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Wireless Body Area Networks

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Abstract
Recent developments and technological advancements in wireless communication, Micro Electro Mechanical Systems (MEMS) technology and integrated circuits has enabled low-power, intelligent, miniaturized, invasive/non-invasive micro and nano-technology sensor nodes strategically placed in or around the human body to be used in various applications, such as personal health monitoring. This exciting new area of research is called Wireless Body Area Networks (WBANs) and leverages the emerging IEEE 802.15.6 and IEEE 802.15.4j standards, specifically standardized for medical WBANs. The aim of WBANs is to simplify and improve speed, accuracy, and reliability of communication of sensors/actuators within, on, and in the immediate proximity of a human body. The vast scope of challenges associated with WBANs has led to numerous publications. In this paper, we survey the current state-of-art of WBANs based on the latest standards and publications. Open issues and challenges within each area are also explored as a source of inspiration towards future developments in WBANs.

Introduction

WORLD population growth is facing three major challenges: demographic peak of baby boomers, increase of life expectancy leading to aging population and rise in health care costs. In Australia, life expectancy has increased significantly from 70.8 years in 1960 to 81.7 years in 2010 and in the United States from 69.8 years in 1960 to 78.2 years in 2010, an average increase of 13.5%1. Given the U.S. age pyramid2 shown in Fig. 1, the number of adults ranging from 60 to 80 years old in 2050 is expected to be double that of the year 2000 (from 33 million to 81 million people) due to retirement of baby boomers3. It is expected that this increase will overload health care systems, significantly affecting the quality of life. Further, current trends in total health care expenditure are expected to reach 20% of the Gross Domestic Product (GDP) in 2022, which is a big threat to the US economy. Moreover, the overall health care expenditures in the U.S. has significantly increased from 250 billion in 1980 to 1.85 trillion in 2004, even though 45 million Americans were uninsured4. These statistics necessitate a dramatic shift in current health care systems towards more affordable and scalable solutions. On the other hand, millions of people die from cancer, cardiovascular disease, Parkinson’s, asthma, obesity, diabetes and many more chronic or fatal diseases every year. The common problem with all current fatal diseases is that many people experience the symptoms and have disease diagnosed when it is too late. Research has shown that most diseases can be prevented if they are detected in their early stages. Therefore, future health care systems should provide proactive wellness management and concentrate on early detection and prevention of diseases. One key solution to more affordable and proactive health care systems is through wearable monitoring systems capable of early detection of abnormal conditions resulting in major improvements in the quality of life. In this case, even monitoring vital signals such as the heart rate allows patients to engage in their normal activities instead of staying at home or close to a specialized medical service. This can only be achieved through a network consisting of intelligent, low-power, micro and nano-technology sensors and actuators, which can be placed on the body, or implanted in the human body (or even in the blood stream), providing timely data. Such networks are commonly referred to as Wireless Body Area Networks. In addition to saving lives, prevalent use of WBANs will reduce health care costs by removing the need for costly in-hospital monitoring of patients. The latest standardization of WBANs, IEEE 802.15.6.aims to provide an international standard for low power, short range (within the human body) and extremely reliable wireless communication within the surrounding area of the human body, supporting a vast range of data rates from 75.9 Kbps (narrowband) up to 15.6 Mbps ultra wide band; for different sets of applications. This standard will be introduced in more detail in Section III. WBANs may interact with the Internet and other existing wireless technologies like ZigBee, WSNs, Bluetooth, Wireless Local Area Networks (WLAN), Wireless Personal Area Network (WPAN), video surveillance systems and cellular networks. Hence, marketing opportunities for services and advanced consumer electronics will thoroughly expand, allowing for a new generation of more intelligent and autonomous applications necessary for improving one's quality of life. WBANs are expected to cause a dramatic shift in how people manage and think about their health, similar to the way the Internet has changed the way people look for information and communicate with each other. WBANs are capable of transforming how people interact with and benefit from information technology. WBAN sensors are capable of sampling, monitoring, processing and communicating various vital signs as well as providing real time feedback to the user and medical personnel without causing any discomfort. The use of a WBAN allows continuous monitoring of one's physiological parameters thereby providing greater mobility and flexibility to patients. Importantly, as WBANs provide large time intervals of data from a patient's natural environment, doctors will have a clearer view of the patient's status. However, formidable technical and social challenges must be dealt with to allow for their practical adoption. These challenges offer various system design and implementation opportunities with the major objectives of minimum delay, maximum throughput, maximum network lifetime and and reducing unnecessary communication related energy consumption (e.g. control frame overhead, idle listening and frame collisions). The user-oriented requirements of WBANs are equally challenging and have been defined as: ease of use, security, privacy, compatibility, value and safety . Our intent in this paper is to investigate recent studies in WBANs, present the challenges in each underlying subfield, and survey the important results in the field. Existing WBAN surveys have explored recent academic literature, but do not cover the actual standardization efforts. Most of these papers have mentioned some aspects of WBANs in terms of applications but do not comprehensively provide detailed study on all the important criteria in WBANs. Therefore, the need for such a survey in an area with such a fast growth is crucial to researchers to provide the latest updates on WBANs, their characteristics, challenges and open issues. One of the benefits of this paper is that it draws from the existing WBAN surveys and provides the following main contributions:

