A Review of Three-Layer Wireless Body Sensor Network Systems in Healthcare for Continuous Monitoring

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***Abstract*- Using wireless body sensor network system (WBSN) based on information and communication technologies (ICTs) to monitor the health status of the elderly gradually becomes popular in the scope of telemedicine. eHealth services based on such technologies can offer healthcare to elderly and chronically ill in and outside their homes, enabling an independent life even under difficult health conditions. In this review we study 35 out of 129 articles published in 2006-2012, focusing on health monitoring using wireless technologies and three-layer architecture for the elderly. The main trends, standards, protocols and communication technologies are examined and discussed in details. Potential challenges are pointed out for the further development of WBSN monitoring systems. From the result of this review, wearable sensors for multi-parameter measurements, handheld devices and Bluetooh/Zigbee are the most popular components when the system designers construct remote monitoring systems.**

Keywords- Wireless Communication; Sensor Networks; Telemonitoring; Healthcare; Sensors; Elderly; WBSN

I. INTRODUCTION

Ageing society is a global phenomenon. It leads to increasing healthcare cost, as care for the elderly is usually much more expensive than for the other age groups [1, 2, 3]. Moreover, the growing number of elderly with chronic diseases who require long-term continuous healthcare services imposes heavy pressure on public healthcare expenditure [4, 5, 6].

Novel technological solutions are required to enable prolonged independent living of elderly, through continuous health monitoring and reduction of hospitalization. Home monitoring using ICT-based systems has been proved to be able to highly reduce the healthcare cost while saving time for both doctors and patients [7, 17, 18].

Wireless Sensor Network (WSN) is an emerging technology area of utilizing wireless sensors to build a complete ICT-based wearable health monitoring system. The WSN has been widely used nowadays in industry and also in civil living like home automations, process monitoring and healthcare applications, although it was first motivated by the military applications. Spatially distributed sensors, each equipped with a radio transceiver or other wireless communication devices, cooperate with each other to form a wireless ad-hoc network, in order to monitor physiological or environmental conditions, such as heart rate, physical activity, temperature etc.. Each sensor inside the WSN scope functions as a forwarder to relay data packets to the base station, which is usually supported by a multi-hop routing algorithm.

However WSN was not specially designed for monitoring human body as the human body is a smaller scale environment which requires appreciation of a slightly different set of challenges. The unsuitable WSN design for monitoring human body and its internal environment has directly triggered the development of wireless body sensor network (WBSN) with locally computational intelligence, which could provide pervasive monitoring environment while at the same time guaranteeing the mobility of monitored patients [8]. WBSN comprises a series of miniaturized wearable or implantable sensors which accurately capture physiological data from patients and transmit all the data, either raw or low-level processed, wirelessly to a local mini-processor unit (or known as a base station) for further processing. After all required data are collected in this way they would be transmitted to a remote central server via wireless LAN, Bluetooth or GPRS/GSM networks [9].

Fig. 1 Three layer hierarchical network architecture of wireless body sensor network

A typical architecture of WBSN prototype is of three

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layers which includes the interactions among sensors, the base station and the remote server. Figure 1 depicts the typical architecture of three layers in healthcare systems. However, other types of WBSN architecture still exist. Based on the purpose of the project, system designers usually adapt the three layers into other alternatives. Sometimes when it is not necessary to conduct telemonitoring in real time, the data streams are stored in the base station instead of being forwarded to reduce the cost [33]. However sometimes the patient is limited in a small living area like in the hospital, in that case the base station does not really help so that it is excluded from the architecture, for instance a patient with holter ECG. Besides, there is multi-layer architecture proposed in France which takes use of both home PC and PDA as base station to fit various scenarios [19].

The aim of this review paper is to investigate recent trends in the domain of telemonitroing which realize remote healthcare monitoring through the current development of information and communication technologies (ICT). As telemonitoring is able to highly reduce public healthcare cost, WSN and BSN become popular research topics and quite a lot of promising prototypes and products have come into reality. Studies and validation of those products are following closely in academic literature. In this review, we will illustrate a general overview of what is going on so far in the scope of WBSN monitoring systems, especially focusing on the excellent examples of WBSN platforms using 3-layer hierarchy. Here we focus on 3-layer hierarchy because this architecture is a complete model on which other variants are based. Therefore, it is possible to learn more from different technologies used in the 3-layer WBSN systems compared to 2-layer systems. Overall this approach should well reflect the current state of the art in this field.

