A Survey on Wireless Body Area Network

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Abstract— BANs are commonly regarded as an enabling technology for a variety of applications, including health and fitness monitoring, emergency response and device control. Recent breakthroughs in solid-state electronics afford for the creation of low-power, low-profile devices that can be modularly interconnected in order to create so-called sensor nodes comprised of one or more sensor devices, a microcontroller unit (MCU), and a radio transceiver that eliminates the need for wires to communicate with the coordinator node in order to transfer the collected data. In this survey, a review of the on-going research in WBANs in terms of system architecture, applications, how it different from Wireless Sensor Network and also describes the MAC protocols in WBAN.

***Keywords**:* Wireless Body Area Networks, Wireless Sensor Network, Health care, Architecture, ECG

I. INTRODUCTION

The increase in average lifespan and health cost in many developed nations are catalysts to innovation in health care. These factors along with the advances in miniaturization of electronic devices, sensing, battery and wireless communication technologies have led to the development of Wireless Body Area Networks (WBANs). WBANs consist of smart miniaturized devices (motes) that are able to sense, process and communicate. They are designed such that they can be worn or implanted, and monitor physiological signals and transmit these to specialized medical servers without much interference to the daily routine of the patient. [1]

A WBAN consists of several sensors and possibly actuators equipped with a radio interface. Each WBAN has a sink or personal server such as a PDA, that receives all information from the sensors and provides an interface towards other networks or medical staff. Connecting health monitoring sensors wirelessly improves comfort for patients but induces a number of technical challenges like coping with mobility and the need for increased reliability.

An important requirement in WBANs is the energy efficiency of the system. The sensors placed on the body only have limited battery capacity or can scavenge only a limited amount of energy from their environment. Consequently, in order to increase the lifetime of the network, energy efficient measures needs to be taken. From that point of view, several researchers are developing low power sensors and radios. Another possibility is the design of optimized network protocols to lower the energy consumption while satisfying the other requirements [2].

A Wireless Body Area Network consists of small, intelligent devices attached on or implanted in the body which are capable of establishing a wireless communication link. These devices provide continuous health monitoring and real-time feedback to the user or medical personnel. Furthermore, the measurements can be recorded over a longer period of time, improving the quality of the measured data [3]. Generally speaking, two types of devices can be distinguished: sensors and actuators. The sensors are used to measure certain parameters of the human body, either externally or internally. Examples include measuring the heartbeat, body temperature or recording a prolonged electrocardiogram (ECG). The actuators (or actors) on the other hand take some specific actions according to the data they receive from the sensors or through interaction with the user. E.g., an actuator equipped with a built-in reservoir and pump administers the correct dose of insulin to give to diabetics based on the glucose level measurements. Interaction with the user or other persons is usually handled by a personal device, e.g. a PDA or a smart phone which acts as a sink for data of the wireless devices. In order to realize communication between these devices, techniques from Wireless Sensor Networks (WSNs) and ad hoc networks could be used. However, because of the typical properties of a WBAN, current protocols designed for these networks are not always well suited to support a WBAN.

II. WBAN ARCHITECTURE

The WBAN technology is the consequence of the existing WSN technology. A number of tiny wireless sensors, strategically placed on the human body, create a wireless body area network that can monitor various vital signs, providing real-time feedback to the user and medical personnel. In a WBAN, each medical sensor monitors different vital signs such as temperature, blood pressure, or ECG. The system consists of multiple sensor nodes that monitor body motion and heart activity, a network coordinator, and a personal server running on a personal digital assistant or a personal computer [4].

Figure 1 shows secure 3-level WBAN architecture for medical and non-medical applications. Level 1 contains in-body and on-body BAN Nodes (BNs) such as Electrocardiogram (ECG) – used to monitor electrical activity of heart, Oxygen saturation sensor (SpO2) –used to measure the level of oxygen, and Electromyography (EMG) – used to monitor muscle activity [5].

Level 2 contains a BAN Network Coordinator (BNC) that gathers patient's vital information from the BNs and communicates with the base-station. Level 3 contains a number of remote base-stations that keep patient's medical/non-medical records and provides relevant (diagnostic) recommendations. The traffic is categorized into on demand, emergency, and normal traffic. On-demand traffic is initiated by the BNC to acquire certain information. Emergency traffic is initiated by the BNs when they exceed a predefined threshold. Normal traffic is the data traffic in a normal condition with no time critical and on-demand events.

