A Distributed Wireless Body Area Network for Medical Supervision

Changhong Wang, Qiang Wang, Member, IEEE and Shunzhong Shi
Department of Control Science and Engineering, Harbin Institute of Technology, Harbin, China
Email: hitwch@163.com

***Abstract*—The emerging of wireless body area network has profound impacts on our daily life, such as pervasive medical supervision and outdoor exercises, and the large scale application of wireless body area network can effectively reduce higher cost burden owing to the aging society and long term healthcare for the chronic illness. It can also enhance the quality of life for elderly people and chronic patients, and decrease the harm of the sudden diseases. The paper presents a distributed wireless body area network for medical supervision. The system contains three layers: sensor network tier, mobile computing network tier, and remote monitoring network tier. It provides collection, demonstration, and storage of the vital information such as ECG, blood oxygen, body temperature, respiration rate. Furthermore, it also provides medical service management and disease warning. The system has many advantages such as comfort, low-cost, low-power, easy configuration, convenient carrying, easy transplantation, real-time reliable data, and friendly human-machine interaction. And then the design and implementation issues of the system composition are discussed in this paper.**

***Index Terms*—wireless body area networks; ZigBee; Android; medical supervision;**

I. INTRODUCTION

The aging population in many countries and the rising costs of health care have triggered the introduction of novel technology-driven enhancements to current health care practices. The traditional medical care systems use fixed medical care apparatus and the wired connection turns out to be so cumbersome as to greatly impact on the daily life of patients and involves a high cost for deployment and maintenance, while the diagnosis for diseases is also limited in hospital. In addition, there are some difficulties for early detection and long-term observation of diseases. To solve these problems, a new type of wireless sensor network emerges: the Body Sensor Network or the Wireless Body Area Network(WBAN) [1]. In WBAN, small and intelligent medical sensors can be worn on, around or implanted in the human body to monitor humans physiological activities and actions, such as health status and motion pattern.

At present, many research projects and products have been proposed by some universities and corporations. They can be divided into different categories by different criterions. By the number of the vital signal type, they are divided into single and multiple. By the the location of bio-sensor, they are divided into implantable, wearable and environmental. By wireless transmission method, they are divided into ZigBee, Bluetooth, Wi-Fi and etc. By access point to Wide Area Network(WAN), they are divided into laptop computers, Personal Digital Assistants (PDAs) and smart phones. Some of them are list in Table I.

LifeGuard[2], which was developed for astronauts in the first place, can also be used for general vital signs monitoring. It can support different types of sensors such as ECG, respiration, pulse oximeter, and blood pressure. The vital data are collected and stored by a wearable device called Crew Physiological Observation Device(CPOD). It also has 3-axis accelerometers and skin temperature sensors internally. The base station part is a Bluetooth capable tablet, and can display and also store the data streaming from CPOD for further evaluation.

CodeBlue[3] is a hardware and software platform developed at Harvard University. The hardware design part includes the design and development of a mote-base pulse oximeter, two-lead ECG, and a motion analysis sensor board. It uses different kinds of medical modules connecting with Mica2/MicaZ mote platform [6], [7]. The software architecture is based on a publish/subscribe routing framework. Each end-user device communicates with the CodeBlue network through a mote programmed with a specialized base station program called PubSubBase.

WristCare[4] can provide long-term monitoring of the user's circadian rhythm, which in turn, may be used to monitor changes in wellbeing. It consists of a Home System, and an Institutional System. The basic Home System includes one wrist unit and a base station, which are intended for users living independently in their own homes. The Institutional System is intended for users living in sheltered accommodation or nursing homes.

Medisn[5] carries out the task of monitoring unattended Emergency Room patients at the Johns Hopkins Hospital. It includes a miTag (medical information Tag), a miNet (wireless network infrastructure that transports the miTags), a miStore (persistently store the collected measurements) and a miViewan (deliver the vital information to authenticated end-users). It could easily integrate medical sensors, such as heart and respiration rate, blood pressure, ECG and etc. The average patient satisfaction level was 3.47 (on a 1-4 scale) and 91% of the patients indicated that they would be willing to use the device in the future.