The rest of this paper is organized as follows: Section 2 describes the elaborative literature search conducted through suitable databases, followed by an analysis of publications meeting our selection criteria in Section 3. Here the main trends of each component of WBSN including sensors, base stations and central server, as well as the novel WBSN systems have been examined in details. Section 4 discusses the techniques, protocols, communication standards and points out the potentials and challenges of WBSN in future. Section 5 concludes the worth of applying 3-layer architecture in WBSN systems.

II. METHODOLOGY

As WBSN systems have been explored for decades, there are plenty of publications available discussing WBSN platforms. The publications in this field may be exploding especially for recent years. After exploring some other databases e.g. the ACM Digital Library and conducting searches respectively, we found the relevance of the indexed papers was higher in IEEE Xplore Digital Library than others. Therefore we think IEEE database is the most appropriate database for the technology-oriented topics we are working on. To select typical systems and meanwhile limit the number of the selected publications in a reasonable range, the literature review mainly aimed at IEEE publications.

Literature was searched in IEEE Xplore Digital Library [44] using the search term ((Wireless Sensor Network*) AND (health*) AND (*monitoring) AND (elderly)). The search was limited to the last six years, namely between 2006 and 2012. Last update was on April 22, 2013.

For selection of relevant articles from the search results, we applied the following inclusion criteria when going through the abstracts and full texts of the articles we found: (1) focus on the elderly health monitoring, for chronic diseases, rehabilitation, etc; (2) use of the wireless communication technologies and wearable sensors; (3) a complete 3-layer architecture for the sensor network, which offers a basis for other solutions with fewer layers. We excluded (1) articles addressing mainly ambient sensing and implantable sensors (beyond the scope of this review); (2) articles concentrating on directly wireless communication between sensor nodes and the servers, and (3) publications not written in English or not full papers.

III. RESULTS

IEEE Xplore returned a search result of 129 articles. Of these results, 35 articles fulfilled our selection criteria. We summarize the key information of these 35 studies in Table 2.

A. *General Global Trends*

The outcomes of scientific literature on healthcare remote monitoring systems in the past five years were carefully examined. Table 1 shows that among 35 articles from worldwide research institutes, nearly 25% of the studies were conducted in Europe. Asian countries contributed 43% of the publications and the remaining 32% came from other parts of the world, including Australia and North America. To our surprise, Asian countries, represented by the studies from China and South Korea, played the same important role as US and Europe did in the global development of healthcare monitoring systems. Those far-eastern developing countries now seem to suffer from the same ageing problem as Europe, and what makes things worse is that the large population and low income there directly burden the less sophisticated public healthcare services. Thus it is quite reasonable for Asian research institutes to find out some fast and cheaper solutions to this problem urgently, which explains perfectly the reason why large amount of research work on WBSN monitoring systems has been done in Asia in such short period of time.

TABLE I COUNTRY WHERE THE FIRST AUTHOR'S INSTITUTE LOCATES

Country	# Articles	Country	# Articles	Country	# Articles
China / Taiwan	9	Germany	2	Spain	1
Australia	4	Canada	2	UK	1
US	4	France	1	Ireland	1
Korea	3	New Zealand	1	Romania	1
Singapore	3	Greece	1	Morocco	1