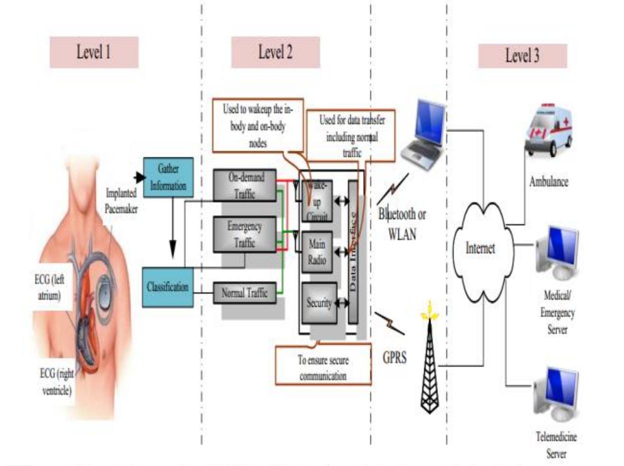

Fig. 1: Secure 3-Level WBAN Architecture For Medical And Non-Medical Applications

The normal data is collected and processed by the BNC. The BNC contains a wakeup circuit, a main radio, and a security circuit, all of them connected to a data interface. The wakeup circuit is used to accommodate on-demand and emergency traffic. The security circuit is used to prevent malicious interaction with a WBAN.

III. Difference between WSN and WBAN

The following illustrates the differences between a Wireless Sensor Network and a Wireless Body Area Network:

A. Deployment and Density

The number of sensor/actuator nodes deployed by the user depends on different factors. Typically, BAN nodes are placed strategically on the human body, or are hidden under clothing. In addition, BANs do not employ redundant nodes to cope with diverse types of failures—an otherwise common design provision in conventional WSNs. Consequently, BANs are not node-dense. WSNs however, are often deployed in places that may not be easily accessible by operators, which require that more nodes be placed to compensate for node failures.

B. Data Rate

Most WSNs are employed for event based monitoring, where events can happen at irregular intervals. By comparison, BANs are employed for registering human's physiological activities and actions, which may occur in a more periodic manner, and may result in the applications' data streams exhibiting relatively stable rates.

C. Latency

This requirement is dictated by the applications, and may be traded for improved reliability and energy consumption. However, while energy conservation is definitely beneficial, replacement of batteries in BAN nodes is much easier done than in WSNs, whose nodes can be physically unreachable after deployment. Therefore, it may be necessary to maximize battery life-time in a WSN at the expense of higher latency.

D. Mobility:

BAN users may move around. Therefore, BAN nodes share the same mobility pattern, unlike WSN nodes that are usually considered stationary [6].

IV. Challenges in a WBAN

For quality life healthcare is always a big concern for an individual. The growing population of developed countries presents a raising slice of government's budget, and presents new challenges to healthcare systems, particularly with elderly people living on independent senior housing. Generally, health monitoring is performed on a periodic check basis, where the patient must remember its symptoms; the doctor performs some tests and plans a diagnostic, then monitors patient progress along the treatment. Healthcare applications of wireless sensor networks allow in-home assistance, smart nursing homes, clinical trial and research augmentation. Before describing medical applications of WBANs, the following section focuses on several challenges and general aspects that describe this kind of technology. Challenges in healthcare application includes: low power, limited computation, security and interference, material constraints, robustness, continuous operation, and regulatory requirements [7].

A. Power Challenge

As most wireless networks based devices are battery operated therefore, power challenge is present in almost every area of application of wireless sensor networks, but limitation of a smart sensor implanted on a person still poses even further challenge. In a full active mode a node can't operate more than a month because a typical alkaline battery provides about 50 watt-hours of energy. In practice, for many applications, they have to guarantee that the device will work for a year or two without any replacement. This could include devices such as heart pacemakers. To deal with these power issues the developers have to design better scheduling algorithms and power management schemes.

B. Computation

Due to both limited power as well as memory, computation should also be limited. The biosensors cannot perform large bit computations due to lack of enough memory. Unlike conventional wireless sensor network nodes, biosensors do not have much that computational power. Since communication is vital and memory is low, little power remains for computation. A solution is that some sensors may have varying capabilities that communicate with each other and send out one collaborative data message [8].