- An overview of research conducted thus far in different sectors of Wireless Body Area Networks.
- An investigation of the many strict WBAN constraints from different perspectives.
- A classification of the various applications of WBANs in different sectors of medical and non-medical.
- A detailed review and classification of routing protocols and address allocation schemes for these networks.
- An in-depth insight into security challenges in WBANs and proposed protocols.
- Open issues in each area of research for WBANs and explanation of why further research is required.
- The most detailed recent compilation of WBAN projects and publications.

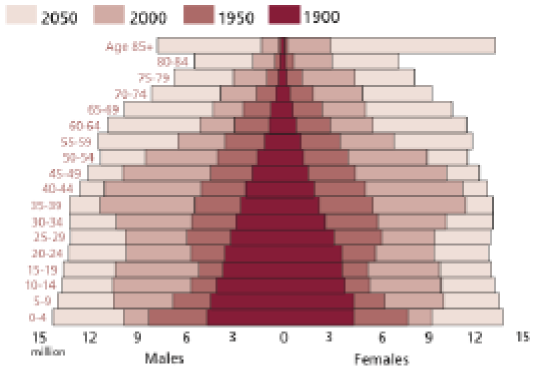

Fig. 1. U.S. Age Pyramid

APPLICATIONS OF WBANS

WBAN applications span a wide area such as military, ubiquitous health care, sport, entertainment and many other areas. IEEE 802.15.6 categorizes WBAN applications into medical and non-medical (Consumer Electronics) as can be seen in Table I. The main characteristic in all WBAN applications is improving the user's quality of life. However, the technological requirements of WBANs are applicationspecific.

A. Medical Applications

WBANs have a huge potential to revolutionize the future of health care monitoring by diagnosing many life threatening diseases and providing real time patient monitoring. Demographers have predicted that the worldwide population over 65 will have doubled in 2025 to 761 million from the 1990 population of 357 million. This implies that by 2050 medical aged care will become a major issue. By 2009, the health care expenditure in the United States was about 2.9 trillion and is estimated to reach 4 trillion by 2015, almost 20% of the gross domestic product. Also, one of the leading causes of death is related to cardiovascular disease, which is estimated to be as much as 30 percent of deaths worldwide. Based on advances in technology (in micro-electronic miniaturization and integration, sensors, the Internet and wireless networking) the deployment and servicing of health care services will be fundamentally changed and modernized. The use of WBANs is expected to augment health care systems to enable more effective management and detection of illnesses, and reaction to crisis rather than just wellness.

