Wireless Body Area Networks Medium Access Control (MAC): IEEE 802.15.4 and IEEE 802.15.6

Aparna A R
Research Scholar, Department of Electronics and Communication Engineering, SNGCE, Ernakulam, Kerala, India.

Malini Soman
Assistant Professor, Department of Electronics and Communication Engineering, SNGCE, Ernakulam, Kerala, India.

Abstract – With recent advances in wireless networking, Wireless Body Area Networks (WBANs) became practically feasible. Body Area Networks are defined by the IEEE 802.15.6 standard. However, IEEE 802.15.4 MAC can also be used for WBANs as it is cheap and simple. This paper presents a study about the standards IEEE 802.15.4 and IEEE 802.15.6. In this paper, both IEEE 802.15.4 and IEEE 802.15.6 are explained with their super-frame structures.

Index Terms – Wireless Sensor Networks, Wireless Body Area Networks, Medium Access Control.

1. INTRODUCTION

A WBAN will be a network containing sensor nodes monitoring, and a more intelligent node which can be called as a central coordinator. The sensor nodes could be on the body (wearable) as well as inside the body (implant).

In November 2007, IEEE 802 established a Task Group called IEEE 802.15.6 for the standardization of WBAN [4], and [5]. Earlier, IEEE 802 had many success stories in developing international standards on wireless communications. Examples include IEEE 802.11 [21], IEEE 802.15.1 [22] and IEEE 802.15.4 [1] standards. The purpose of the IEEE 802.15.6 is, to establish a communication standard at Physical (PHY) and MAC layers that should support a variety of medical, Consumer Electronics (CE) and entertainment applications. According to the IEEE 802.15 (TG6) [6], a BAN consists of "low power devices operating on, in or around the human body (but not limited to humans) to serve a variety of applications including medical, consumer electronics/ personal entertainment and other".

It is clear from figure 1, that WBAN is basically a short range wireless network for an individual. It consists of wearable or implanted electronic devices that transmit ID or sensor data to a gateway device. This gateway is then connected to an external Access Point which is not more than several meters distance. Now let us have a look into WBANs and Wireless Sensor Networks. Some basic differences to be noted are as shown in the following table.

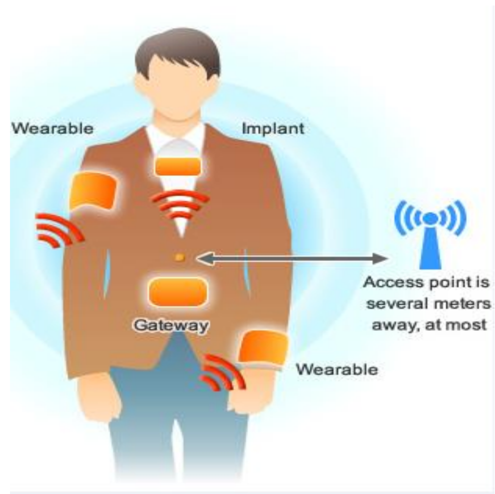

Figure 1: WBAN [20]

	WSN	**BAN**
Scale	Wide area coverage	Limited by the human body
Node number	Huge number of nodes for coverage	Limited number of pervasive nodes
Accuracy	Compensated by the redundancy	Accurate measurements are required by each node
Failure	Nodes often disposable	Difficult replacement of

		implanted nodes
Energy scavenging	Solar or wind power	Motion or body heat

Table 1.Some differences between WSNs and BANs. [19]

WBAN applications can be listed as follows:

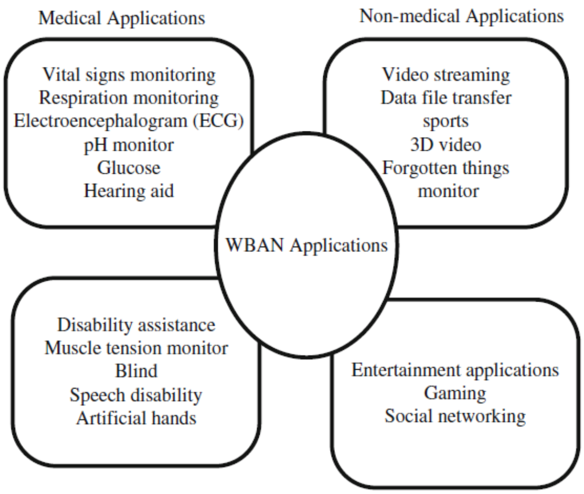

Figure 2: WBAN Applications [9]

In most networks, multiple nodes share a communication medium for transmitting their data packets. The MAC protocol is primarily responsible for regulating access to the shared medium [23]. The fundamental task of MAC protocol is to reduce collision. Also, MAC protocol plays a significant role in reducing the average energy consumption of the sensor nodes. The MAC protocol is required to achieve maximum throughput, minimum delay and to maximize the network lifetime.

The subsequent session gives an idea about works related to the study of IEEE 802.15.4 and IEEE802.15.6 MAC protocols. Section III discusses the WBAN requirements. Section IV is an investigation about IEEE 802.15.4 and IEEE802.15.6 MAC protocols. The collision avoidance techniques are listed in section V. finally section VI concludes the research work.

2. RELATED WORK

Studies about IEEE 802.15.4 MAC protocol and its effectiveness in WBANs can be seen in [1], [3], [4]. More facts about IEEE 802.15.4 can be obtained from [16], [17], [18]. The low power performance of three modes of the IEEE 802.15.4 standard were evaluated, in relation to a body area network of implanted medical sensors by Timmons et.al in [17]. The modes evaluated were beacon, beacon plus guaranteed timeslots and non-beacon, all at 2.4 GHz. Analysis of performance of IEEE 802.15.6 carried out by several researchers, as IEEE 802.15.6 is very important and inevitable standard for WBANs. Details are available in [6], [7], [8], [9], [10]. The throughput and delay analysis of IEEE 802.15.6 based CSMA/CA protocol carried out by S. Ullah et.al in [12]. From [2], the packets received remain the same for IEEE 802.15.6, regardless of the state of GTS but a significant improvement is seen when GTS is turned on while implementing IEEE 802.15.4 and shows that IEEE 802.15.4 is better than IEEE 802.15.6.

3. WBAN ARCHITECTURE AND REQUIREMENTS

Many considerations are required for WBAN architecture and systems. A WBAN consists of both wearable and implanted sensor nodes that are intended to continuously monitor patients' information's, for diagnosis. Some wearable nodes can be used for multimedia and gaming applications. These nodes can have different topologies (eg: star, tree, mesh). Actually the most common one is star topology. Here the nodes are connected to a central gateway or coordinator in a star manner. A WBAN uses Wireless Medical Telemetry Services (WMTS), unlicensed Industrial, Scientific, and Medical (ISM), Ultra-wideband (UWB) and Medical Implant Communications Service (MICS) bands for data transmission. WMTS is a licensed band used for medical telemetry system. The Federal Communication Commission (FCC) urges the use of WMTS for medical applications due to fewer interfering sources However, only authorized users such as physicians and trained technicians are eligible to use this band. Furthermore, the restricted WMTS (14 MHz) bandwidth cannot support video and voice transmissions. The alternative spectrum for medical applications is the 2.4 GHz ISM band that includes guard bands to protect adjacent channel interference. But this band is also used by other technologies, such as Bluetooth, Zigbee, and WiFi. A licensed MICS band (402–405 MHz) is dedicated to implant communication. [4].

The most important requirements for WBANs includes energy-efficiency, security, traffic heterogeneities, quality of services, the topology and multiple frequency bands and physical layers. WBAN has heterogeneous traffics, which are on-demand, emergency and normal traffic. Traffic on-demand is used for diagnostic recommendations.