In this paper, we present a novel medical supervision system architecture based on a distributed wireless body area network and carry out the implementation and the laboratory testing of it.

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TABLE I

THE WBANS OVERVIEW

	LifeGuard	CodeBlue	WristCare	Medisn
vital signal type	multiple	multiple	single	multiple
location for body	wearable	wearable	wearable	wearable
transmission method	Bluetooth	ZigBee	868MHz ISM band	ZigBee
access point to WLAN	laptop	PDA or laptop	basestation	basestation

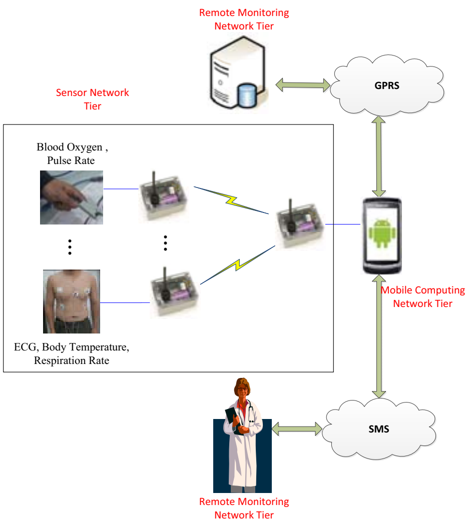

Fig. 1. The hierarchical network architecture of the proposed system

The system has two distinctive feature different from the existing system:

i) The first is so-called "distributed" that the different kinds of vital signs, such as ECG, blood oxygen and ambient temperature, are provided by individual modules and form a self-organization network by ZigBee. This method has two advantages:first it avoids inconvenient affection and cumbersome feelings caused by the leads winding the body to collect vital signals from the different parts of the body, and secondly users can only purchase a single functional module to cut the spending and to adapt to his own demanding.

ii) The second is that the system contains smartphones with Android operating system. It expands monitoring scope from only indoor to indoor and outdoor, while the users don't need to purchase the PDAs specially.

The remainder of this paper is organized as follows. Section II briefly describes the system architecture. A detailed description of our implementation issues is presented in section III. Finally, we conclude this paper in section IV.

II. THE SYSTEM ARCHITECTURE

This section introduces the proposed network architecture with multiple hierarchical tiers. The system contains three layers: sensor network tier, mobile computing network tier, remote monitoring network tier. Fig.1 depicts the details and relationships among the tiers.

Among the three layers of the system, the sensor network tier mainly contains wireless medical sensors and their probes, and this layer is in contact with human body. It is used to sample physiological parameters, including pulse rate, blood oxygen, ECG, body temperature and et. al. These nodes form a star-network composed of one sink node and other normal nodes. The sink node acts as a bridge between sensor network tier and the mobile computing network tier. It receives vital information messages from the normal medical nodes and sends them to the smartphone by serial. Note that the wireless transmission method in this layer is ZigBee, since the study in [8] has shown that the technologies like Bluetooth and Wi-Fi fail to provide support for energy efficient systems since they can only offer one or two weeks runtime on a small energy source like a coin battery.

The upper layer is mobile computing network tier. This layer contains a smartphone with the Android operating system. It is responsible for integrating of ZigBee wireless sensor network and CDMA cellular network to provide a mobile healthcare solution, and acts as a monitoring terminal for users. The vital information is shown on the screen of the smartphone and sends to the remote monitoring network tier by GPRS networks at a specified time interval.

The top layer is remote monitoring network tier. It contains doctors' smartphones and a remote monitoring center. The remote monitoring center receives data from the GPRS network, classifies and stores the users' information, and uses a database to manage a large volume and complexity vital data. This is good for observation to an illness, especially some chronic diseases or cancers. In another hand, when user's vital information is anomaly, the doctor will receive the cell phone message from the user's smartphone to know GPS location and physical condition of the user. This is good for treatment to a sudden illness, such as cardiovascular and cerebrovascular diseases.

