Wireless Body Area Network in a Ubiquitous Healthcare System for Physiological Signal Monitoring and Health Consulting

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Abstract. We developed a ubiquitous healthcare system consisted of a physiological signal devices, a mobile system, a device provider system, a healthcare service provider system, a physician system, and a healthcare personal system. In this system, wireless body area network (WBAN) such as ZigBee is used to communicate between physiological signal devices and the mobile system. WBAN device needs a specific function for ubiquitous healthcare application. We propose a scanning algorithm, dynamic discovery and installation, reliable data transmission, device access control, and a healthcare profile for ubiquitous healthcare system.

Keywords: Wireless Body Area Network, Healthcare, Physiological Signal Device.

1 Introduction

The number of elderly people is rapidly increasing around the world. The worldwide population of people over 65 years old will reach 761 million by 2025, more than double the 1990 figures [1]. Generally, providing more efficient utilization of physicians, shortened hospital stays, reducing the skill level and frequency of visits of home-care professionals, reducing hospital readmission rates, and promoting health education can all contribute to reduced healthcare costs [2]. The ubiquitous healthcare system enables medical professionals to remotely perform real-time monitoring, early diagnosis, and treatment for potential risky disease. Furthermore, the medical diagnosis and patient consultations can be delivered via wire/wireless communication

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channels. Thus, the ubiquitous healthcare system can provide a cheaper and smarter way to manage and care for patients suffering from age-related chronic diseases, such as heart disease [3], because chronic diseases require continuous, long-term monitoring rather than episodic assessments.

In [4], they told that a continuous health monitoring system should be wearable and easy to use. So they propose a wearable, plug-and-play system using Bluetooth as the wireless communication protocol. In [5], they propose a mobile patient monitoring system, which integrates current personal digital assistant (PDA) technology and wireless local area network (WLAN) technology. This paper shows that the wireless PDA model is superior to the currently used monitors both in mobility and in usability and is better suited to patient transport. In [12], it encourages paradigm shift of moving a monitoring system for at-risk patient from the health facility to the patient's daily living environment (the locations where they happen to be during normal living).

Several technologies are needed for implementing a wearable healthcare system. That is, a physiological signal measurement technology to measure user's physiological signals continuously and wireless communication technology to construct a wireless body area network (WBAN). In this paper, we show our physiological signal devices, WBAN and ubiquitous healthcare system. It enables continuous physiological signal monitoring and supports health consulting information anywhere and anytime.

2 Wearable Physiological Signal Devices

We developed several type wearable physiological signal devices as shown in figure 1. Our strategy is that every possible physiological signal instruments is built into a physiological signal device and a central processor supervise the operation of each component, analyzes the measured data and then rapidly transfer these data using WBAN such as ZigBee. The technical challenge is to make the physiological device easy to operate and manage, reliable under various operating conditions, and affordable for most possible users.

(a) wrist watch type. (b) chest belt type. (c) shoulder type. (d) necklace type.

Fig. 1. Wearable Physiological Signal Devices.

I will explain wearable physiological signal devices with the wrist watch type. The central unit of a micro-controller (CC2430-RF Chip, Chipcon-TI, USA) manages the operation of each measurement module. The hardware of the actual device is composed of a wrist body and a band attached its. Two PDMS(Polydimethylsiloxane) electrodes for ECG(electrocardiogram) and a ribbon type temperature sensor are attached to the back of the body and a reflective flat type SpO2 sensor is mounted to the top of the wrist. The wrist watch type physiological signal device (W-PSD) contains three printed circuit boards, which include analog and digital circuitry and other onboard sensors. The size of the W-PSD is 60x65x15mm and the total system weighs 160g including one Lithium-polymer batteries. The software of W-PSD was developed for operational simplicity and efficiency. Considering the fact that possible users are relatively old and infirm, any complicated user interface would be counterproductive in daily life or in emergency situations. The W-PSD provides relatively small LED of current state for low power consumption, which indicate electrical function (power on/off, communicating, and battery charging).

In the developed system, wireless-transferring was accomplished in two separate ways. The first involved an RF link between the W-PSD and the mobile system for short range transmission using Zigbee communication. The second involved the transmission of information to remote caregivers and/or a server computer through the commercial wide network. We used ZigBee chip CC2430 (1.2GHz, Chipcon-TI, USA) as RF transmission and reception modules, respectively, the latter is connected to the mobile system (BIP-5000, Bluebird, Korea) via an RS-232 connection. Recently, the mobile system equipped with a code division multiple access module has become available and provides more processing power as well as a local wireless function. This is especially helpful when a larger amount of data is collected and analyzed.