TABLE II INCLUDED STUDIES WITH KEY INFORMATION

Publication	Objective	Parameters & Devices	Comm. protocols	System validation
Lee, Lee, Chung, Myllyla [2006]	Healthcare monitoring for elderly, clinical and trauma patients, in hospital	ECG, BT, PDA	Ad hoc	Validated
Cabrera-Umpierrez, Fico,Arredondo, *et al.* [2006]	An architecture of a complete communication platform for biosensor-based applications in sleep disorders	PDA, PC	Zigbee, GPRS, Wi-Fi	Only framework, with QoS
Kumar, Rahman [2006]	A customizable wireless health recording and alert system for elderly	BT, SpO2, HR, Laptop	RF, GSM	Validated
Leijdekkers, Gay [2006]	A personalized heart monitoring system for high risk cardiac patients including rehabilitation programs	ECG, GPS, Smartphone	Bluetooth, Wi-Fi, GSM	N/A
Otto, Jovanov, Milenkovic [2006]	Continual health monitoring at home	ECG, PA, PDA, home PC	Zigbee, (W)LAN	Validated
Chung, Bhardwaj, Purwar, *et al.* [2007]	Monitoring the patients and the elderly, recording and analyzing the results	ECG, PA, PDA	Zigbee, WLAN	Validated
Whitchurch, Abraham, Varadan [2007]	Remote monitoring of the patients and elderly to reduce visit time of a medical facility	EEG,ECG, PA, Gyroscope, BT, Single board computer	Bluetooth, Ethernet	N/A
Saadaoui, Wolf [2007]	Healthcare monitoring for elderly, indoors & ourdoors	ECG, SpO2, PDA	Zigbee, WLAN, GPRS	Validated
Biswas, Jayachandran, Shue, *et al.* [2007]	An extensible framework for sleep activitity pattern monitoring	ECG, PDA, PC	Bluetooth, GPRS/3G, Wi-Fi	N/A
Triantafyllidis, Koukias, Chouvarda, Maglaveras [2008]	Reconfigurable health monitoring system with easy extension to additional sensors	HR, Blood glucose, PDA	Bluetooth, SDP,	N/A
Jang, Lee and Yoo [2008]	Portable monitoring system for emergency and chronic patients	ECG, SpO2, BT, PDA	RF, CDMA, WLAN	Validated
Li, Jiang, Li [2008]	Health monitoring for patients, everywhere	ECG, Carotid Dopplers, PDA, cellular phone	Ad hoc, WLAN	Only a framework
Pan, Li and Wu [2008]	A novel in-community healthcare monitoring system	ECG, PA, PDA	Zigbee, WLAN	N/A
An, Liu, Ma, *et al.* [2008]	Wireless multi-parameter monitoring with two loops of feedback for users, new design of sensor node	ECG, BT, BP	RFID, GPRS, Wi-Fi	N/A
Fischer, Lim, Lawrence, Ganguli [2008]	Remote healthcare monitoring with video streaming	HR, SpO2, Home PC,	CodeBlue, Internet	Validated
Attllah, Lo, Yang, Siegemund [2008]	Service-based architecture for elderly monitoring	PA, SpO2, HR	RFID, IEEE1451	N/A
Huang, Hsieh, Chao, Hung, Park [2009]	Health monitoring for elderly or chronic patients in their residence	ECG, PDA, laptop	Zigbee, GSM/GPRS	AES-based, secured
Dinh, Teng, Chen, *et al.* [2009]	Monitoring the PA of elderly with fall detection	PA, Gyroscope, HR	Zigbee, Internet	Validated
Sleman, Alafandi, Moeller [2009]	A wireless Fieldbus system integrated with existing wired system for elderly	Home PC	Zigbee, GSM, Ethernet	N/A
Navarro, Lawrence, Lim [2009]	Health monitoring for elderly and infirm	SpO2, laptop	Zigbee, GSM/GPRS, Wi-Fi,	Validated SNMP-based
Lawrence, Navarro, Hoang, Lim [2009]	A personal health monitoring system incorporated by SNMP and Codeblue	SpO2, PDA	Zigbee, SNMP, Wi-Fi, GSM/GPRS	N/A
Van de Ven, Bourke, Tavares, *et al.* [2009]	A wireless platform for health signs sensing, with the decision support capability to help diagnosis	PA, ECG, SpO2, BT, Mobile phone	Bluetooth, Internet	Validated
Shen, Hsiao, Liu, He [2009]	An ultra-wearable smart sensor system	ECG, PA, GPS, Mobile phone	Bluetooth, GPRS/GSM	Validated
Docksteader, Benlamri [2010]	Health status monitoring using mobile units for chronic illness	SpO2, GPS, mobile phone	Bluetooth, HTTP	Validated, Including modules of knowledge management and reasoning techniques
Wang,Peng,Wang, *et al.* [2010]	A resource-aware architecture for secure ECG data	ECG, mobile phone, PDA	GSM,WLAN, WiMAX	Validated, Supporting important information identification and resource reallocation

