A MultiTiers Service Architecture based Diabetes Monitoring for Elderly Care in Hospital

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Abstract

With the increasing number of diabetes patients, the cost for monitoring the patients is generating a great financial burden. In this paper, we present a three-tier network architecture which facilitates healthcare monitoring for the diabetes patients automatically. We also proposed two flowcharts for our packet transmit based connection (PTC) method and received signal strength based reconnection deliver (RSSRD) method. Once powered-up the coordinator of the wireless body area network will use PTC method to connect the base station immediately. On the other hand, the RSSRD method provides an effective way to enable sustaining monitoring for diabetes patients.

Keywords: *healthcare, wireless body area network, wireless communication method, network lifetime*

1. Introduction

Body area networks (BANs), wireless body area networks (WBANs) or wireless body area sensor networks (WBASNs) are terms used to represent the application of wearable monitoring devices. The rapid growth in sensors, Micro-Electro-Mechanical-Systems (MEMS), low power integrated circuits and wireless communications made this new generation of wireless sensor networks possible [1, 2]. The wireless body sensor networks are an interdisciplinary area which could allow inexpensive and continuous healthcare monitoring with real-time updates of body signs via Internet. This area depends on the feasibility of implanting tiny bio-sensors into the human body which are comfortable and have no injections of daily activities [3]. As a subcategory of the wireless sensor networks (WSNs), WBANs have their own characteristics in architecture, density, data rate, latency and mobility [4].

Reference [5] reveals that most researches in these WBANs area target problems at the physical and medium access control (MAC) layers which are usually related with IEEE 802.15.4 radio technology. The point is on very low cost communication of nearby devices with little to no underlying infrastructure. The physical layer is responsible for frequency selection, carrier frequency generation, signal detection, modulation and data encryption [1]. The ZigBee standard allows operating in the frequency range belonging to the radio band known as industrial, scientific, and medical (ISM). It operates on one of three possible unlicensed frequency bands: (1) 868.0-868.6 MHz: Europe, allows one communication channel, (2) 902-928 MHz: North America, up to ten channels, extended to thirty, (3) 2400-2483.5 MHz: worldwide use, up to sixteen channels. The MAC method in a wireless multihop self-organizing sensor network is needed to achieve two goals, (1) creation of the network infrastructure, (2) fairly and efficiently share communication resources between sensor nodes [1]. In WBANs, besides regular MAC layer challenges of WSN like present above, there are still challenges that are specific to healthcare monitoring applications, such as Quality of Service (QoS) requirements of emergency traffic are needed to be studied [3].

Nowadays, making the patients themselves aware of their medical situation is increasingly important in healthcare. Thus, it is necessary to place the patients at the center of their care and empower them to do self-examinations, even self-treatments [8, 9]. Cares focused on patients create a new requirement for representing their needs. The use of an explicit representation can allow the patients to formulate their own care plans, e.g., the patients can easily specify their medication-taking patterns using a software tool, SMS text message, or smart physical cards [10, 11]. Although a lot of research works have been dedicated to the development of WBAN, most of these programs do not consider the end-to-end solutions, and the system will face challenges in the actual deployment. These challenges include the ability to extract information from WBANs and the ability for residents or caregivers to set requirements which can drive the operation of the sensors [18].

The growing cost of the healthcare and the aging population in developed and developing countries have introduced amount of challenges for governments, industry and healthcare giver [3]. Diabetes is considered a global epidemic as more than 246 million people worldwide are affected by it. It is expected that the number will hit 380 million by the year 2025. Diabetes, if not treated properly, may result in serious complications such as heart disease, stroke, kidney disease, blindness, foot problems or skin problems. Diabetes and its complications also incur an enormous amount of financial burden. A person with diabetes spends $1,000 to $15,000 each year on medications and supplies. By 2010, it is estimated that diabetes will cost the Canadian healthcare system $15.6 billion a year and that this number will rise to $19.2 billion by 2020 [7].