3 Wireless Body Area Network (WBAN)

The W-PSD performs all measurements and sends the measured data to pre-assigned caregiver using PDA as quickly as possible. Nowadays, Multiple wireless communication standards exist [6]–[8], each suited to certain applications, e.g. BluetoothTM, wireless LAN, radio frequency (RF) transceiver and a cellular phone. We compared the wireless communication methods to be used with a same type for emergency situation. Based on the results of the previous study and considering the system complexity, power consumption, size of body and reliability, we chose an ZigBee(IEEE 802.15.4) for short range wireless communication. The goal of ZigBee(IEEE 802.15.4) was to provide a standard with ultra-low complexity, cost, and power for low-data-rate wireless connectivity among inexpensive fixed, portable, and moving devices [9, 10].

3.1 Scanning Algorithm

The physiological signal device (PSD) may always connect with the same mobile system (PDA). Thus, the PSD can know the address of the mobile system by using last or the most recent mobile system connected. However, according to the scanning algorithm of IEEE 802.15.4, the PSD that wants to connect with a mobile system should scan all channels, even if the PSD knows the address of the mobile system. Thus, establishing a connection may take a long time in certain situations.

In the proposed algorithm, the mobile system has a channel priority to select a channel for making a WBAN. The PSD can also know the channel priority of the mobile system by using the past connection information between the PSD and the mobile system. That is, the PSD can know the IEEE address and channel priority of the mobile system to which it is connected. Because the PSD knows the IEEE address and the channel priority of the mobile system, it does not need to scan all channels before establishing an association. If the PSD finds the mobile system during the scan and then tries to connect with it immediately, the duration of scanning time can be reduced greatly. We compared the scanning time of the proposed algorithm with the scanning time of the IEEE 802.15.4. We excluded the possibility of network error because the wireless network error is random and mostly effected by RF environment. Based on the IEEE 802.15.4 algorithm, the scanning time can be calculated with base superframe duration and scan duration [11]. Equation1 shows the equation about the length of scanning time in IEEE 802.15.4. aBaseSuperframeDuration is the number of symbols forming a superframe when the superframe order is equal to 0 and is consisted of aBaseSlotDuration × aNumSuperframeSlots. aBaseSlotDuration is the number of symbols forming a superframe slot when the superframe order is equal to 0 and the default value is 60. aNumSuperframeSlots is the number of slots contained in any superframe and the default value of it is 16. Scan Duration is a value used to calculate the length of time spent scanning each channel for scan.

$$\sum_{ch=first}^{ch=last}((S \times (2^n + 1))symbols) \quad . \tag{1}$$

where S : aBaseSuperframeDuration ,
n : Scan Duration (0 – 14)

Equation2 shows the equation for scanning time in the proposed algorithm. The P_i is the probability that the PSD finds the mobile system at i channel.

$$\sum_{i=1}^{i=last}\{P_i \times [(i - \frac{1}{2}) \times (S \times (2^n + 1))](symbols)\} \quad . \tag{2}$$

where S : aBaseSuperframeDuration ,
n : Scan Duration (0 – 14)
P_i : i-th Channel Probability

3.2 Dynamic Discovery and Installation

There are a lot of small devices in ubiquitous healthcare system. There is much difficulty in using a new small device if it is not discovered automatically. The small devices should be discovered and installed automatically to implement ubiquitous healthcare system. Nowadays, the middleware like an UPnP discovers the service between electronic devices but it does not fit for a small device like sensor. So, this paper proposes the dynamic discovery and installation algorithm suitable for the ubiquitous healthcare system.

The PSD has the sending module for device description and communication module. The sending module sends the device description regularly. The communication module uses the zigbee to communicate with the mobile system. The device provider system has the device installation module and communication module. The device installation module receives the installation data request message from the mobile system and then sends the device installation data to the mobile system. The communication module uses the (W)LAN to communicate with the mobile system. The mobile system has the several modules. The management module for receive data decides whether the received data from PSD is a device description message or not. It sends the data to the decision module for PSD if the received data is a device description message. It sends the data to the data management module if the received data is a physiological signal data. The decision module for PSD decides whether the received device description message come from a necessary PSD or not. The management module for PSD manages the PSD. This module decides to install or uninstall of PSDs. The data management module treats the physiological signal data properly and then sends the data to the middleware or application. In our ubiquitous healthcare system, the master device such as the mobile system can discover and install the new PSDs by using a network automatically. Therefore even if new PSDs are very small and plenty, the master device can manage the new PSDs very easily and conveniently.

3.3 Reliable Data Transmission

We made a reliable data transmission by using a retransmission. The sensor device transmits the data with AR(Acknowledgement request). If the sensor device doesn't receive an acknowledgement within apscAckWaitDuration seconds from the mobile system, the sensor device repeats the process of transmitting the frame up to a maximum of apscMaxFrameRetries times. If an acknowledgement is not received after apscMaxFrameRetries retransmissions, the APS sub-layer shall assume the transmission has failed and notify the next higher layer of the failure [11]. In this case, the next higher layer retransmits the data until the buffer is overflowed. APS sub-layer Constants say that the apscAckWaitDuration is 0.05 × (2 × nwkcMaxDepth) + (security encrypt/decrypt delay) where security encrypt/decrypt delay is 0.1, nwkcMaxDepth is 0x0f. The apscMaxFrameRetries is 3.

