

Table 1. Traffic Type vs QoS

- Urgent Traffic (non-tolerant): automatic data proceeded from a patient's critical state that needs immediate attention. Some urgent alarms can be categorized in this category.
- Important traffic (non-tolerant): data collected from a manual input requested by a medical staff's action e.g. respiratory frequency, medical's drain and diuretic classification and stool volume.
- Important traffic (tolerant): data obtained from spirometers, glucose level, and other input derived from vital constants such as: temperature, blood pressure and pulse.
- Best Effort (tolerant): this group includes data such as files, medical history or other kind of traffic that does not need high requirements and does not directly affect a patient's health.

One of the advantages of the data model proposed, is that it permits to generate a network session based in predefine attributes. In this case, when a data has to be sent, the Control Element existing in every node, that already has the data model, informs the SIP agent about the data communication requirements. As a result, the SIP module negotiates the session with the Intermediate Server using Session Description Protocol (SDP) and at the same time, taking in consideration the network resources availability. Once the session has been established the Mirth Module transmits the bio-data through a constructed channel with the SDP information and the selected protocol. The improvement of this method is that many protocols can be used for transmitting multiple data types. For example if a health streaming data is generated by a bio-sensor the Mirth Module chooses a Real Time Protocol (RTP) or a User Datagram Protocol (UDP) in order to prevent network overloading. Similar scenarios have been analyzed in some papers [24][25]. However if the data does not demand QoS but high reliability, TCP can be applied. Finally the Control Module has two crucial tasks in the data processing: to manage the relationships between data type and quality of service assigned, and interoperate between upper layers and functionalities such as: UA SIP and Mirth.

5. Conclusions

In this paper, we present an improved Communication Architecture for Smart Services in Hospital Environments that fulfills all the previous requirements established for an improved hospital scenario. This scenario could easily be upgraded with other technologies without affecting the core elements of the architecture. We have considered many aspects such as network topology and management in order to ensure a proper validation of the architecture, and also exposed a realistic way to apply it. The architecture resolves problems regarding expanding information availability and compatibility with the standard HL7. In addition, the architecture ensures the interaction with smart services that could be executed in other OSGi platforms.

Since generic systems adaptation demands specific requirements we just defined the communication architectures reference in an isolated way. Finally, we have used Ethernet and Wi-fi as network access technologies. In order to further improve the architecture other alternatives, such as Bluetooth or 3G, have to be considerated.

6. Planned Activities and Future Work

A prototype has been planned in order to verify the validity of the architecture. The prototype will have the key components of the system, and will use real bio-sensors attached to several iBed modules. The prototype will be located in a Hospital of Tarrasa, Catalonia, Spain with the aim of ensuring a real-interoperability with other medical devices. The Central and Intermediate Servers will run over Linux OS and the iBeds an embedded version of Windows XP. As a result, we expect to have real medical data and corroborate the concept regarding the network reliability, overall system efficiency and interaction with the medical staff. In a future work, we will examine the characteristic that some technologies such as P2P-SIP can contribute to emergency situations in which a quick deploy of medical services are needed. We will also analyze some medical constrains regarding the traceability of drugs and the enhancements for health service composition oriented to medical staff.

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