Yang,Su,Zhao, *et al.* [2010]	Measuring multi-parameter of the patients by using mobile phone	ECG, Blood glucose, BP,BT, Smartphone	Bluetooth, GPRS/CDMA	Validated
Campo, Bonhomme, Chan, Esteve [2010]	Monitoring the behavior of dependent elderly people in community, detecting risk situation	PA, local PC	RF, Internet	Validated
Biswas, Jayachandran, Kavitha, *et al.* [2010]	As part of the sleep monitoring project, monitoring the sleep-awake cycle of elderly by accelerometer	PA, PDA	Bluetooth, GPRS, Wi-Fi	Validated
Lv, Xia, Wu, Yao,Chen [2011]	Wellbeing monitoring of the elderly, offering living assistant functions	ECG, PA, BP, Smartphone	Bluetooth, GSM/GPRS	N/A
Rotariu, Costin, Andruseac, Ciobotariu, Adochiei [2011]	Long-term health monitoring as a part of diagnostic procedure	ECG, SpO2, BT, BP, PDA, Smartphone	Zigbee, GSM/GPRS, WLAN	N/A
Ambrose, Cardei, Cardei [2011]	Monitoring and tracking patients in nursing home under difficult conditions, e,g, hurricane	PA, GPS, Smartphone	Bluetooth, Wi-Fi, 3/4G cellular networks	N/A Robust for lack of cellular&Internet, scarce energy resources, etc.
Jiang, Lu, Huang, Tan [2011]	Low cost model of home healthcare system with emotion detection	HR, BT	Zigbee, 8051	Validated
Suryadevara, Quazi, Mukhopadhyay [2012]	Integration of WSN based systems for monitoring elderly health perception and daily activity behavior recognition	HR, BT, PC	Zigbee	Validated 20 subjects user trial
Wang, Wang, Shi [2012]	A distributed wireless body area network for medical supervision containing three layers	ECG, blood oxygen, BT, HR, Android Smartphone	Zigbee, GPRS	N/A
Boulmalf, Belgana, Sadiki, *et al* [2012]	A layered approach architecture for a lightweight portable middleware with the Android technology	PDA, mobile phone	GPRS	Only technically validated

PA=Physical Activity; HR=Heart Rate; BT=Body Temperature; BP=Blood Pressure

B. *Major Findings*

Among the 35 included studies all of which employ 3-layer hierarchy, 24 studies use mobile devices (PDAs or smartphones) as base stations (Table 2). As a relaying unit, the base station distinguishes monitoring locations if the patients staying at home or outside, and then executes different tasks correspondingly. The most important concern in task-shifting is to select the best routing path. Figure 2 shows a proposal of typical routing selection [7]. At the patient's home, the base station forwards data via home gateway through WLAN to remote server; however in the scenario of outdoor activities, the base station becomes less active and transmits data at a lower frequency via WWAN and GPRS. To realize long-distance wireless transmission, some nearby relay stations in the range of available wireless networks might be involved.

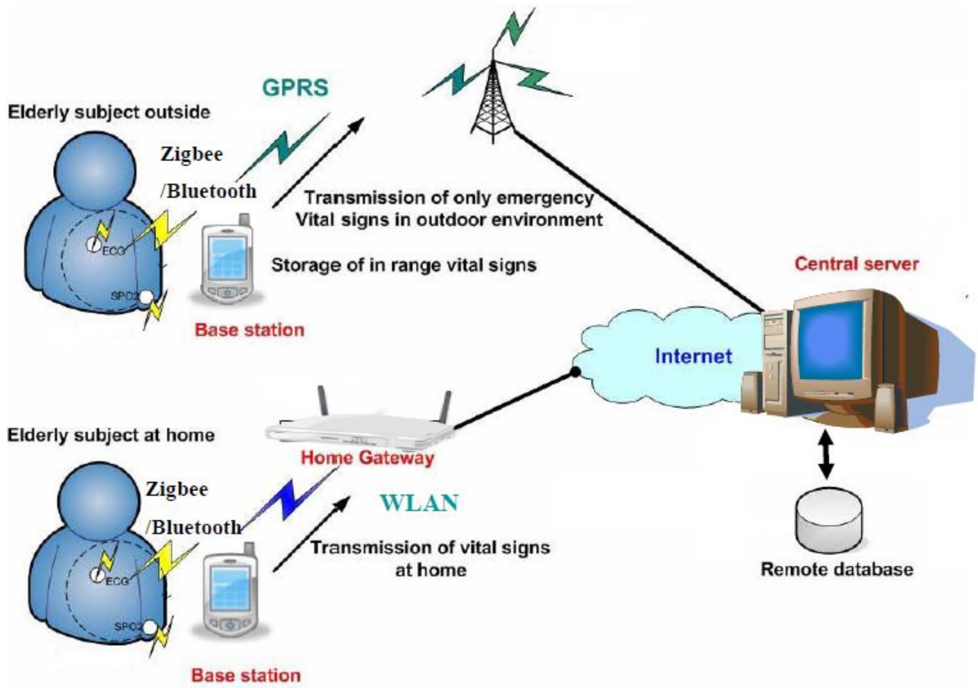

Fig. 2 Routing of base station in an elderly healthcare monitoring system architecture