Some of the diabetes patients have suffered this illness for a long time and some of them are aged. In the advanced stage of diabetes, the symptoms can be dehydration, malnourished, diabeticretinopathy (DR), renal failure, stroke, heart attack and high blood pressure. The most important is that it can cause atherosclerosis (AS), which can be the precipitating factor of acute myocardial infarction (AMI). AMI results from the interruption of blood supply to a part of the heart, causing heart cells to die. It is deadly to the olds, once it happens, the old could be dead in less than three days or even faster. To reduce the high blood sugar, sometimes the resident will ask the patients to stay in the hospital for a longtime observation. During this hospital stay days, the residents need to monitor the patient’s body vital signs. Due to the large amount of patients and the lack of caregivers, we develop this three-tier architecture including sensing tier, network architecture tier and a cloud base tier to sensing, processing and delivering data that around and inside the patients’ body. We sum up our contributions as follows: (1) we proposed a three-tier system architecture to detect and gather the patient’s body signs, and update them through Internet to the service for residents, caregivers and the patients themselves, (2) we detailed discussed the personal area network which lies in Tier 1, (3) we proposed a PTC method to connect the WBAN with the base station (BS), and a RSS based method which is called RSSRD that can be used to re-contact the WBAN with the BS when the signal of WBAN coordinator falls below a set-up threshold, (4) we discussed the network topology of the WBAN in Tier 1.

Organization of the paper: The main content of this paper is constructed in 6 sections as follows: Section 2 gives the system architecture and design considerations. Section 3 describes the WBAN coordinator connection method designation. Section 4 describes our body area network combination. Section 5 discusses the WBAN topology. Section 6 concludes our work and future work.

2. System Architecture and Design Considerations

In the following section, we will describe the detail of our proposed system architecture, along with the important design considerations about the IEEE 802.15.4 wireless communications standard. At the first beginning, we assume that our proposed architecture oriented to a hospital environment, where there are needs for health monitoring system for multiple patients. Each of the patients wears couples of sensors which connected as a WBAN.