Using WBANs in medical applications allows for continuous monitoring of one's physiological attributes such as blood pressure, heart beat and body temperature. In cases where abnormal conditions are detected, data being collected by the sensors can be sent to a gateway such as a cell phone. The gateway then delivers its data via a cellular network or the Internet to a remote location such as an emergency center or a doctor's room based on which an action can be taken. Additionally, WBANs will be a key solution in early diagnosis, monitoring and treatment of patients with possibly fatal diseases of many types, including diabetes, hypertension and cardiovascular related diseases. Medical applications of WBANs can be further classified into three subcategories as follows:

1) **Wearable WBAN:** Wearable medical applications of WBANs can further be classified into the following two subcategories: a) Disability Assistance, b) Human Performance Management. Some of these applications are mentioned bellow:

Assessing Soldier Fatigue and Battle Readiness – The activity of soldiers in the battlefield can be monitored more closely by WBANs. This can be achieved through a WBAN consisting of cameras, biometric sensors, GPS (Global Positioning System) and wireless networking combined with an aggregation device for communication with other soldiers and centralized monitoring. However, in order to prevent ambushes, a secure communication channel should exist among the soldiers.

WBANs can also be used by policemen and fire-fighters. The use of WBANs in harsh environments can be instrumental in reducing the probability of injury while providing improved monitoring and care in case of injury. Aiding Professional and Amature Sport Training – The training schedules of athletes can easily be tuned via WBANs as they provide monitoring parameters, motion capture and rehabilitation. Moreover, the realtime feedback provided to the user in these networks allows for performance improvement and prevents injuries related to incorrect training.

Sleep Staging – Sleep is an important behavior and regular physiological function which consumes one-third of our everyday life. A large population is suffering from sleep disorders - an average of 27% of the world population5. The consequences of such disorders can be quite severe and lead to cardiovascular diseases, sleepiness at work place and drowsy driving. The effect of sleep disorder on work performance is estimated to cost 18 billion in lost productivity. Therefore, sleep monitoring has gained great interest in the recent years. Sleep disorders can be realized through a polysomnography test which requires analysis of a number of biopotentials recorded over night in a sleep laboratory. However, these measurements require a lot of cables that run from the head to a box connected to the patient's belt and interrupt the patient from falling sleep. It also disturbs the patient's motion and initiates artifacts and noise that reduce the signal quality. WBANs are capable of delocalization of the intelligence and instruments in their sensor nodes and removal of all cables.

Asthma – A WBAN and accompanying sensors are capable of monitoring allergic agents in the air and providing real time feedback to a physician, which can help millions of patients suffering from asthma.

Wearable Health Monitoring – WBANs in conjunction with sensors and other devices on the human body can provide real time health monitoring. For instance, a Gluecocellphone which is a cell phone with a glucose module can be used for patients with diabetes. The cellphone receives glucose diagnoses from the glucose module which may then be stored or sent to a doctor for analysis.

2) **Implant WBAN:** This class of applications is relative to nodes implanted in the human body either underneath the skin or in the blood stream.

Diabetes control – 6.4% of the world's adult population, which represent 285 million people, suffered from diabetes in 2010. This number is estimated to reach 438 million by 2030, 7.8% of the adult population6. Research has shown Diabetes to result in long-term medical issues if not carefully monitored and treated7. Frequent monitoring provided by WBANs is capable of reducing the risk of fainting, enables proper dosing, and eliminates risks of loss of circulation, later life blindness and more complications.

Cardiovascular Diseases – Cardiovascular diseases are known as the major cause of death for 17 million people annually8, which can be significantly reduced or prevented with appropriate health care strategies. Myocardial Infarction (MI) can be greatly reduced by monitoring episodic events and other abnormal conditions through WBAN technology.

Cancer Detection – Cancer death rates are estimated to increase by 50%, reaching up to 15 million by 20209. WBAN based sensors capable of monitoring cancer cells in the human body will enable physicians to continually diagnose tumors without biopsy providing more timely analysis and treatment.

3) Remote Control of Medical Devices: The ubiquitous Internet connectivity of WBANs allows for networking of the devices and services in home care known as Ambient Assisted Living (AAL), where each WBAN wirelessly communicates with a back-end medical network. AAL aims to prolong the self-conducted care of patients that are assisted in their home, minimizing the dependency on intensive personal care, increasing quality of life and decreasing society costs. In fact, ambient assisted living will foster a new generation of IT systems with characteristics such as anticipatory behaviour, context awareness, user friendliness and flexibility.