1) The Sensor Nodes:

In a WBSN system, on the base level there stay biosensors, mono- or multifunctional, to measure various physiological vital signals. Sensor nodes sense, collect and process life signals. Pedometer, accelerometer and ECG are widely used sensors on the first layer. All the sensors should be equipped with a wireless transceiver unit, a mini-processor, and an energy supply device like battery. Miniaturization technology nowadays is a key in sensor design which allows the device to be small enough to contain several transistors on the same integrated circuit [8]. Usually wireless transceiver components using leading communication protocols such as Bluetooth, ZigBee, by which monitoring data are sent out, are placed together on the circuit board. Since sometimes those sensors are programmable, there is often a small operating system particularly for sensor networks running on the sensor's processor. TinyOS is an excellent representative of such operating systems which provides open source code for many common tasks of biosensors'. Biosensors then collect data from time to time (for instance, at a sampling frequency of 50 Hz) or continuously and transmit either raw data or preliminarily processed data wirelessly in real time to a base station where those data will be further processed. Most of the sensors nowadays have storage capacity although their embedded memory vary from 16 MB to 2 GB or even larger. Once their memory fills [7], they transmit data to the base station at the same time of storing the vital data locally for future use.

2) The Base Station:

A base station is a local processing unit that is in charge of data forwarding, data processing and analysis and giving feedback to patients. PDA, smartphone or laptop are the most common equipments used as base stations in WBSN. Nevertheless some sensor research organizations and companies on the market prefer to develop their own base stations for the innovative sensors, e.g. the e-AR sensor developed by London Imperial College [1]. Principally base stations are portable devices, for releasing the patients from bounding to their houses at the same time providing them real-time feedback. There is no need for patients to worry about going out of wireless transmission range and breaking the connection between sensors and the base station. Different platforms could be chosen to run on the base station, for instance for smartphones, Android [42, 61] is a good option because of its compatibility and extendibility to many monitoring applications. Other alternatives like Microsoft Windows Mobile Pocket PC platform [10], one of the representatives is the newly released Window Mobile 7, are sometimes also preferred under certain development circumstances, e.g. when considering security or compatibility. Mobile network is a kind of convenient resource for data transmission tasks, so GSM/GPRS are all preference to WBSN developers.

When the base station receives data, it reacts in three steps: 1) collecting and storing the received data, 2) streaming data to a remote central server via an Internet access point, and 3) analyzing the data in order to provide feedback services to the patients or any predefined destination, either via SMS or by initializing a telephone call [11, 12]. In some case the base station is more intelligent to be used as a personal medical guidance [53]. Its operation modes allow the application to switch between indoor and outdoor environments and make decisions on taking out either a periodical transmission of routine physiological data, or immediate transmission of emergency data [7]. To reduce the cost of wireless streaming, in most of the cases the base station will store the in-range vital signs locally, and initiate uploads when the patient returns to the home network coverage [11]. In case an abnormal condition is triggered, it uploads the emergency data immediately to the remote central server over GPRS network. The thresholds for emergency data can be predefined according to the healthcare providers' advices.

The intelligence of base stations depends on the monitoring requirements and individual implementation. In general, portable hardware devices, processor software platforms and transmission channels constitute the second layer of WBSN infrastructure.

3) The Central Server:

To complete the WBSN model, a top layer comes up with remote server, where monitoring information of the patients' is stored and deeply examined by health care professionals. The main task of the server is to store data into its database for further reference. This ensures the doctors a possibility of long-term analysis, and keeps records of analysis results and patients personal data for diagnosis and healthcare instructions. Once any indication of life threatening to the patients has been found, corresponding departments and resources could get prepared in advance. The servers mainly utilize web applications and services, while taking advantage of Internet when communicating among service centers on the same layer. The three-layer WBSN is easy to scale and configure according to the concrete system requirements [11], so that this infrastructure could be applied to whatever healthcare settings: in-home, global or in-hospital monitoring systems.