3.4 PSD Access Control

We use the access control between PSDs and a mobile system for security. First of all, the user of a mobile system inputs and saves the device ID of PSD at a mobile system. A ZigBee dongle requests device ID table from mobile system when the ZigBee dongle is powered on. If the mobile system receives a device ID table request message from the ZigBee dongle, it sends the device ID table to the ZigBee dongle. If the ZigBee dongle receives the device ID table from the mobile system, it saves device ID table. We use the group ID to communicate between the mobile system and a PSD. If the group ID of the PSD is same with it of the mobile system, the PSD can communicate with the mobile system. A PSD requests group ID from the ZigBee dongle when the PSD is powered on. If the ZigBee dongle receives group ID request message, it decides whether there is the device ID that requests the group ID in the device ID table or not. If there isn't the device ID in the device ID table, the ZigBee dongle sends the fail message to the PSD. If there is the device ID in the device ID, the ZigBee dongle sends the group ID to the PSD. The PSD can communicate with the ZigBee dongle after receiving the group ID. The group ID of the PSA should be same with the group ID of the ZigBee dongle to communicate each other.

3.5 Ubiquitous Healthcare Profile

The ubiquitous healthcare system may use a lot of PSDs and environment sensor devices (ESDs) to get context information. We justify a devices specified in the ubiquitous healthcare (UH) profile. A product that conforms to this specification shall implement at least one of these device descriptions. Devices are classified by the PSD for measuring a physiological signal and the control and monitor devices for controlling and/or monitoring the PSD and the ESD for measuring an environment context. PSDs are consisted of ECG for measuring ECG pulse rate, respiration for respiration rate, SpO2 for SpO2 value and so on. The plural device can measure two or more physiological signals simultaneously. It has physiological signals information about the number and the kind; for example, it has three physiological signals, ECG, PPG and body temperature. ESDs can measure environment such as temperature, relative humidity and so on. The context-aware ubiquitous healthcare system may know where the patient is by using sensor devices information. The control & monitoring device can control and monitor PSDs. For example, it can turn off PSDs and changes device status and so on. The accelerometer device in Etc. may be needed for detecting the falling down of a patient. This list will be added to in future versions of the profile.

4 Service Scenario and Application

A ubiquitous healthcare system infrastructure is shown in figure 2. This system consists of PSDs, a mobile system, a device provider system, a healthcare service provider system, a physician system and a healthcare personal system. PSDs measure the physiological signals of the patient and send the data to the mobile system using ZigBee. The mobile system can display the physiological signal data from PSDs and send them to a healthcare service provider system by using WLAN or CDMA. The device provider system provides device installation data to the mobile system. The healthcare service provider system is the portal server deciding all comprehensive tasks regarding health care. A physician logs in the healthcare service provider system and then can monitor and analysis the patient's physiological signals at the physician system. The patient logs in the healthcare service provider system and then can monitor own physiological signals at the healthcare personal system.

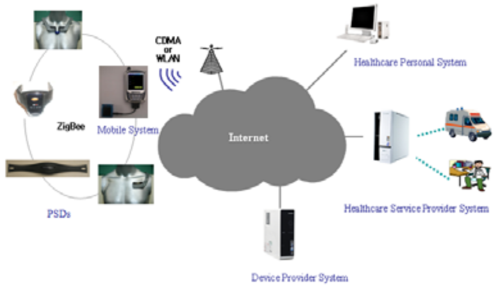

Fig. 2. Ubiquitous Healthcare System Infrastructure.

In our scenario, we developed 4 healthcare applications including the Self-Diagnosis Service, the Remote Monitoring Service, the Exercise Management Service and the Emergency as shown in figure 3. The Self-Diagnosis Service shows the user's physiological data. When the user selects the Self-Diagnosis service in the user interface of the mobile system, the value and status of physiological data such as skin temperature, blood pressure, pulse and respiration are displayed. If a medical doctor desires to monitor the physiological data of the user, the Remote Monitoring Service transfer user's physiological raw data to the remote heath care center. Thus the doctor can monitor the user's data in remote. The Exercise Management Service shows the consumed user's calories in the mobile system. If the state of the user is determined to be an emergency state, the Emergency State Management Service (ESMS) is invoked. The ESMS call the Short Message Service (SMS) transfer and transfer the user's physiological data to the remote healthcare center. Therefore, the medical doctor can monitor the emergency physical data of the patient.

Fig. 3. Ubiquitous Healthcare Application.

5 Conclusion

We developed a ubiquitous healthcare system that allows the patient to be managed and have their health monitored anytime and anywhere. We demonstrate that the developed PSDs provide convenient and comfortable multi-parameter health monitoring for a period of weeks or months, or even continuous monitoring in a very cost effective manner with acceptable reliability.

However, we have a problem to solve. The PSD is a wearable device, so it has a small battery. Now, it can work for about 6 hours without recharging. We should improve this problem.

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