III. THE IMPLEMENTATION ISSUES AND LABORATORY TESTING

In this section, we describe the implementation issues of the proposed system in detail. The system consists of some wireless medical sensors, a wireless sink node, a Android development board, a personal computer(PC). The wireless medical sensors are small, lightweight, easy-to-use devices that are worn on the body to log physiologic data as well as wirelessly transmit data to the wireless sink node. The wireless sink node receives the data and then send it into the Android

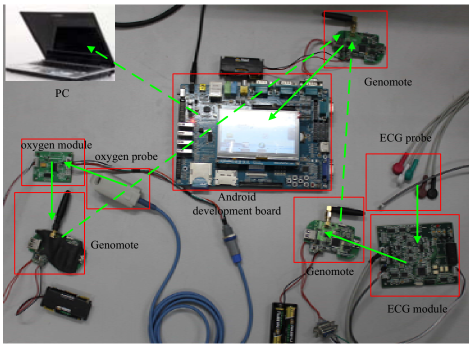

Fig. 2. The picture of the laboratory testing. Green lines indicate the flow direction of the data, thereamong solid lines represent wired transmission, dotted lines represent wireless transmission.

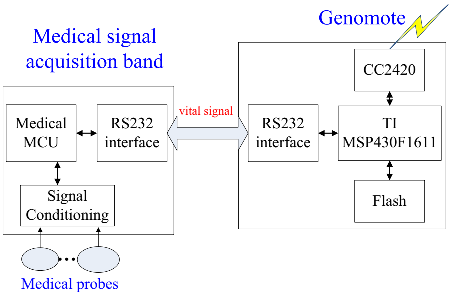

Fig. 4. The block diagram of the wireless medical sensors

development board. The Android development board displays the vital information on its LCD and transmits the data to the personal computer. The whole real system is showed in Fig.2, and the program flow diagram is showed in Fig.3.

A. The sensor network tier

As section I refers, the system is "distributed", so there are some kinds of the wireless medical sensors in the sensor network tier. The difference of the different kinds of wireless medical sensors is that they contain different kinds of bio-medical modules, such as a ECG module or a blood oxygen module, while the same point is that they all have Genomote nodes [9] to process and wirelessly transmit the vital data. We purchase some different functional medical modules from the Shanghai Berry Electronic Tech Co., Ltd to form the wireless medical sensors. For example, the ECG module could obtain a seven-channel ECG, a one-channel respiration and a two-channel body temperature, and the blood oxygen module could obtain blood oxygen content and pulse rate. The Genomote has a MSP430 microcontroller, a CC2420 radio, a 1MB of flash memory, and a temperature/humidity sensor (SHT11). It also has a RS232 port to connect the peripheral devices, and the bio-medical module communicates with the Genomote through it. Besides, the Genomote also acts as the wireless sink node and uses the RS232 port to connect with the Android development board. The block diagram of the wireless medical sensors is showed in Fig.4.

We develop a program on the Genomote in TinyOS platform

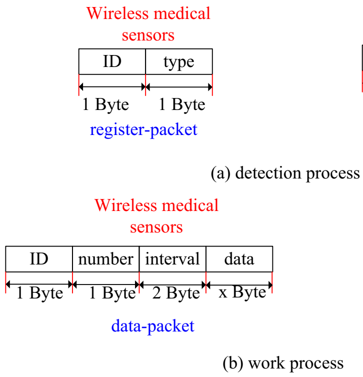

Fig. 6. The packet protocols of the sensor network tier.(a) in the detection process, (b) in the work process.

to receive the vital data through the serial from the medical module and wirelessly transmit to the wireless sink node, and the wireless sink node also has a program to relay packets to the Android development board. Besides, a custom, application-specific MAC protocol is designed and applied into the sensor network tier. The protocol is aimed to increase the energy efficiency and reduce the loss of packets and the signal interaction since several sensors transmit their messages at the same time slot and compete for the common channel.