Patient Monitoring – One key application of WBANs is its use in monitoring vital signals, as well as providing real time feedback and information on the recovery process in health monitoring applications. More specifically, they sense and wirelessly transmit vital signal measurements such as heart rate, body temperature, respiration rate, blood pressure, body implant parameters and chest sounds. WBANs are also capable of adminstration of drugs in hospitals, remote monitoring of human physiological data, aid rehabilitation and provide an interface for diagnostics. Continuous patient monitoring, and providing necessary medication when required, are considered as important development areas for WBANs. As WBANs can provide interconnection amongst various devices in or around the body such as hearing aids, digital spectacles and so on, their application could go beyond patient monitoring and also include post-treatment follow-up, pharmaceutical research, trauma care, remote assistance in accidents and research in chronic diseases.

Telemedicine Systems – Available telemedicine systems either use a power demanding protocol like Bluetooth, which is open to interference from other devices working in a similar frequency, or dedicated wireless channels for transferring information to remote stations. Therefore, they restrict prolonged monitoring. Whereas integrating WBANs in a telemedicine system allows for long periods of unobtrusive ambulatory health monitoring.

B. Non-Medical Applications:

Non-Medical applications of WBANs can be further classified into five subcategories as follows:

1) **Real Time Streaming:** This class of applications involve video streaming such as capturing a video clip by the camera in a cellular phone, trading shows for sport goods along with the latest fashion designs and 3D video. Audio streaming is also possible through voice communication for headsets for instance listening to explanation of art at the museum or listening to the bus schedule information on the bus stop, multicasting for conference calls, browsing music samples in a music CD store. This category also includes stream transfer which is used for remote control of entertainment devices, body gesture recognition/motion capture, vital sign and body information-based entertainment service, identification, emotion detection and to monitor forgotten things by sending an alert to the owner.

2) **Entertainment Applications:** This category consists of gaming applications and social networking. Appliances such as microphones, MP3-players, cameras, head-mounted displays and advanced computer appliances can be used as devices integrated in WBANs. They can be used in virtual reality and gaming purposes (game control with hand gesture, mobile body motion game and virtual world game), personal item tracking, exchanging digital profile/business card and consumer electronics.

3) **Emergency (non-medical):** Off-body sensors (eg. Built into the house) are capable of detecting a non-medical emergency such as fire in the home or flammable/poisionous gas in the house and must urgently communicate this information to body-worn devices to warn the wearer of the emergency condition.

4) **Emotion Detection:** Recent research has shown the effective realization of human emotions via speech and visual data analysis. More specifically, wearable sensing technologies have enabled emotion detection through the induction of physical manifestations throughout the body that leads to the production of signals to be measured via simple bio-sensors. For instance, fear increases respiration rate and heart-beat, which results in palm sweating and more. Therefore, one's emotional status can be monitored anywhere and anytime through monitoring emotion-related physiological signals like ElectroCardioGraph (ECG), ElectroMyoGraph (EMG), ElectroEncephaloGraph (EEG), Electrodermal Activity (EDA), etc. This can be achieved through wearable bio-sensors that can be integrated in blood pressure sensors, earrings or watches, respiration sensors in T-shirts, conductivity sensors deployed in shoes and more.

5) **Secure Authentication:** This application refers to utilizing both physiological and behavioral biometrics such as iris recognition, fingerprints and facial patterns. This is one of the key applications of WBANs due to duplicability and forgery, which has motivated the use of new behaviorial/physical

characteristics of the human body, in essence multi-modal biometric, gait and electroencephalography

