UPHSM: Ubiquitous Personal Health Surveillance and Management System via WSN Agent on Open Source Smartphone

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***Abstract* — Taking the technology advances of bio-monitoring sensor, wireless sensor network (WSN), pervasive Internet and prevalent smartphone, we design a ubiquitous personal health surveillance and management system called UPHSM. Our system cost-effectively integrates health-related sensory devices with the application-layer gateway (ALG) implemented on an open-source smartphone (i.e. Google Android phone). It can aid senior citizens and patients who need long-term attention to their illness, like chronic diseases, with ubiquitous surveillance and remote management of the recorded health data. The proposed smartphone ALG (SmartALG) between WSN and Internet can multiplex different health/environment sensory data in both reliability and security. Through the smartphone's Internet connection over 2.5G/3.5G/WiFi, SmartALG delivers the multiplexed sensory data with user's location to remote server to enable the ubiquitous health surveillance and management. Not only the medical expertise can remotely browse the stored sensory data for diagnosing, but also, while the remote sever detects abnormality in sensory data, a short message with concise information will be immediately sent to user's relatives and healthcare professionals to provide proper treatment for personalized and timely care.**

***Index Terms*—Wireless Sensor Network, Internet, Application Layer Gateway, Google Android, Ubiquitous Personal Health Surveillance and Management.**

I. INTRODUCTION

In developed countries, advancement of medical technologies has successfully extend people's life, but the civilization disease and chronic disease are also introduced. Thus, lots of medical resources are required to consume in aging society nowadays. To further release not only the burden of medical resources, but also the human resources in health care, the IT technology has been targeted as the mediator between hospital and patient for pervasive heath services in aging society. Thanks to the technologies of Wireless Body Area Networks (WBAN) [1], Wireless Sensor Network (WSN) and prevalent Internet access, they can be applied together to sufficiently close the time and distance gap between individuals and their medical staff in remote health care and management to attain proper treat immediately.

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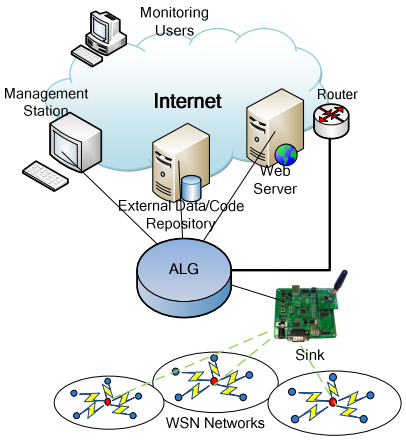

Figure 1. Using ALG to connect WSN network and Internet.

As shown in Figure 1, application-layer gateway (ALG) [2][3][6][7][10] is needed to cost-effectively deliver the sensory data from the link layer of WSN protocol to the network layer of IP protocol over Internet. Then ALG can provide the solution for diversified Internet applications with ubiquitous access to remote WSN data. However, while WBANs and nomadic WSNs are applied for patients' remote health care and management in ubiquity, ALG must be implemented on portable devices, such as smartphones, personal digital assistant (PDA) and notebooks, with Internet access [5][6]. Due to the prevalence of smartphone and its openness trend to developers and users, we implement ALG on smartphone (SmartALG) for personal health surveillance and management in ubiquity.

Therefore, we propose a system of ubiquitous personal health surveillance and management (UPHSM) via SmartALG on open source smartphone. The UPHSM's SmartALG can cost-effectively multiplex different health-related sensory data with different sensory frequency to real-time deliver to remote server with user's GPS location through pervasive Internet in reliability and privacy protection. The stored health data can be

accessible and managed by different users such as patients, patients' relatives, medical staffs and authorized administrator. Besides, while the remote server detects the abnormality in sensory data, a SMS's short message with concise information including GPS coordinates will be sent to help user to immediate receive proper treat as soon as possible.

The remainder of this paper is organized as follows. Section II presents the system architecture of UPHSM and its subsystems. The details of design and implementation in UPHSM and UPHSM's performance are simply described in Section III. Finally, conclusion and future works are given in Section IV.