Emergency traffic is launched by nodes, when they exceed a predefined threshold. This kind of traffic that is produced on a regular basis is very unpredictable. The security is a major requirement, which should be ensured. In fact, the patient data are only derived from the WBAN system dedicated to each patient and are not mixed up with other patient data. Moreover, patient data should have a limited access and not exceed the medical use and when those data are transmitted over the internet to servers, they should be encrypted to protect the patient's privacy. Security and privacy protection mechanisms use a significant part of the available energy and they should be energy efficient and lightweight. [6]

4. WBAN MAC

Two MAC protocols, named IEEE 802.15.4 and IEEE 802.15.6 are being analyzed in this section.

4.1 IEEE 802.15.4 MAC

The IEEE 802.15.4 standard can be also called as Low Rate Wireless Personal Area Networks (LR-WPAN). This standard defines the physical and MAC layers of the LR-WPANs. It is easy to install and provides reliable data transfer. As it's using unlicensed ISM, these are said to be extremely low cost, flexible and extendable networks.

The LR-WPAN is used for short range of operations while maintaining integrated intelligence for network setup as well as routing. IEEE 802.15.4 maintains a simple and flexible protocol stack which helps LR-WPAN in achieving a reasonable battery life. Our discussion is giving emphasis to the MAC sub-layer.

4.1.1. The MAC Sub-Layer

802.15.4 Can support star topology, peer-to-peer topology. Commonly used topology for WBANs is star topology. Advantage is that an external coordinator can be used with access to rechargeable power supply. [26].There are two communication methods with the star topology: the beacon mode and the non-beacon mode.

In beacon mode, communication is controlled by the network coordinator, which transmits regular beacons for device synchronization and network association control. The network coordinator defines the beginning and end of a super-frame by transmitting a periodic beacon. The length of the beacon period (and hence the duty cycle of the system) can be defined by the user between certain limits as specified in the standard [17]. The advantage of this mode is that the coordinator can communicate at will with the nodes, and the disadvantage is that the nodes must wake up to receive the beacon.

In non-beacon mode a network node can send data to the coordinator at will using CSMA/CA if required. However, to receive data from the coordinator, the node must power up and poll the coordinator. To achieve the required node lifetime, the polling frequency must be pre-determined by power reserves and expected data quantity. The advantage of non-beacon mode is that the node's receiver does not have to regularly power-up to receive the beacon, and the disadvantage is that the coordinator cannot communicate at will with the node but must wait to be invited by the node to communicate.

The MAC layer is responsible for

- Generating and managing beacons
- Channel access
- Guaranteed Time Slot (GTS) management
- Frame validation and acknowledging frame[2]

4.2. IEEE 802.15.6 MAC

The first draft of the IEEE 802.15.6 standard is issued in May 2010 [28]. The need for a standard model for making the BAN implementation made IEEE 802, to set up the IEEE802.15.6 Task Group. The purpose behind was defining new PHY and MAC layers for WBAN. The IEEE 802.15.6 defines the physical layer into three separate layers and the MAC as a sophisticated protocol to control channel access.

4.2.1. The MAC Sub-Layer:

IEEE 802.15.6 defines a MAC protocol that controls access to the channel. In IEEE 802.15.6, the entire channel is divided into super-frame structures. The super-frames are bounded by equalized length beacon periods. A beacon from the hub at the beginning of each frame is broadcasted containing information about the structure of the frame. For example, the length of the frame (in number of slots), the contention period length (in number of slots), and the length of a single allocation slot are given. The hub selects the boundaries of the beacon period and thereby selects the allocation slots [27]. The hubs are responsible for coordinating channel access by establishing one of the following three access modes:

- Beacon mode with beacon period super-frame boundaries
- Non-beacon mode with super-frame boundaries
- Non-beacon mode without super-frame boundaries
- Beacon mode with beacon period super-frame boundaries: In this mode, the beacons are transmitted by the hub in each beacon period except in inactive super-frames or unless prohibited by regulations
- Non-beacon mode with super-frame boundaries: In this mode, the entire super-frame duration is covered either by a type I or a type II access phase but not by both phases.
- Non-beacon mode without super-frame boundaries: In this mode, the coordinator provides unscheduled Type II polled allocation only.