Basically, we could divide all the monitoring systems using 3-layer architecture into three groups [56]: the first group contains the systems that do not really provide "real-time" services. This includes the systems doing some offline or postponed processing. The second group comes up with the demand of operating real-time monitoring but the remote server will do the processing. Many of the selected articles fall into this category [20, 57]. The third group performs the data analysis tasks on the base station and only once the emergency happens, the smartphone or PDA will contact the remote server for help [53].

C. Novel Systems

A lot of existing healthcare monitoring systems focusing on WBSN have been introduced into the market according to literature we found since 2006. For instance, interest following CodeBlue [14, 15] project is proposed by An et al. in

China. They called their system “SENS-U” [16], which in nature is similar to CodeBlue. A declared that SENS-U distinguished from node design and feedback loop mechanism. First of all, they integrated as many sensors as possible on one node, for the purpose of wearable convenience. Moreover, they included 2 feedback loops for users. It performed a short-loop simple analysis with a family care center locally, or a long-loop sophisticated analysis system with a remote care center when necessary. The wireless transmission protocol used in SENS-U was proprietary developed by themselves, rather than any of off-the-shelf standards.

A recently proposed project called iCare [53], which was motivated partially from the project MORF [57], brought us a new idea to deal with the real-time feedback services. The sensors connected with the mobile phone by an off-the-shelf software via Bluetooth. It processed data on the smartphone instead of on the server, in order to deliver medical advices and feedback in time. In this case they empowered the smartphone as a fat client, while the main task of the server was reduced to store the data and providing web applications to the doctors. Also they built a knowledge database so that the server could also act as a medical guidance. The so-called “local-processing” scheme discovered a new field for 3-layer WBSN systems, which must be supported by the technology development of the mobile phones.

There are still some other excellent examples of WBSN platforms [21, 22, 23, 24]. While taking these interesting results into consideration, basically each of them has its own drawbacks. Among many concerns of WBSN development, a recently rising one is communication cost. Because most of the WBSN frameworks take advantage of wireless mobile networks, usually it is quite expensive for patients to take the 24 hours continuous monitoring services. From this perspective, base stations have to reinforce their capability of recognizing routine and emergency data and storing routine data locally more than ever, which requires large memory on the sensors and mobile devices. Through periodically transmission scheme communication cost could be reduced as much as possible. Buffered information will be uploaded when reaching the range where WLAN is available, which is obviously a much cheaper choice for patients.

D. WBSN Impacts on Healthcare Services

Some of the included studies do not mention any system performance validation [20, 53, 58]. Even though for those which mention, they all claimed their prototypes detected patients’ health status with an accuracy of above 90% [7], which appears to be very high. However, we can still identify some common agreements of impacts that WBSN can have on healthcare services through those tests and validations [25, 47]. First of all, current WBSN monitoring systems have reached a good level of accuracy and reliability for wireless data transmission. The performance of sensing and transmission process seldom dissatisfies the requirements from medical professionals [7, 47]. Minimal technical errors and problems have ever been encountered during the clinical trials of WBSN monitoring systems tests.

Second, WBSN monitoring systems did take positive contribution to reduce healthcare cost for elderly. A statistics about the monitoring cost from Scanaill et al. [26] stated that in general expensive residential care cost approximately €100 per capita per day, while home visits by healthcare professionals cost €74 and prolonged stays in hospital cost almost €820 every day for each patient. Contrarily home monitoring based on WBSN cost every patient only €30 per day, highly releasing the burden of paying for healthcare bills, especially for chronically ill patients who need uninterruptible monitoring all day long.

Third, WBSN technologies set the patients free from hospital environment, despite periodically or in long term. Home living helps relax the patients, so as to make monitoring system more acceptable to the patients, with the reason of on one hand they escape the meeting with doctors who sometimes cause “white-coat syndrome” among chronically ill patients [26], on the other hand the monitoring systems do not limit their mobility too much around the house [60]. Moreover with a lower bill of healthcare services, most studies reflected the active change of patients’ attitudes towards being monitored. And they are willing to receive helpful feedback from the system to improve their life quality under the control of reliable technologies.

IV. DISCUSSION

In this chapter, we are going to discuss different technical aspects that constitute a WBSN system and also conclude the potentials and challenges WBSN design in future.