C. Security and Interference

One of the very important issues that could be consider, especially for medical systems is Security and interference. Physiological data collected by the sensor network is the health information, which is of personal nature. It is critical and in the interest of the individual, to keep this information from being accessed by unauthorized entities. This is referred to as Confidentiality, which can be achieved by encrypting the data by a key during transmission. Data Authenticity is also one of the security requirements. This property is very important for the biosensor network because absence of this property may lead to situations where an illegal entity disguise as a legal one and reports false data to control node or gives wrong instructions to the other biosensors possibly causing significant harm to the host .

D. Material Constraints

Another issue for wireless sensor networks application to healthcare is Material constraints. A biosensor should be implanted within the human body, therefore the shape, size, and materials might be harmless to the body tissue. For example, a smart sensor designed to support the retina prosthesis might be small enough to fit within an eye. Also chemical reactions with body tissue and the disposal of the sensor are of extreme importance [8].

E. Robustness

Whenever the sensor devices are deployed in harsh or hostile environments Robustness rates of device failure becomes high. Protocol designs must therefore have built-in mechanisms, that the failure of one node should not cause the entire network to cease operation. A possible solution is a distributed network where each sensor node operates autonomously though still cooperates when necessary. For instance, if the sensor part is not working, the communication part should be used if it benefits the network and communication is operating as expected. One way to achieve this would be that a node might be comprised of a sensing block, a communication block, a scheduling block, and a data block. This would be a good way to isolate the malfunctioning block from the rest of the components in the node, as well as reducing power consumption among the various components. In order to ensure that the proper data is being sent and received, there are few alternatives that can be used, like checksums, parity check, and cyclic redundancy check.

F. Continuous Operation

Continuous operation must be ensured along the lifecycle of a biosensor, as it is expected to operate for days, sometimes weeks without operator intervention. Hence it is important to keep the amount of communications to the minimum. It is necessary that those communications which occur for purposes other than the actual data communication should be minimized if it is not possible to eliminate them [9].

G. Regulatory Requirements

Regulatory Requirements must always be met, there must be some testimony that these devices will not harm human body. The wireless transmission of data must not harm the surrounding tissues and the chronic functioning and power utilization of these devices must also be non-malignant. Design for safety must be a fundamental feature of biomedical sensor development, even at the earliest stages [10]. It is conceivable that some immoral researchers could perform tests and trials with devices that are dangerous to the volunteers. Therefore, it is imperative to have diligent oversight of these testing operations.

V. WBAN APPLICATIONS

WBANs have great potential for several applications including remote medical diagnosis, interactive gaming, and military applications. Table 1 shows some of the in-body and on body applications [11]. In-body applications include monitoring and program changes for pacemakers and implantable cardiac defibrillators, control of bladder function, and restoration of limb movement [12]. On-body medical applications include monitoring heart rate, blood pressure, temperature, and respiration. On-body non-medical applications include monitoring forgotten things, establishing a social network, and assessing soldier fatigue and battle readiness. The following part discusses some of the WBAN applications:

Application Type	**Sensor Node**	**Date Rate**	**Duty Cycle (per device)% per time**	**Power Consumption**	**QOS (Sensitive to Latency)**	**Privacy**
In-body Applications	Glucose Sensor	Few kbps	<1%	Extremely Low	Yes	High
	Pacemaker	Few kbps	<1%	Low	Yes	High
	Endoscope Capsule	>2Mbps	<50%	Low	Yes	Medium
On-body Medical Applications	ECG	3 Kbps	<10%	Low	Yes	High
	SpO2	32 bps	<1%	Low	Yes	High
	Blood Pressure	<10 bps	<1%	High	Yes	High
On-body Non-Medical Applications	Music for Headsets	1.4 Mbps	High	Relatively High	Yes	Low
	Forgotten Things Monitor	256 Kbps	Medium	Low	No	Low
	Social Networking	<200 Kbps	<1%	Low	No	High

Table 1: In- Body And On- Body Sensor Networks Application

VI. MAC PROTOCOLS FOR WBAN

MAC protocols used in WBAN must be low power consuming, accurate and with less latency. The most important thing is the protocol should give good performance on varying traffic load. Some popular protocols for WBAN are TMAC, SMAC, ZigBee MAC and Baseline MAC [4].