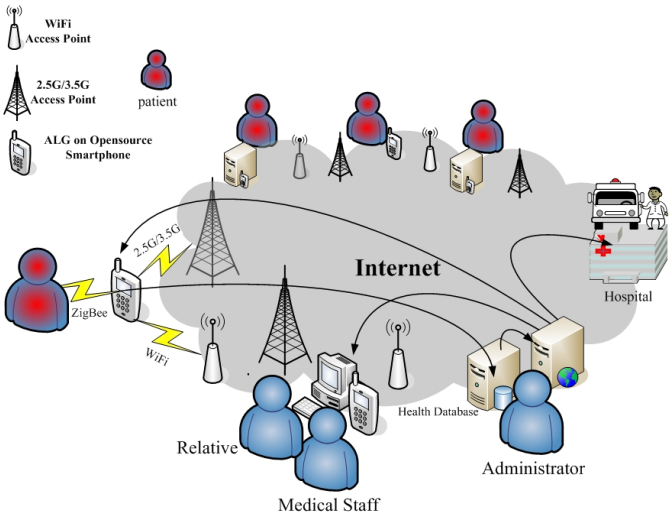

Figure 2. UPHSM scenario.

II. UPHSM System Architecture

As illustrated in Figure 2 the UPHSM is demonstrated. The sensory data from sensor gadgets next to patient's skin will be sent to patient's nearby smartphone with USB-attached WSN receiver via the ZigBee protocol. Then, the smartphone will forward the health data from WSN sensor nodes to remote server of health database via Internet connection from either 2.5G/3.5G or WiFi wireless channel.

On receiving the health data from the remote sensor nodes, the health database server will store it and provide remote authenticated users for later queries. For example, the medical staff can actively real-time browse and monitor the possible severity of the specific patient's current health condition. Moreover, a specific patient's severe condition can be immediately detected by the remote health surveillance server, which will look over health data in database and validate if the new health data meets the health conditions preset by medical staff.

If user's health condition is severe, the short message with user's concise health information including user's GPS position will be immediately sent to user's relative, and hospital. Therefore, a patient can be treated with prompt and proper health care from the helps from ambulance corps and medical staff for the severe condition. Besides, the patients and their relatives, medical staffs and authorized administrators can remotely access, review and manage the stored health-related data.

Our proposed UPHSM is composed of four subsystems including Health Sensor Data Sink (HSDS) subsystem, ALG on Smartphone (SmartALG) subsystem, Remote Health Data Management (RHDM) subsystem and Real-time Health Surveillance & Alarming (RHSA) subsystem. They are described as follows.

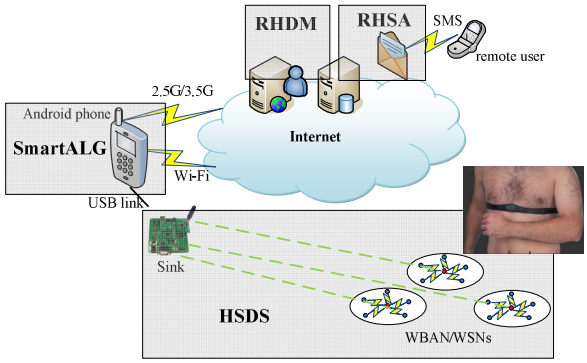

Figure 3. UPHSM subsystems.

A. HSDS Subsystem

As shown in Figure 3, the HSDS subsystem will take the responsibility to use ZigBee (IEEE 802.15.4) protocol to constantly deliver physiology data from WBAN or health sensors on user's body to the sink device in the HSDS subsystem, which is directly connected to open source smartphone via the USB port or Wireless PAN Bluetooth.

There are a large number of sensors , which are commercially available, can be used to observe health status [1] such as electrocardiogram (ECG) sensor for heart activity, electromyography (EMG) sensor for muscle activity, electroencephalography (EEG) sensor for brain activity, blood pressure sensor, blood glucose sensor, breathing sensor for respiration, and etc.

Due to the different sampling rates from different kinds of sensor devices mentioned above, the device identifier must be also sent with sensory data to the HSDS sink device on open source smartphone. Therefore, after the HSDS sink receiving the sensory data with device identifier, the sensory data can be indentified which sensory device come from.

As the HSDS sink is connected to USB port on open source smartphone, the power life time of HSDS sink can be prolonged with the power life time of open source smartphone. The UPHSM's SmartALG subsystem on open source smartphone will treat the USB port as RS232 serial communication port to receive the health-related data from HSDS sink.

B. SmartALG Subsystem

As shown in Figure 4, because of the different network layers applied between WSN applications and Internet applications, SmartALG subsystem must play as a gateway to make health sensory data from HSDS on WBAN/WSN transparent to the Internet applications of RHDM and RHSA subsystems [10].

