Architectural models for realization of Web-based Personal Health Systems

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Abstract: *Recent advances in Information and Communication Technologies (ICT) and more specifically in wireless networks and mobile computing have driven new directions in the development of e-Health sector. New emerging concepts like mobile health (m-Health) and Personal Health Systems (PHS) are expected to revolutionize the way healthcare services are delivered. In the paper a description on the specifics of the PHS's building blocks is presented. An example multi-tiered architectural model for realization of PHS is included and a description of characteristics and functions of the tiers is suggested.*

Key words: *Personal Health Systems (PHS), Body Sensor Networks (BSN), Medical Web Portals, Web-based PHS.*

INTRODUCTION

Recent advances in Information and Communication Technologies (ICT) and more specifically in wireless networks and mobile computing have driven new directions in the development of e-Health sector. New and emerging concepts like mobile health (m-Health) and Personal Health Systems (PHS) are expected to revolutionize the way the healthcare services are delivered. M-Health incorporate mobile computing, medical sensors, and wireless communication technologies for delivering of healthcare in a non-restrictive manner. It is also defined as the next step in the continuous shift from traditional desktop telemedicine systems toward new wireless, mobile, and unobtrusive healthcare platforms. Its deployment is accelerated by the increased availability, performance, miniaturization, and enhanced data rates of current and future wireless communication and network technologies and power-efficient microcontrollers [4], [5].

The PHS is concerned with the individualisation of prevention, treatment and well being procedures available through the healthcare system. The patient is put at the centre of the health delivery process. The main goal is to bring continuity of care at all levels of healthcare delivery through remote monitoring and management applications, spanning from location, to ambience, and time. This continuity of care is a prerequisite for the delivery of preventive, personalised and citizen-centred health care. PHS as a concept is made possible because of the new micro and nano technologies (e.g. wearable, implantable portable systems), information and communication technologies (ICT) (e.g. contact centres, point-of-care systems, multiparametric decision support systems), as well as medical knowledge mining and management systems [1], [2], [3].

The goal of the paper is to provide an overview of PHS systems, their building blocks and architectural models in the design of Web-based Personal Health System.

BUILDING BLOCKS OF PHS SYSTEMS

There is no standard definition of the structure of PHS systems. However, most of the implementations integrate at least the following major blocks in their design: a network of biosensors (BSN); Personal gateway; Clearinghouses; Medical Servers; Medical Web Portal.

Body Sensor Networks (BSN)

Body sensor network (BSN) consists of a network of miniaturized, low cost, and wireless wearable or implantable bio-sensors and actuators that are interconnected to provide continuous monitoring of the patient's physiological and contextual parameters (e.g. ECG, EEG, Heart and respiration rates, blood pressure, oxygen saturation (SpO_2),

body temperature, glucose level, spatial location and etc). Every node of BSN performs signal pre-processing including detection, amplification, filtration and discretization. In some cases it is also possible to perform digital signal processing which involves analyzing the data to detect abnormal disease situation and creating alerts. This feature is important for cases when a risk of disconnections with patient server exists. The sensor node should then communicate the collected data seamlessly to external devices [1], [2], [3].

Personal Server

Personal Server is responsible for a number of tasks: transparent interface to BSN, interface to the user, and an interface to the medical server, performing high-level data processing, analysis and temporary local storage. The interface to BSN should deal with network configuration and management. The configuration tasks include sensor node registration, initialization, customization, calibration, and setup of secure communication. The management tasks include channel sharing, time synchronization, data retrieval and processing, and data fusion. The personal server can do a local reasoning to determine user's health status based on data from multiple sensors and provide feedback through a user-friendly and interactive graphical or audio interface. Finally the data is communicated to a Medical server or a Healthcare clearinghouse over wireless mobile networks or Internet. The most adoptable platforms for realization of mobile personal server are PDAs and smart cell phones due to their size and processing and communication capabilities. Other possibilities are tablet PCs, laptops, and custom specially designed microprocessor-based devices. [4], [5], [6].

Healthcare Clearinghouses

The current deployments of Healthcare Information Systems (HIS) the raw medical data from sensors are forwarded to a healthcare clearinghouse. The clearinghouse acts as a dedicated reasoning engine processing incoming data and forwarding it to a medical service provider in required form and format. The strict definition of a HC is: a public or private entity, including a billing service, re-pricing company, community health management information system or community health information system, and "value-added" networks and switches, that does either of the following functions [8], [9]:

(1) Processes or facilitates the processing of health information received from another entity in a non-standard format or containing non-standard data content into standard data elements or a standard transaction.