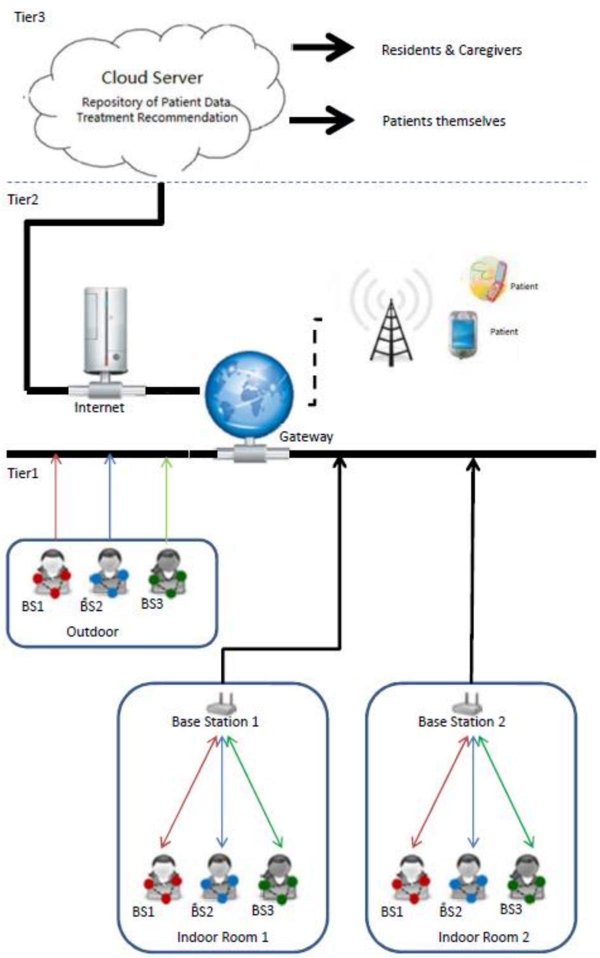

Figure 1. Our proposed three-tier system architecture

To develop a reliable and energy saving system architecture, applications based on WBANs must overcome numbers of difficulties. The common WBANs systems usually suffer from a short board effect, which is the sensors' battery limitation and the topology changes due to the daily activities like walking and running. The nodes in the networks can be defined to two types. The first one is the full-function device (FFD). They can serve as common sensor nodes as well as coordinators of a personal area network (PAN). They implement a general model of communication which allows them to talk to any other devices. The FFD can also relay messages, in which case it is considered as a coordinator (PAN coordinator when it is in charge of the whole network). The other is the reduced-function device (RFD). It is meant to be extremely simple devices with very modest resource and communication requirements. Due to this design motivation, the RFDs can only communicate with FFDs and can never act as coordinators. The WBAN coordinator device is meant to put individual sensors into a pre-managed architecture in order to gather and deliver vital signs of the patient body to the BS which is currently associated [12].

As illustrated in Figure 1, we point that our proposed system architecture to be three-tiers. In fact, the Tier 1 and Tier 2 have been previously put forward by other researchers in this sensor area. It was described in [13], that an ambient intelligence system which implements a service-oriented architecture based platform. It allows heterogeneous wireless sensor networks to communicate in a distributed way independent of time and location restrictions. The system has a two-tier communication and infrastructure schema of telemonitoring. A network of ZigBee devices has been designed to cover the home of each patient to be monitored. In [14], it was described that electronic information and communication technology based telehealth system, which was meant to deliver health and medical information and services over large and small distances. In addition it proposed a network of low-cost sensors and wireless systems help in creating constantly vigilant and pervasive monitoring capability at home and work.

As proposed previously, the worldwide used unlicensed frequency bands have sixteen channels. Our contribution about the interconnection system is to promote a multichannel method that every single WBAN is assigned a unique frequency. In Tier 1, our contribution here is that we divide the basic tier into two parts, indoor part and the outdoor part. For the outdoor part, the sensors make directly contact with the BS which is placed on the patient pocket or wrist. Thus, the BS will deliver the data to the gateway to be transmitted it to the Internet with a unique identity (ID). On the other hand, when we take the indoor scenario into consideration, each coordinator has an assigned operating frequency that response to the channel allocation scheme managed by the respective BS in range. Due to the wireless signal's exhaustion and reflection of the reinforced concrete wall, the wireless signals in each room cannot influence the others in the adjacent room. We can set BS1 in room 1 to the same frequency of BS1 which is in the room 2. If the patient is in the room, then we take the indoor scenario into consideration, close the on-body BS, making the coordinator update its data directly to the public BS. To identify whether the patient is indoor or outdoor, we can put two radio frequency identification device (RFID) tags on the room's door and one RFID recognizer on the patient body. Distinguishing whether the patient is going in the room or not, we can divide the RFID tags into two kinds, inside one and the outside one. If the recognizer first recognize the inside one following by the outside one, then we can figure the patient is going out the room, and if on the opposite is going in the room.

In Tier 2, we divided the wireless communication into two parts: (1) contact the Internet through PC or wired devices, (2) contact the wireless network through PDA or smart phone. Via the wireless network, the patients can download or monitor the raw data collected by the sensors in, on or around their bodies. To keep the data privacy, the user might need to input their username and password which only corresponding to the raw data of their own. If the smart phone is powerful enough, they can do the calculation on it themselves. On the other hand, the raw data is transmitted to the cloud server through the Internet to update the data base and waiting for a further analysis

In Tier 3, the raw data collected in Tier 1 by the sensors attached on the patient is analyzed in real-time and more deeply to aware the resident or the caregivers of the patients' condition. The vital signs of the patients include blood pressure, electrocardiography (ECG), acceleration, blood oxygen level and the temperature or the humidity around the body. As shown in Fig. 1, all the data collected from the patients which living in the same hospital will be uploaded to the cloud server for the residents to have an entirely awareness of the patients' condition. In summary, our proposed Tier 3 architecture can provide real-time and accurate monitoring for the patient living in the hospital based on cloud computing.