A. TMAC:

It is a duty-cycling protocol. In this protocol the node is awaken for a particular period that is called active time. Duty cycle changes according to the information traffic load of the network. When traffic load is high than the duty cycle becomes large so that nodes can handle high traffic load. When traffic load is low then duty cycle is adjusted to small value so that nodes can save their power reducing the problem of idle listening. TMAC protocol is able to handle varying load with low power consumption.

B. SMAC

SMAC protocol is similar to TMAC but only difference is its fixed duty cycle. This protocol is the previous version. This protocol is not efficient in handling continuously varying data rates in WBAN.

C. ZigBee MAC

ZigBee MAC protocol can use two schemes- CSMA/CA or TDMA. While using CSMA/CA mechanism this protocol gives average performance but using TDMA mechanism (applying Guaranteed Time Slot or GTS) it reduces the power consumption up to a great extent. At high rates the data loss becomes high in TDMA mechanism so it is best when there is less no of nodes or low traffic load.

D. Baseline MAC:

This MAC protocol uses CSMA/CA scheme. The performance of Baseline MAC in terms of energy consumption is not average but throughput is average.

VII. LITERATURE SURVEY

Jocelyne Elias et al. [13] (2012) proposed a reliable topology design and provisioning approach for Wireless Body Area Networks (named RTDP-WBAN) that takes into account the mobility of the patient while guaranteeing a reliable data delivery required to support healthcare applications' needs. To do so, they first proposed a 3D coordinate system able to calculate the coordinates of relay-sensor nodes in different body postures and movements. This system uses a 3D-model of a standard human body and a specific set of node positions with stable communication links, forming a virtual backbone. Next, they investigated the optimal relay nodes positioning jointly with the reliable and cost-effective data routing for different body postures and movements. Therefore, they use an Integer Linear Programming (ILP) model, that is able to find the optimal number and locations of relay nodes and calculate the optimal data routing from sensors and relays towards the sink, minimizing both the network setup cost and the energy consumption. They solved the model in dynamic WBAN (Stand, Sit and Walk) scenarios, and compare its performance to other relaying approaches.

N. Javaid et al. [14] (2013) presented an analytically discussion about energy efficiency of Medium Access Control (MAC) protocols for Wireless Body Area Sensor Networks (WBASNs). For this purpose, different energy efficient MAC protocols with their respective energy optimization techniques; Low Power Listening (LPL), Scheduled Contention and Time Division Multiple Access (TDMA), are elaborated. They also analytically compared path loss models for In-body, On-body and Off-body communications in WBASNs. These three path loss scenarios are simulated in MATLAB and results shown that path loss is more in In-body communication because of less energy level to take care of tissues and organs located inside human body. Secondly, power model for WBASNs of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and beacon mode is also presented. The results shown that power of CSMA/CA mode is less as compared to beacon mode. Finally, they suggested that hybrid mode is more useful to achieve optimization in power consumption, which consequently results in high energy efficiency.

S. Ahmed et al. [15] (2014) proposed a mechanism to route data in WBANs with minimum path-loss over the link; and in which the merits of single-hop and multi-hop are utilized. The proposed scheme uses a cost function to select the most appropriate route to sink. This cost function is calculated based on their distance from the sink as well as their residual energy. Nodes with lesser value of cost function are elected as parent node. Other nodes become children of that parent node and forward their data to parent node. Two of the eight nodes forward their data directly to sink as they are placed near the sink; and will serve as the parent nodes. The channel for wearable BAN can be basically described by path loss models with two parameters of frequency and distance. It is calculated from its distance to sink with constant frequency 2.4GHz. The results shows that proposed routing scheme has considerably enhanced the network stability time and in terms of cross-layer application, it has reduced the path-loss to a significantly low-level

VIII. CONCLUSION

The increasing use of wireless networks and the constant miniaturization of electrical devices has empowered the development of Wireless Body Area Net- works (WBANs). In these networks various sensors are attached on clothing or on the body or even implanted under the skin. The wireless nature of the network and the wide variety of sensors power numerous new, practical and innovative applications to improve health care and the Quality of Life. The sensors of a WBAN measure for example the heartbeat, the body temperature or record a prolonged electrocardiogram. In this survey, we have reviewed the current research on Wireless Body Area Networks. In particular, this work presents an overview of the research on the human body, MAC-protocols in WBAN, challenges in WBAN and also describes the various applications in WBAN.

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