(2) Receives a standard transaction from another entity and processes or facilitates the processing of health information into non-standard format or non-standard data content for the receiving entity.

Disadvantage of this approach is the huge amount of unprocessed sensor data sent to the clearinghouse resulting in increased communication and power cost at the BAN side and an increased processing at the remote side. To deal with this increased processing the functions of clearinghouse should be distributed among several physical servers. The synchronization between them is crucial for the correct operation.

With the increased processing capabilities of today's mobile devices this approach is no more relevant and is included only as a transitional step. The functions of this block in the PHS systems are now distributed between Personal Gateway and Medical Server.

Medical Server(s)

Medical server typically is situated in medical centres where medical services are provided. The medical server keeps electronic patient records (EPR) for observed patients, which are accessible by different players of medical services providers, including general practitioners, specialists or doctors from clinics in hospitals from their offices over

the Internet. All of them can observe the current patient state. Medical server is responsible for user authentication, accepting data from personal server, insertion of the data in EPR in proper format, recognition of emergency situations and contacting medical service provider to take the corresponding actions, and also to provide feedback instructions such as physician prescribed exercises to users. The medical server supports some elements of telemedicine functionality.

Medical Web Portal

The Web is widely used to ensure universal access to information resources and it enables new directions in development of e-health. Web-based, portal technologies and multi-tiered architectures have proven its advantages in the ubiquitous access to information in device independent manner and provide many benefits over traditional client/server architectures [1], [5]:

- Installing and deploying the user interface is virtually instantaneous - only the Web interface in the middle tier needs to be updated
- Without a client-side user interface, it is easier to deploy, maintain, and modify applications no matter where the client is located
- Instead of managing multiple applications everything is managed under one portal
- Satisfy clinicians' requirement for one interface.

An example of medical Web portal is Google Health (http://www.google.com/health). It allows you to store and manage all of your health information in one central place and gives you access to various services and features: build online health profiles, import medical records from hospitals and pharmacies, share your health records, and explore online third-party health services.

ARCHITECTURAL MODELS FOR PHS SYSTEMS

In the design of PHS systems the current best practices dictates the use of hierarchical distributed architectural models. In vertical aspect the architectures of PHS system is naturally hierarchical and is usually separated into tiers representing one or more of the building blocks of the system. The tiered architecture brings flexibility and separation of presentation and functional roles within the healthcare process. The additive benefits are increased security, information generalization, data reasoning, and functional isolation.

Several research works focus on the integration of PHS systems with HIS and other enterprise systems to achieve seamless interoperation. One approach is to build the system around an integration engine. The engine is responsible for the understanding of message context, converting the healthcare information into a unified format, and storing the information in data repositories. The communication with information systems with different integration interface is done through appropriate engine's interface adaptor [10].

In their work, the authors of [7] suggest the use of network-centric approach in design of Healthcare System of Systems. The backbone of the system is build on top of the World health information grid, consisting of a set of interconnected Web enabled information networks with intelligence capabilities. The grid provides the means for data transfer and sharing.

From the patient-centric view of the PHS, the system architecture is usually represented into tree tiers [6], [4], [11], [12]. The exact system architecture and the number of system tiers depend predominantly on target applications, available infrastructure, and type and number of users. Such three tier architectural model is shown on figure 1. Tier 1 is formed around BSN and performs the functions of collecting, processing and communicating of medical data from sensors to next tier. It could include also data from

ambient sensors situated in home or office. The communication with next tier is usually based on one of the wireless standards from IEEE 802.15 (WPAN) family.

Tier 2 encompasses the personal server and/or home gateway. Personal server is a mobile device like smart phone or PDA. It brings the advantage to be in constant connection to BSN, but has power and energy limitations. Home gateway on other hand is a desktop computer or dedicated medical set-top box device with custom designed microcontroller. It could support most communication channels, including wired and wireless, and to use the advantage of Internet for wide bandwidth, low-cost data transmissions. It could realize some local reasoning over data from BSN, saving time and reducing cost.