3. WBAN Coordinator Connection Method Design

In this part, we will discuss our proposed connection method which implements a two-way method for a BS to link up with a WBAN coordinator device, and an optimized solution while the coordinator is in a low-energy or low RSS condition. Any full-function device (FFD) in the network can play the role of a WBAN coordinator device. At the beginning part to the PTC procedure, a preliminary channel scanning process is carried out by a WBAN coordinator to discover the nearby BSs. Due to the multichannel operation method proposed previously and the goal to minimize the multichannel interference from other BSs in the adjacent rooms, BSs are assigned distinct operating frequency depending on their actual locations.

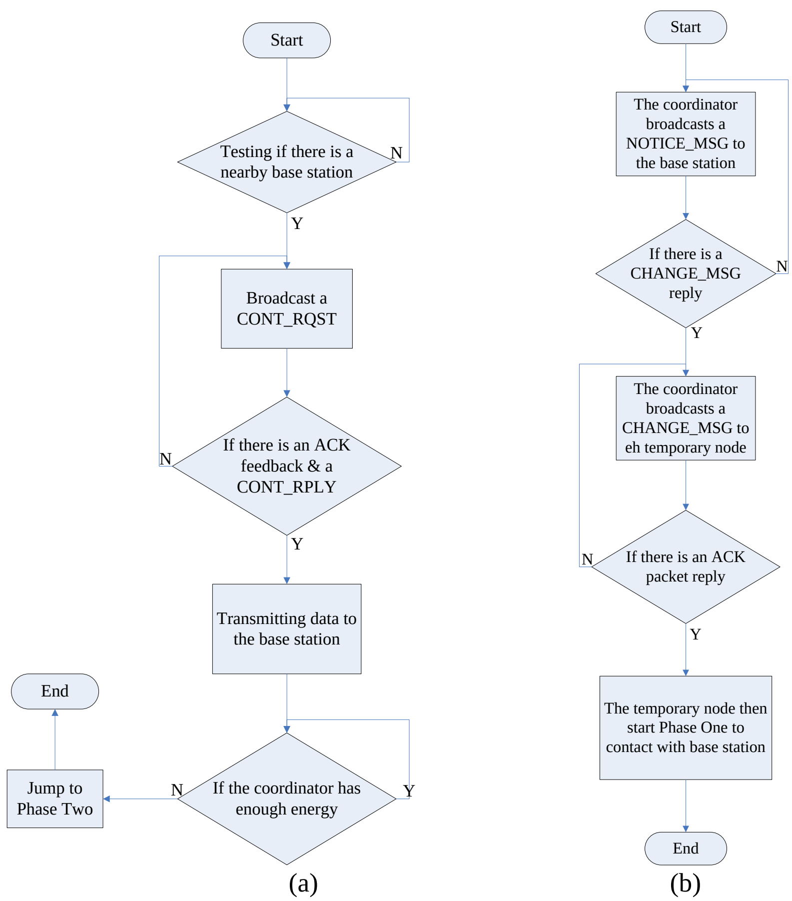

Figure 2. (a)The flowchart for our proposed PTC method, (b) flowchart for our given RSSRD method

Once powered up, all system devices are predetermined having a feedback of any packets type immediately. After receiving the acknowledgement (ACK) packet, the coordinator is required to have the acknowledgement of the received signal strength indicator (RSSI) value by the just arrived ACK packet and the ID of the associated BS. These two values are stored temporary in the register, waiting for the next BS scanning procedure. If the coordinator fails to get an ACK packet from any BS, it will trigger a timeout event method which is meant to scanning the neighbor environment for BS, again. In the following scanning, the system will compare the original RSSI value with the latest one, if the original data is lower and it will be replaced by the newest value along with the ID of the BS. So only the best BS's RSSI value is maintained in the register.

Once the scanning stage finished, the coordinator is asked to start the connection procedure with the BS which has the highest RSSI value. The procedure starts with the coordinator retuning its radio frequency into the chosen channel which is used by the previously selected BS. Thus, the coordinator will broadcast a connection request (CONT_RQST) packet to the BS. As discussed previously, the BS would then response with a corresponding ACK packet, automatically. Shortly after the ACK packet, the BS will then broadcast a connection reply (CONT_RPLY) packet which contains the information of collected data and some other vital signs. Due to the corresponding IEEE specification does not make any provision for the user-defined information. At last, after the ACK packet of the CONT_RPLY is received, the coordinator reaches the associated state. The coordinator will then broadcast messages to the BS periodically.