The proposed MAC protocol for the data transmission are based on two process in the Fig.5. The first is the detection process. In the detection process, the wireless medical sensors broadcast register-packet containing their IDs and data-type identifiers(such as ECG, temperature or pulse rate), and the sink node computes and arranges the time slots of the work process to different wireless medical sensors based on the number and the kind of the wireless medical sensors. Then it will send the slot-packet to inform the wireless medical sensors how long they work. The second process is the work process. In this process, when there is no alarm situation, the sink node periodically sends control-packets with the certain ID to aware the wireless medical sensor to detect some kind of vital signal, and the wireless medical sensor continuously works for a slot time and sends data-packet with the vital information. The data-packet also has "number" to count packet number which the sensor has transmitted, and "interval" to represent wireless transmission frequency of the medical sensor. In the last several bytes of the packet, the length of useful medical information isn't fixed since different kinds of medical sensors have different amounts of the vital signals.When the sink node receives the command from the mobile computing network tier, it will change the slot arrangement. The packet protocols are showed in the Fig.6.

B. The mobile computing network tier

In the mobile computing network tier, the Android development board replaces the smartphone as the laboratory simulation platform. It has a Samsung's S5PC100 processor (ARM Cortex A8 Kernel), a 256M bytes DDR memory, a 256M bytes Nand Flash and a 2M bytes Nor Flash. It also

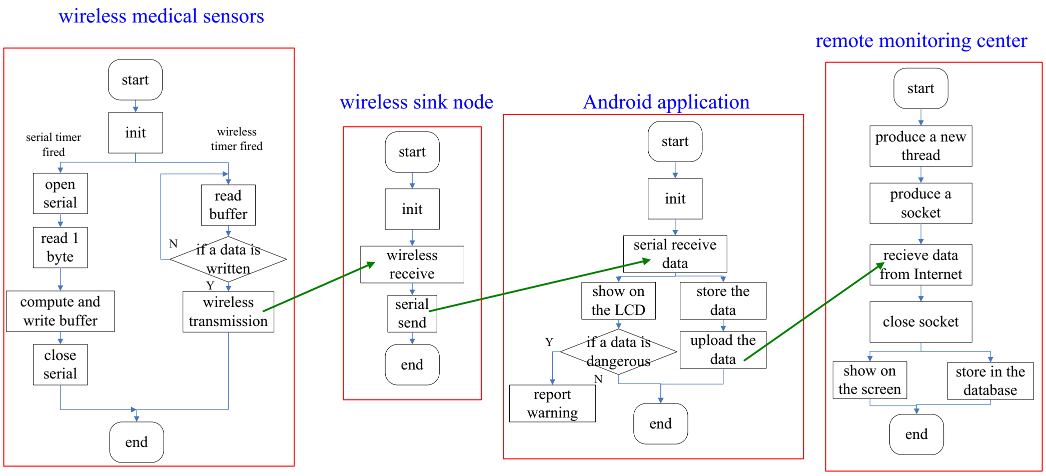

Fig. 3. The program flow diagram of the proposed system. Green lines indicate the flow direction of the data.

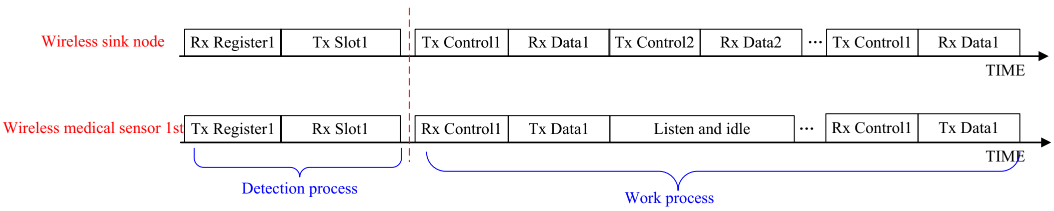

Fig. 5. The MAC protocol

equips some kinds of common device interfaces such as USB, UART, SD and etc. We connect it with the wireless sink node through a RS232 port to make it expand a ZigBee ”interface”, so it can communicate with the wireless medical sensors. Besides, the Android 2.1 operating system is installed on the development board.