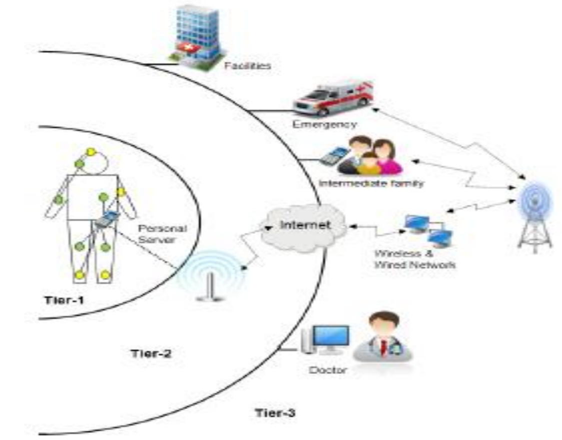

Fig. 2. Communication Tiers in a Wireless Body Area Network

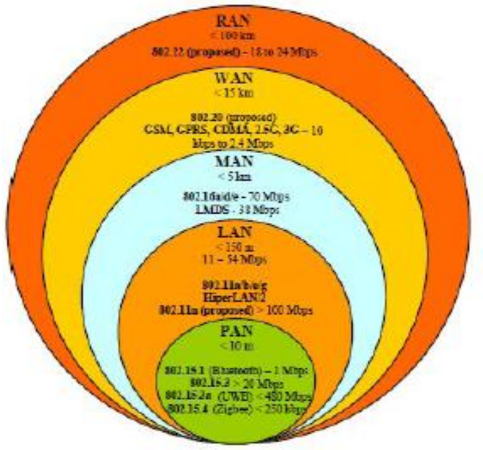

Fig. 2. 802.22 WRAN classification as compared to other popular wireless standards [4]

Characteristics of Wireless Technologies:

CHARACTERISTICS	WLAN	WMAN	WWAN	WRAN
Acceptable cost	NO	NO	YES	YES
Broadband multimedia	YES	YES	YES	YES
Coverage	LIMITED	LARGE	LARGE	VERY LARGE
Standards	802.11	802.16	802.20	802.22
Speed	30mbps	50mbps	60mbps	70mbps
Fast deployment	NO	NO	YES	YES
RANGE	150m	5km	15km	100km

CHARACTERISTICS OF WIRELESS TECHNOLOGIES USED IN WBANS

Technology	Frequency	Data Rate	Coverage	Modulation	Network Topology
Bluetooth V.1 802.15.1	2.4 GHZ ISM	780 Kbps	10-150 m (on-body only)	GFSK	star
Bluetooth V.2 + Enhanced Data Rate (EDR)	2.4 GHZ ISM	3 Mbps	10-100 m (on-body only)	GFSK,PSK,8-DPQSK,π/4DQPSK	star
Bluetooth V3.0 + High Speed (HS)	2.4 GHZ ISM and 5 GHz	3-24 Mbps	10 m (on-body only)	GFSK	star
Bluetooth V4.0 + Low End Extension (LEE)	2.4 GHZ ISM	1 Mbps	10 m (on-body only)	GFSK	star
ZigBee (IEEE 802.15.4)	868 MHz, 915 MHz, 2.4 GHz ISM	20,40,250Kbps	10-100 m (on-body only)	O-QPSK,BPSK(+ASK)	star, mesh, cluster-tree
Ultra Wideband (UWB)	3.1-10.6 GHz	110-480Mbps	5-10 m (on-body only)	OFDM,DS-UWB,BPSK,QPSK	star
RFID (ISO/IEC 18000-6)	860 to 960 MHz	10 to 100Kbps	1 to 100 m	FSK,PSK,ASK	peer-to-peer
Near Field Communication (NFC)	13.56 MHz	106,212,424 Kbps (1 Mbps planned for future)	up to 20 cm	ASK	peer-to-peer
Sensium	868 MHz,915 MHz	50 Kbps	1-5 m (on-body only)	BFSK	star
Zarlink (ZL70101)	402-405MHz,433-434 MHz	200-800 Kbps	2 m (in-body only)	2FSK,4FSK	peer to peer
RuBee (IEEE 1902.1)	131 KHz	9.6 Kbps	30 m	ASK,BPSK,BMC	peer-to-peer
Z-wave	900 MHz ISM	9.6 Kbps	30 m	BFSK,FSK	mesh
ANT	2.4 GHz ISM	1 Mbps	30 m (on-body only)	GFSK	star, mesh, peer to peer, tree