On the other hand, transmitting data to the BS will cost a lot of energy of the WBAN coordinator. Figure 3 is the power consumption of a working sensor node which was brought out in an invited lecture in the ACM MobiCom 2002, the Eighth Annual International Conference on Mobile Computing and Networking, by Deborah Estrin. The coordinator may not have the ability for a long real-time transmitting. Thus, we bring in a temporary node in case the original coordinator turns in only sensing mode, which was named RSSRD method. Once the coordinator is in a low-power scenario, it will broadcast a notice message (NOTICE_MSG) to the BS immediately. The BS will then send a change message (CHANGE_MSG) packet back to the coordinator, and an automatically response an ACK packet will be received by the BS. Soon after broadcasting the ACK packet, the coordinator will then send a CHANGE_MSG packet to the temporary node. Once received this CHANGE_MSG packet, the temporary node will then automatically response an ACK packet to the original coordinator, following which a testing message (TEST_MSG) is ought to be sent to the BS. After the temporary node receives an ACK packet from the BS, it will start the connection procedure with the BS to replace the role of the original coordinator. The flowcharts of these two methods are shown in Figure 2.

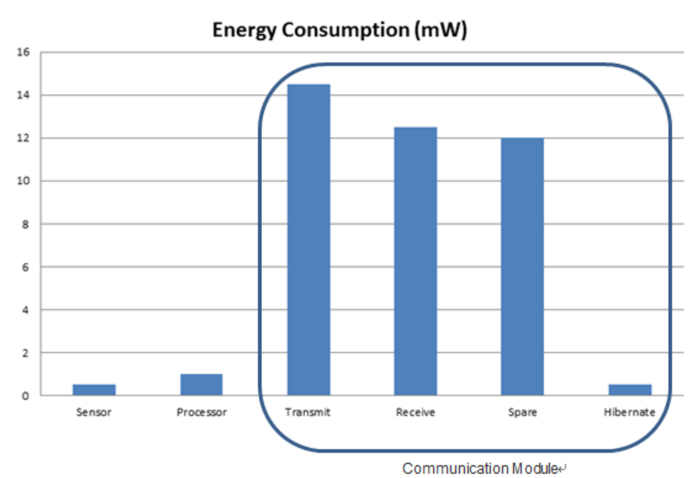

Figure 3. Energy Consumption for a Working Sensor Node

4. Body Area Sensor Network

As Figure 4 proposed, each BS represents a body area network, which contains several sensors gathering context information in an automatic and ubiquitous way. We divide the sensors into three categories, namely “Around-body” sensors, “On-body” sensors and “In-body” sensors. Around-body sensors refer to the sensors that are place in the room or the facilities around our daily life, such as the infrared sensor and the pressure sensors implemented in the olds home for fall detection. On body sensors refer to the sensors that are strategically attached on the skin, while in-body sensors refer to implanted sensors. In-body sensors usually require a unique antenna design, because of the user’s posture, weight loss and gain, and even his or her aging skin. In addition, antenna design should consider the intrinsic on-body environment, restrictions on size, shape and material.

Wireless body area network is constituted by lots of sensors which are placed on the surface of the body or implanted under the skin, as previously talked about. Thus, sensors can be self-organized to transmit data to the Internet, which cover the information from vital signs of human body to the condition of the circumstance surroundings of the patient. So far, these kinds of sensor networks have taken great progress in the biomedicine domain.

As introduced above, in the advanced stage of diabetes, arteriosclerosis, high blood pressure and hypopsia may occurred in the patient body. Due to the arteriosclerosis, there can be myocardial infarction, acro-agnosis which may lead to a quick dying and a surgery of amputation. Here we propose a system to monitor the condition of a diabetes patient. The WBAN contains lots of sensors including accelerometer/gyroscope sensors, blood glucose, blood pressure sensors, ECG sensors, pulse oximetry sensors, humidity and temperature sensors.