A. Sensor Types

As found in the literature search, most studies concentrated on hardware design [47, 58]. To improve the system performance, innovation of sensor hardware design is the most frequently used method. Types of the popular sensors which are integrated to the nodes are: pulse oximeter [7, 50], accelerometer [49, 53], ECG [7, 49, 52], EEG [51], body temperature [52], blood pressure [53], etc. For the convenience of the patients’, wearable devices are preferable, as they are usually easier to initialize and maintain after being issued to the patients. Nowadays implantable sensors also offer the most exciting component to WBSN [8], following the success of pacemaker. But sometimes people keep distance from implantable devices unless they get life threatening from the illness, because those devices scare people a lot. Ambient sensors form another important part to accelerate the wide spreading of pervasive sensing.

B. Software Platforms

On sensor node side, TinyOS is a popular platform to program on the sensor microprocessors [27, 28, 29, 60]. Because it is open source, the sensor developers could easily access to its repository for some existing components that share the same purposes, such as Blink, Test Serial, etc., for different types of sensor motes [54]. It is written in the programming language called nesC, a variant of C, ensuring a straightforward understanding of the code to any developer with basic knowledge of C.

Scenarios for the central server seem much simpler. Since the central server has various web applications running on it, the most practical technology is XML. Besides, ASP.net and JSP also appear frequently with the presence of XML and HTML [11, 10, 32, 53]. For the integrated database, usually people use some relational database server like SQL server 2008 [58].

What makes WBSN complicated is the design of the base station. For several concerns, developers have to choose a suitable communication protocol, an appropriate operating system as well as cost-effective telenetworks. Leading operating systems for mobile devices include MS Windows Mobile [10, 13], Android [38, 60] and iPhone [43]. Android was adopted in most of the studies for its openness, flexibility and compatibility during the life cycle of deployment. Currently WBSN platforms usually take the communication channel of GSM (2G), GPRS (2.5G), UMTS (3G) or other wireless mobile networks [30, 11, 31, 33, 60] to realize data streaming from the base station towards the remote server. However the cost for these networks is considerably high, which makes 4G [55] a new hope to cool down the communication cost for healthcare services.

C. Communication Protocols

As we found in the included 35 articles, dominating wireless communication standards in WBSN domain currently focus on IEEE 802.15.1 (Bluetooth), IEEE 802.15.4 (ZigBee) and IEEE 802.11b (WLAN). Several points have to be taken into account when applying them into medical care fields [34]. With the concerns of data traffic, coverage range, network architecture and the most important, power management, many studies claimed that IEEE 802.15.4 radio was the ever best choice for WBSN applications [7, 11, 60]. In principle, the standards IEEE 802.15.4, IEEE 802.15.1 and IEEE 802.11b offer respectively 0.25 Mb/s, 1 Mb/s and 11 Mb/s data rate. In the WBSN design, IEEE 802.15.4 is capable to cover personal area while the IEEE 802.11b covers the local area. Moreover, since ad-hoc network scheme is appreciated by most of the WBSN researchers and designers, IEEE 802.15.4 works appropriately for those applications with low data rate and low power requirements.

Table 3 illustrates the specification comparison of the three aforementioned wireless standards. The parameters in the table indicate that although IEEE 802.15.1 and IEEE 802.11b offer high bandwidth, they are more expensive and power-consuming, and neither of them is suitable for wireless multi-hop networking [12]. On contrary IEEE 802.15.4 obtains the advantages of low cost, low power consumption, portability, unobtrusiveness, easiness of deployment, scalability, almost real-time reconfigurability and self-organization [11, 35].

TABLE III COMPARISON OF WIRELESS COMMUNICATION STANDARDS FOR WBSN

	IEEE 802.15.4 ZigBee	**IEEE 802.15.1 Bluetooth**	**IEEE 802.11b WLAN**
Frequency	2.4Ghz/915Mhz/868Mhz	2.4Ghz	2.4Ghz
Data rate	250K/40K/20Kb/s	1Mb/s	11Mb/s
Range	10-30m	10m,30m,100m	100m
Network Size	65535	8	32
Protocol complexity	Simple	High	Medium
Security	Authentic, encryption	Authentic, encryption	Authentic, encryption
Power consumption	60-70mW (Chipcon CC2420)	200mW (National LMX9820A)	400-700mW (Philips BGW200)