In our UPHSM system prototype, the SmarALG subsystem is implemented on the open source smartphone of Openmoko Android [8][9] and it will receive the sensory data from the HSDS sink, which is physically connected to the USB port of smartphone, and then forward the received sensory data to

remote server over Internet via the wireless network of 2.5G/3.5G or WiFi.

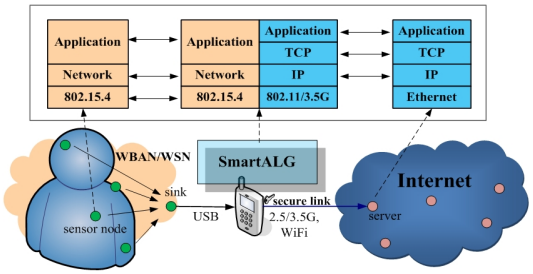

Figure 4. Network layers in SmartALG between WBAN/WSN and Internet.

Because the RS232 communication port is applied for HSDS sensor sink to connect to external device, we need to emulate the smartphone's USB as an RS232 port to supply sensory data to SmartALG's receiving module. Then, SmarALG can apply Linux serial port API to read data from HSDS sink and then the sensory data will be forwarded to remote sever through reliable link via Android TCP socket API with reliable connection.

Besides, the health sensory data preserves the sensitivity of the user's privacy, the delivered data to public Internet will be encrypted via AES encryption. As shown in Figure 4, the sensory data will be delivered via secure link to RHDM subsystem in remote server over public Internet. Before the beginning of delivering sensory data from SmartALG subsystem to RHDM subsystem in remote server, the encryption key will be negotiated by Elliptic-Curve Diffie-Hellman (ECDH) [11] procedure as shown in Figure 5 and the negotiated K will be the encryption key to secure the link between SmartALG and RHDM subsystems.

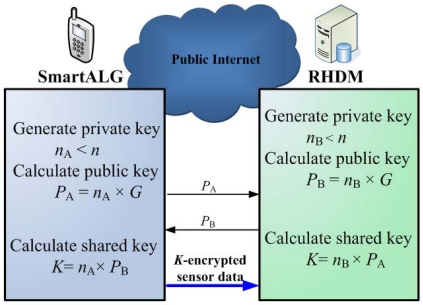

Figure 5. ECDH procedure between SmartALG and RHDM subsystems.

C. RHDM Subsystem

As shown in Figure 3, RHDM's primary job is to store the received sensory data from remote SmartALG to local database. Since RHDM will be connected to many SmartALGs, RHDM must identify each connection from different SmartALGs of different users. While a SmartALG start to register UPHSM service to RHDM subsystem, RSDM will have to assign a unique user identifier to the corresponding SmartALG. The user identifier can be a unique number such as user's phone number. Then, all the sensory data can be identified and stored to database in different user account.

The secondary job of RHDM is to provide authenticated users like patients, relatives, medical staff and system administrator to remote access the corresponding database and configure the UPHSM system settings, such as the thresholds of abnormality in sensory data, via the ubiquitous Web service. In the prototype of proposed UPHSM system, RHDM use MySQL database, Apache web server and PHP script language to complete above-mentioned jobs.

D. RHSA Subsystem

To provide real-time surveillance for personal health in UPHSM service, RHSA will constantly examine the incoming sensory data to RHDM to find the severe abnormality in user's health conditions. That's to say, if the sensory data value running beyond a preset threshold within a preset period, a short message via telecommunication SMS service with concise information, including health information and GPS location, will be immediately sent to user's relatives, medical staff or even the hospital for emergency help in the best way.

Therefore, the RHSA subsystem and some modules of RHDM will be running on the same host over Internet, for RHSA needs to immediately access the related data in RHDM database.

Figure 6. SmartALG prototype on Openmoko Android.

III. UPHSM System Design Details

The design details of UPHSM's working flow and connection interface between modules are shown in Figure 7. In Figure 7(a) the user should register his personal data first through SmartALG module, which may include personal health information, sensor number, emergency contact and etc. All the data will be recorded in RHDM. In Figure 7(b), multiple sensors in HSDS collect the health data and then HSDS sends them out to SmartALG module. In Figure 7(c), after the SmartALG receives user's health information, the SmartALG will try to send them to RHDM module for backup and analysis. If the data value runs over the threshold, alarm message will be sent to RHSA. The RHSA module will immediately redirect alarm message to emergency contact person. In RHSA module, we consider the users' alarm message of critical health information may be lost during transmission, so we repeat the sending of alarm message to make sure that the alarm message has been successfully acknowledged by the contact person. In Figure 7(d), RHDM module provides the web interface to browse the user's history data for reference and administration.