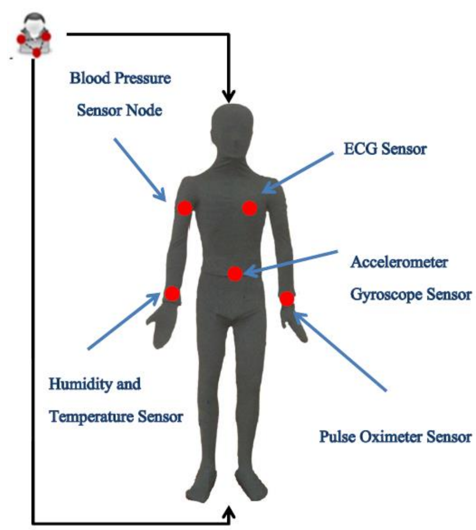

Figure 4. Sensors included of each WBAN group

The functions of the sensors described above are as follows:

- Accelerometer/Gyroscope: An accelerometer is a device that measures proper acceleration, which is the acceleration it experiences relative to free-fall and is the acceleration felt by people and objects. The accelerometer sensor used for WBANs usually consists of a tri-axial accelerometer. They can measure the g-force changing velocity, to test if there is a fall happened. We here provide a MEMS gyroscope, which takes the idea of Foucault pendulum and use a vibrating element.

- Blood glucose: The blood sugar concentration or so called blood glucose level is the amount that sugar contained in a human body. The body naturally regulates blood glucose levels tightly as a part of metabolic equilibrium. Traditionally, glucose measurements are done by pricking a finger and extracting a drop of blood, which is applied to a test strip which composed of chemicals sensitive to the glucose in the blood sample [5].
- ECG sensor: Electrocardiography is a transthoracic (across the thorax or chest) interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the outer surface of the skin and recorded by a device external to the body [15]. In order to obtain an ECG signal, several electrodes are attached at specific sites on the skin (*e.g.*, arms, and chest), and the potential differences between these electrodes are measured [5].
- Pulse oximetry sensor: Pulse oximetry determines the arterial oxygen saturation (SO_2) and heart rate (HR) by a combination of optical plethysmography and spectrophotometry [16]. The sensor is placed in the patient's body, usually the fingertip or the thin part of the earlobe. A blood-oxygen monitor displays the percentage of arterial hemoglobin in the oxyhemoglobin configuration. Acceptable normal ranges for patients with chronic obstructive pulmonary disease hypoxic drive problem are from 95 to 99 percent, those with a hypoxic drive problem would expect values to be between 88 to 94 percent and values of 100 percent can indicate carbon monoxide poisoning [17].
- Humidity and temperature sensors: Humidity refers to the amount of water vapor in the air. Higher humidity reduces the effectiveness of sweating to cool the body by reducing the rate of evaporation of moisture to the skin. The physical characteristic of temperature refers to the concept of cold and hot. The rate of chemical reactions also refers to the surrounding temperature. Thus, we need these sensors to monitor the changes of humidity and temperature in real-time.

5. WBAN Topology Models

The inside section of a WBAN can be divided into three parts: sensor nodes, sink nodes and portable mobile devices. The sensors attached the body can be self-organized into a network which center is the sink node. Every sensor of the network can play the role of sensing, processing and transmitting kinds of vital signals. From the sight of network function, that each sensor have the ability to be a master or a slave. Once powered up, every sensor node need to gather and fuse the vital data of the patient, and some of them are designed for storing and transmitting.