Nevertheless, from above we could see clearly that IEEE 802.15.1 and IEEE 802.11b which offer much higher data rate are good options for the applications requiring frequent burst data transmission. IEEE 802.15.1 sometimes has a limitation of communicating up to 8 nodes simultaneously e.g. as in a piconet, but the fact is that most of the studies are small-scaled projects including less than 5 sensor nodes together into the systems [53, 58]. The worst drawback of IEEE 802.15.1 concerning energy consumption compared to IEEE 802.15.4 would be solved soon with the release of new low-power Bluetooth standard [36]. With the appearance of the Smart Ready mobile phones using the latest Bluetooth technologies like iPhone 4S, the existence of ZigBee will be threatened to the biggest extent. Bluetooth overwhelms ZigBee by its compatible common interface available on most of the mobile devices nowadays. Mobile phones, PDAs, laptops are almost equipped with Bluetooth components, which ensures quick and convenient deployment if using them as base stations in WBSN. Unfortunately seldom of these devices have the integrated ZigBee components. From this perspective it makes sense to exploit Bluetooth's further potentials for healthcare monitoring services.

Other standards like UWB and XBee [37, 33, 39] have gradually come into WBSN developers' view. Due to their unsophisticated technologies, most WBSN studies tended to accept either Bluetooth [10] or ZigBee [30, 24, 59], each of which appears more than 10 times in different WBSN platforms out of 35 included articles, sharing nearly the same proportion among our literature search results.

D. Challenges

WBSN technologies bring new opportunities to healthcare monitoring, at the same time more challenges rise with the ongoing development of WBSN systems. The first challenge comes along with sensor design. Many researchers nowadays pursue the systems which integrate more sensors on one node and meanwhile consume less power [47]. Multi-parameter measurement is highly cost-efficient but meanwhile it would be more expensive than mono-parameter measurement. It also requires higher reliability, robustness and accuracy than single sensor node.

Battery is another concern for sensor design. Principally the battery life of a sensor node depends on the transmission protocol, the memory for data logging, and processor intelligence. The more tasks processors could handle simultaneously, the more energy they require. So power supply and power scavenging is a key topic within WBSN research field [1]. BSN concept itself has already contained the concern for self-powering or drawing energy from outside resources, such as fluorescent lights or sunlight via solar panels and even WiFi signals around. Recently Taylor et al. [41] proposed a new networking structure specifically designed to accept various energy sources, including wireless energy transmission, which sounds interesting enough for any researcher devoting into energy aspect of WBSN. Recharging approach is also something worth to consider for the sake of patients' convenience.

PDA and smartphone [60] are the most preferred handheld devices as the base station for WBSN developers. Principally mobile devices ensure the patients more mobility compared with laptops or home PC. However we should also take the limited capacity of the handheld into account. From the perspective of the elderly, it is still a big challenge for them to operate those modern handheld devices.

Wang et al. [40] raised a new concern for WBSN in their paper. They claimed resource should be reallocation through the cross-layer framework once crucial data were identified for protection purpose. The feasibility and necessity remain to be further investigated. As for the base station design, roaming is an issue when choosing appropriate communication protocol, in order to guarantee robust outdoor monitoring quality without interruption. Furthermore, security [45] and privacy [46], which are the main factors influencing user acceptance of the WBSN systems, are still something for researchers and designers to keep in their mind all the time during development. Ethical aspect will be another important consideration in case one day this technology becomes the mainstream [8].

V. CONCLUSIONS

From our discussion based on the 35 articles, WBSN technology with 3-layer structure appears to be a reasonable choice for the use of remote healthcare monitoring systems in either hospital or free living environment. Its core idea is to utilize any existing ICT-based wireless communication approaches to realize the cooperation among sensor nodes, the base station and the remote server. It ought to be partially intelligent to distinguish indoors and outdoors scenarios and switch between routine monitoring mode and emergency monitoring mode. After having a look at the publications on this topic during the last five years, we found considerably successful examples of the WBSN monitoring prototypes. Applying intelligent mobile devices such as PDAs or smartphones become popular trend. However, we could also point out that current WBSN platforms still face quite challenges because WBSN gives high demands on sensor design, energy saving and wireless protocol selection. No existing monitoring systems achieve a perfect trade-off among all the crucial considerations when designing WBSN. Future work needs to be done to solve these problems.

And also the mobile devices should be more powerful to provide real-time feedback and advices with the patients. The interaction between human (especially those elderly) and machine is supposed to involve new technologies of Human-Computer Interaction (HCI). The local-processing model for 3-layer WBSN systems is the solution to reduce the communication cost and simplify the deployment of the monitoring systems. In this perspective, it is a worthy and wide range to be explored.

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