The UPHSM system is a mobile, intelligent and real-time health care surveillance system. Because the modules in

UPHSM system are all designed to be functional independent, which can easily scale up and deploy in real environment with very low cost.

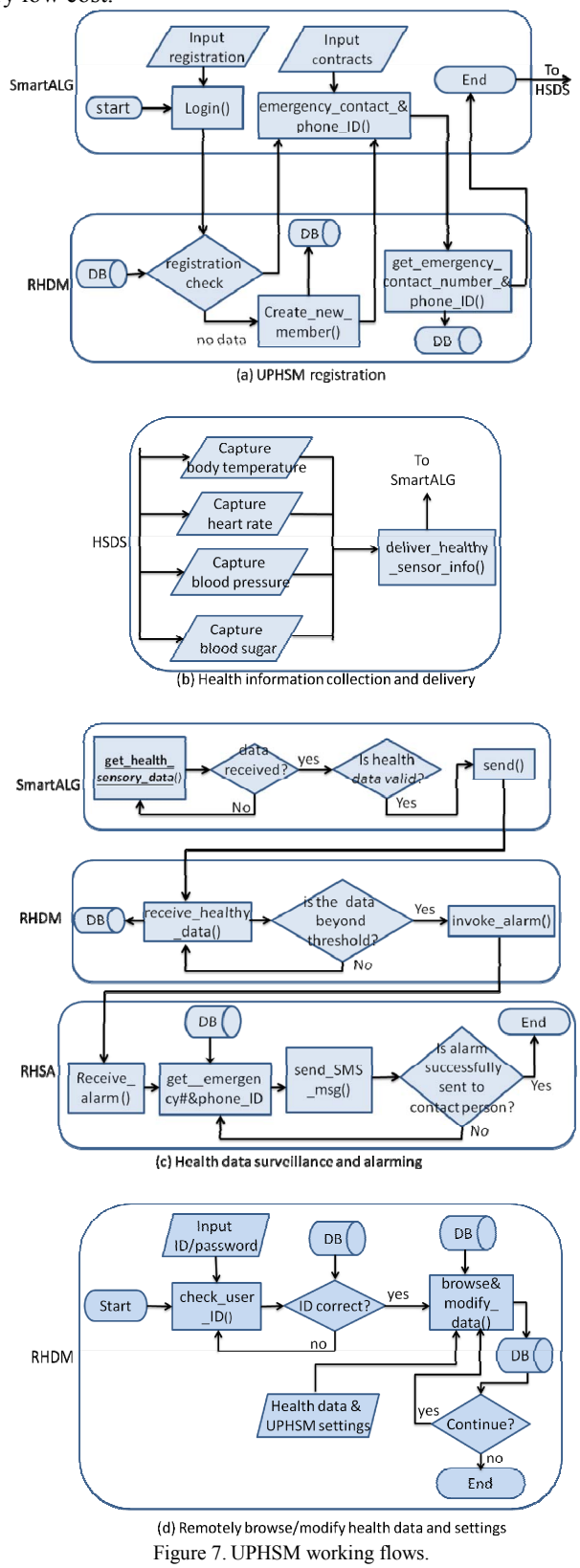

Figure 7. UPHSM working flows.

Furthermore, we also validate the delay time and jitters (i.e. time interval difference between receiving packets and sending packets) of delivered health data from UPHSM. The duration of validation experiments is about 1.5 hours. The performance results of delivered health data packets show that the delay time is less than 1 second and the maximal jitter is merely 80 ms.

IV. Conclusions and Future Works

The proposed UPHSM system includes three domain technologies of WSN, telecom and Internet. The most important goal in UPHSM is to support ubiquitous emergency health care through intelligent mobile device of the smartphone in prevalence. In traditional WSN that only provides environmental information from such as surveillance cameras and temperature gauge, we further integrated WSN with multiple health sensory data for real time health surveillance and alarming. We implement and demonstrate the whole system details of UPHSM with open source smartphone to improve traditional health care management system, because not only the secure health sensory information can be cost-effectively delivered and retrieved through Internet, but also the critical health alarm can be reliably sent to emergency contact person via telecom.

In the near future, we will further investigate the power consumption issue [4] in UPHSM's SmartALG since SmartALG plays the roles of data sink and gateway both. We may extend current health data delivery from one hop to multiple hops in WSN via aggregation and fusion techniques to optimize both data communication throughput and sensor-node power consumption.

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