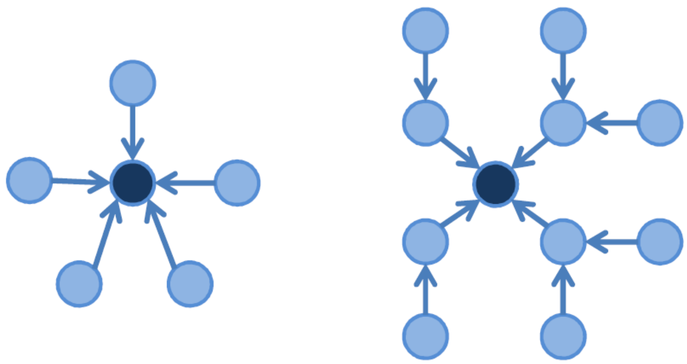

Figure 5. The Topology of Star and Multihop Tree Network

The network topology of the WBAN is commonly divided into two kinds, as shown in Figure 5, one is star networks and the other is multihop tree topology networks. In each network topology the sensor lays in the middle of the frame means the sink and others mean the traditional sensor nodes. A star network consists of one central switch, hub or computer, which acts as a conduit to transmit messages. In the star networks, to reduces the chance of network failure, it connecting all of the systems to a central node. This kind of topology is simple and having a low algorithm complexity and it is easier to be maintained. To the multihop tree topology, the sensors can act as a terminal to sense and process data as well as a router for transmitting. The sensors which are away from the sink node can deliver their data through other sensors to the sink. This topology has the advantage of scalability and easier fault identification and isolation, due to its multilevel network. The comparison of these two topologies is discussed as follows:

- Power consumption: As for sensors next to the sink, in star networks it only need a low energy to meet the information accuracy, as in multihop tree topology it could cost much more energy to transmit the data from other sensor nodes. For the sensors away from the sink, the sensors in the multihop tree topology only require a low energy to transmit the data to its nearest master node, as the sensors in the star topology is required a high energy consumption to transmit the data for a long distance.
- Propagation delay: The data in the star topology only require one hop to be transmitted to the sink, while the multihop tree topology requires a multihop routing. It is obviously that the propagation delay in the star topology network is lower than that in the multihop tree topology network.
- Anti-interference: The sensors in the star network which is far from the sink, need a high transmit power. It obviously has a comparatively higher influence on the other sensor nodes. As to the multihop tree network wherever the sensor is, it only need to transmit the data to its nearest master node which requires a very low transmit power.

As conclude above we proposed that, (1) if the patient is in the room, sensors will self-organized into star topology, due to the sensor nodes are all closed to each other, (2) while the patient is stepping out of the room, the topology will soon change to multihop tree topology, due to the complicated outside scenario.

The lifetime of the network depends on two sides, the lifetime of every single node and the balance of the network's energy consumption. In these two sides, the latter one is more decisive. The lifetime of a single node is depended on the initial energy and the unit energy consumption. On the other hand, the balance of the whole network is mainly about balancing the data traffic between every sensor nodes. Thus, to have balanced data traffic in the network is decisive in the goal of prolonging its lifetime. On the other word, the lifetime of the network depends on the distribution of the residual energy, the waiting collected data and the communication cost. It also depends on how we can distribute the data traffic to any sensor nodes and any data link. We can conclude from the multihop tree topology in the right part of Figure 5, the sensors nearby the sink would have a relative short lifetime than the sensors which are away from the sink. This can remarkable reduce the lifetime of the whole network.

6. Conclusions and Future Work

We proposed a three-tier network architecture that facilitates healthcare monitoring for the diabetes patients which are hospitalized. After the data has been sensed and processed, it will be uploaded to the cloud service for the residents and patients themselves to download and monitor. We divided the basic tier of the system network into two scenarios. Each of them has a unique way to organize the connection method. Additionally, we discussed a novel to pass on the function of the coordinator to a temporary node while the original coordinator is in a low power condition or has a communication problem. On the other hand, the temporary node in the body area network can be used to transmit the data traffic to prolong the lifetime of the bottleneck in order to prolong the lifetime of the whole network.

Our future work could be extended to monitor more patients together. Such as build a robust system architecture and communication method in a community even in the whole city. And we figured that to have a more deeply understanding of the characteristic of our daily life movements, is more useful to give out a model which is more appropriate to our real world. On the other hand, we are going to find a more energy efficient method to prolong the lifetime of the whole network, as we figured that the sensors near the sink will die much faster.

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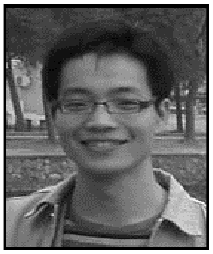

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