EXISTING PROJECTS ON WIRELESS BODY AREA NETWORKS

Project	Target Application	Intra-BAN Comm.	Inter-BAN Comm.	Beyond BAN Comm.	Sensors
Mobi-Health[118]	Ambulatory Patient Monitoring	Manually	ZigBee/Bluetooth	GPRS/UMTS	ECG, Heart rate, Blood Pressure
AID-N[119]	Mass Casualty Incident	Wired	Mesh/ZigBee	WiFi/Internet/ Cellular Networks	Blood, Pulse, ECG, Temperature
MAHS[120]	Health Care	Bluetooth	Wireless Network	Internet	Spirometer, Pulse, Temperature, Pressure
CodeBlue[121]	Medical Care	Wired	ZigBee/Mesh	N/A	Motion, EKG, Pulse Oximeter
LifeMinder[122]	Real time daily self-care	Bluetooth	Bluetooth	Internet	Galvanic Skin Reflex (GSR) Electrodes, Pulse Meter, Thermometer, Accelerometer
SMART[123]	Health Monitoring in Waiting Room	Wired	802.11.b	N/A	SpO_2 sensor, ECG
Tele-medicare[17]	Home-based Care and Medical Treatment	Bluetooth	Internet	Internet	Temperature,ECG, Oximeter, Blood pressure
CareNet[124]	Remote Health Care	N/A	ZigBee	Internet/Multi-hop 802.11	Gyroscope, Tri-axial accelerometer
ASNET[125]	Remote Health Monitoring	Wired or Wireless Interface (WiFi)	WiFi/Ethernet	Internet/GSM	Temperature, Blood Pressure
IBBT IM3[18]	Telecare and Telemedicine Services	N/A	N/A	Internet	Respiration, ECG, Heart rate
MITHril[19]	Health Care	Wired	WiFi	N/A	EKG, ECG
BASUMA [126]	Health Monitoring	UWB	N/A	N/A	ECG, Reactive Oxygen Sensor (ROS), SpO_2 Sensor, Spirometer
WHMS [1]	Health Care	Wired	WiFi	N/A	EKG, ECG
HUMAN++ [127]	Sport, Entertainment, Medical, Assisted Living, Lifestyle	UWB	N/A	N/A	ECG, EMG, EEG
WiMoCA [128]	Sport/Gesture Detection	Star Topology and Time table-based MAC protocol	Bluetooth	WiFi/Internet/ Cellular Networks/Bluetooth	Tri-axial Accelerometer
AYUSHMAN [129]	Health Monitoring	ZigBee	802.11	Internet	EKG, Blood pressure , Oximeter, Gyroscopic sensors, Accelerometer, Gait monitoring sensors
MIMOSA [130]	Ambient Intelligence	RFID/Bluetooth/ Wibree	UMTS/GPRS	Internet	RFID sensors, Any sensors
UbiMon[20]	Health Care	ZigBee	WiFi/GPRS	WiFi/GPRS	3Leads ECG, 2Leads ECG strip, SpO_2
LifeGUARD[21]	Ambulatory physiologic monitoring for space and terestrial applications	Wired	Bluetooth/Internet	Bluetooth/Internet	ECG, Respiration Electrodes, Pulse Oximeter, Blood Temperature, Built-in Accelerometer
HealthService24[22]	Mobile Health Care	Wired	UMTS/GPRS	UMTS/GPRS/ Internet	ECG, EMG, SpO_2, Pulse rate, Respiration, Skin temperature, Activity, Plethysmogram

Conclusion

In this survey, a review of the on-going research in WBANs in terms of system architecture, address allocation, routing, channel modeling, PHY layer, MAC layer, security and applications is provided. A comparison of WBANs with respect to WSNs and other wireless technologies is given. Additionally, a list of existing and applicable sensors, radio technologies and current research projects, open issues, and future work in WBANs is also presented. WBANs will allow for continuous monitoring of patients in medical applications, capable of early detection of abnormal conditions resulting in major improvements in the quality of life. Importantly, even basic vital signs monitoring (e.g. heart rate) can enable patients to engage in normal activities as opposed to being home bound or nearby specialized medical services. In summary, the procedural research on this valuable technology has significant importance in better usage of available resources that will no doubt truly affect our future well being. We truly believe this research to be a source of inspiration towards future developments in WBANs.

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