We develop an Android terminal application on it as a access point of both terminal user and WAN. The Android application mainly contains two sorts of functions: ”activity” and ”service”. The ”activity” manages current screen of the PDA, and the ”service” manages background process. They connect with each other by ”intent” interface. The application can receive the packet from the serial, and then translate and display the real-time vital information in the digital and graph curve demonstration on the LCD of the development board. It can also store the history vital data in the Flash and the SD Card to make the terminal user check his health status of nowadays and old days conveniently. When the user’s vital information is anomaly, the demonstration interface will alarm the user by changing the font color and producing a buzz. Meanwhile, it will send an alarm packet through the local area network to the remote monitoring center. Even the user’s signal is normal, in a specific interval, it will also upload data to the remote monitoring center. Note that the local area network here is to simulate the GPRS network of the smartphone. The signal stream among the components of the application is demonstrated in the Fig.7, and the Fig.8 shows blood oxygen interface of the Android application in a real human test.

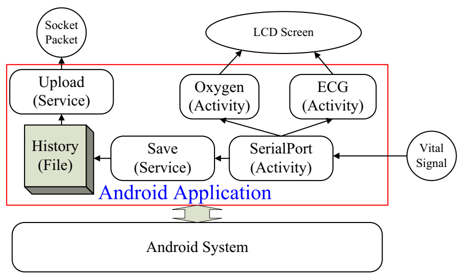

Fig. 7. The signal stream among the components of the Android application

Fig. 8. The blood oxygen curve on the Android development board

C. The remote monitoring network tier

In the remote monitoring network tier, a monitoring application is designed and run on the PC (the remote monitoring center) to receive the data from the Ethernet Port in Fig.9.

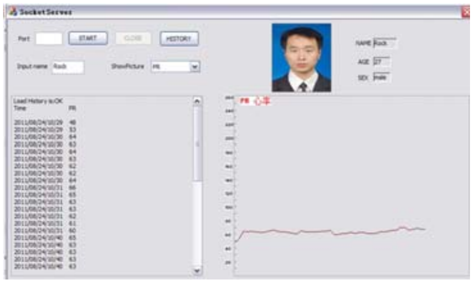

Fig. 9. The robot human-machine interaction interface on the PC

It classifies and stores the users' information, and uses a SQL database to manage a large volume and complexity vital data. The doctors can search and observe a person's personal information and the changes of the vital information in the old days, and send some diagnose and alarm messages to the users to prevent the danger from happening.

IV. CONCLUSION AND FUTURE WORKS

In this paper,we present a distributed wireless body area network for medical supervision. The sensor network tier consists of wireless medical sensors and wireless sink node,and wireless medical sensors are responsible to gather patient's bio-information; the mobile computing network tier consists of a smartphone (a Android development board in the laboratory testing) and is responsible to relay data transmission and demonstrate the vital data; the remote monitoring network tier consists of a database and a robot human-machine interaction interface and is responsible to aggregate and analyze the bio-information, and provides medical service management and disease warning. In addition, the design approaches and real implementation of the proposed system are introduced.

There are still some challenging issues we have to investigate for our prototype system to form a real medical supervision system. One important issue is to make the system more comfortable and easily portable, and the Android application must be implanted into the smartphone to carry out the actually test. Another important issue is optimization of network schedule mechanism for compounding medical data transmission. There are various data transmitted in our system, and these data varies in size, transmission time, priority, and signal property, while some complex signals have to be compressed before transmitting in the sensor network tier.

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