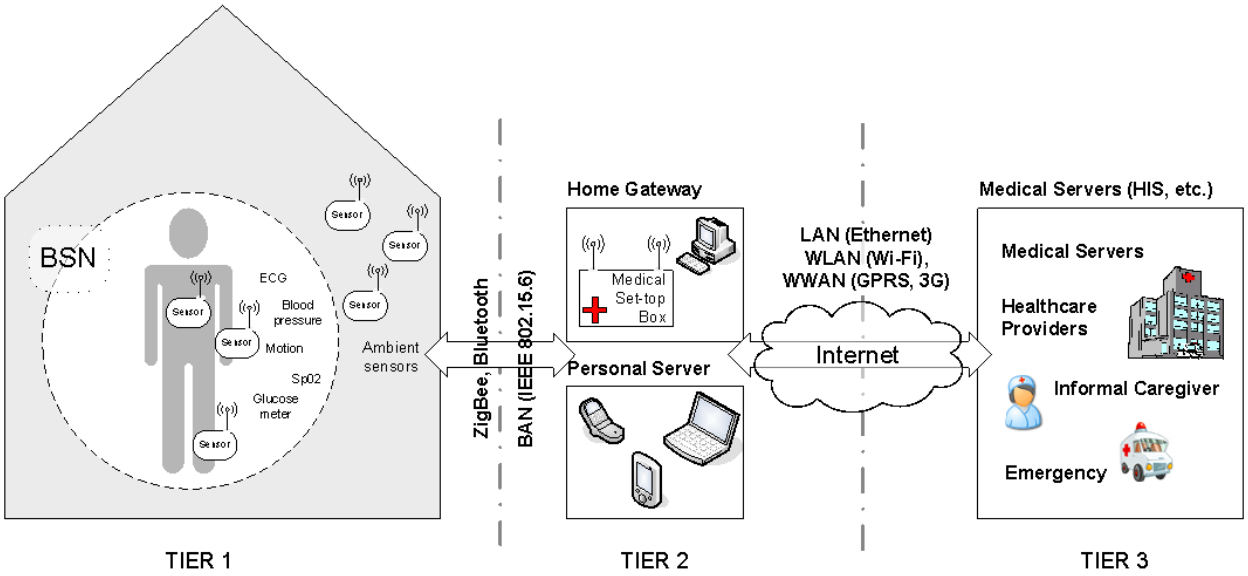

Fig. 1: 3-Tier architecture for PHS

The third tier includes medical servers and various healthcare services. For increased interoperability and common interface to medical services the front-end to this tier could be realized as Medical Web Portal. This will allow easier integration with other enterprise information systems and easier access, and could be implemented using proven best-practises for design of Web applications. The function of this tier includes control of data exchange with tier 2, management and support of Database with electronic medical records, interface to various medical and non-medical services, global reasoning over data from BSN and feedback to the patient.

STANDARTIZATION ON PHS SYSTEMS

Standards are required to ensure interoperability and integrity between the building blocks of PHS system. In general HIS standards for the exchange of medical data and communication between medical devices are well established [13]:

- HL7 (Health Level Seven) defines a standard for exchange of medical, financial and administrative information between HIS, clinical laboratories, enterprise and pharmacy systems;
- IEEE P1073 (Medical Information Bus - MIB) standardise the physical and transport characteristics of communication between medical devices for providing of plug and play interoperability at the point of care. It facilitates the exchange of medical data acquired by patient connected medical devices.
- TC251 (Technical Committee for Medical Informatics) standardise the representation of biomedical signals, measurements, events, and alarms. It is a

complementary to IEEE P1073 by defining higher layer protocols.

Continua Health Alliance [14] has the mission to ensure interoperability between health monitoring devices (BSN) and home-based gateway (Personal Server) that relay the data from the devices to healthcare providers in Personal Health Systems. Its 'Version One Guidelines' defines protocols and standards for secure transport of sensor data over wireless Bluetooth or USB links and standards for records representation (xHR) [14].

CONCLUSIONS AND FUTURE WORK

Personal Health Systems are envisioned as the future of healthcare delivery process. The individual citizen will have the provisions and handles to be self-responsible for his own health and to manage the health delivery process. On the other side, physicians will be provided with more accurate data from continuous monitoring of patients in their natural environment and will be able to give more accurate prescribes. This will improve the overall quality of healthcare while reducing the costs. ICT technologies are the base for these changes by introducing the new achievements from the recent years in the domain of healthcare.

The paper presents an overview of the building blocks and architectural models for PHS systems. An overview of the current and still in draft version standards and specifications is also included. An example multi-tiered architecture is suggested for realization of Web-based PHS systems that will be used for future analytical, simulation and test-bed analysis.

Some future work includes further analysis of the wireless communication protocols and topologies for the formation of body sensor networks and communication with patient server. Other directions for future work are optimization of personal server in terms of power efficiency, digital signal processing, local reasoning, and communications.

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