5. SUPER-FRAME STRUCTURE

5.1. IEEE 802.15.4 MAC

The super-frame structure of 802.15.4 is shown in the figure 3.

The active portion of the super-frame contains 16 equally spaced slots the active portion is composed of three parts: a beacon, a contention access period (CAP), and a contention free period (CFP). The coordinator interacts with nodes during the active period and sleeps during inactive period. There is a maximum of seven Guaranteed Time Slots (GTS) in the CFP period to support time critical traffic. In the beacon-enabled mode, a slotted CSMA/CA protocol is used in the CAP period while in the non-beacon enabled mode, unslotted CSMA/CA protocol is used. [4] When a node is allocated a timeslot it may only transmit data during that timeslot. GTS nodes must listen to the beacon to synchronize prior to communication within its allocated timeslot(s). [17]

Some of the main reasons of selecting IEEE 802.15.4 for WBAN are low power communication and support of low data rate WBAN applications. It is extremely low cost, implementation is easy, offers reliable data transfer, guarantees short range operation, require only very low power [18]. Nicolas et al. investigated the performance of a non-beacon IEEE 802.15.4 for low upload/download rates (mostly per hour) [17]. In [17], the authors concluded that the non-beacon IEEE 802.15.4 results in 10 to 15 years sensor lifetime for low data rate and asymmetric WBAN traffic. However, their work considered data transmission on the basis of periodic intervals, which is not a real WBAN scenario. Furthermore, the data rate of in-body and on-body nodes varies ranging from 10 Kbps to 10 Mbps, which reduces the lifetime of the sensor nodes. Li et al. studied the behavior of slotted and unslotted CSMA/CA mechanisms and concluded that the unslotted mechanism performs better than the slotted one in terms of throughput and latency but with high cost of power consumption [29].

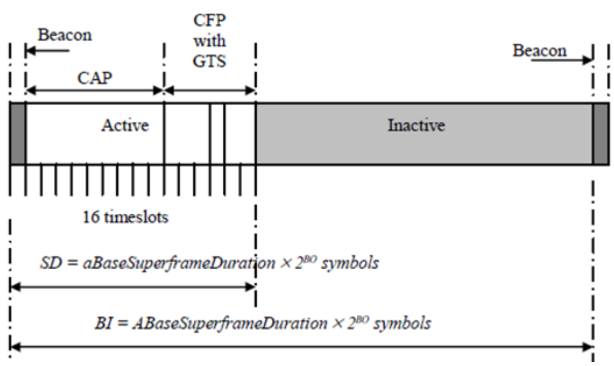

Figure 3 IEEE802.15.4 super-frame structure. [17]

5.2. IEEE 802.15.6 MAC

The IEEE 802.15.6 network operates in one of the following modes, described in the previous section. The super-frame structure and concepts will be clear, by looking to the following figure 4, figure 5, figure 6 and figure 7.

5.2.1. Description of figures

Beacon mode with beacon period super-frame Boundaries: Figure 5 shows the super-frame structure of IEEE 802.15.6, which is divided into Exclusive Access Phase 1 (EAP1), Random Access Phase 1 (RAP1), Type I/II phase, EAP 2,RAP 2, Type I/II phase, and a Contention Access Phase (CAP). In EAP, RAP and CAP periods, nodes contend for the resource allocation. The EAP1 and EAP2 are used for highest priority traffic such as reporting emergency events. The RAP1, RAP2, and CAP are used for regular traffic only. The Type I/II phases are used for uplink allocation intervals, downlink allocation intervals, bi-link allocation intervals, and delay bi-link allocation intervals. In Type I/II phases, polling is used for resource allocation. Depending on the application requirements, the coordinator can disable any of these periods by setting the duration length to zero.

Non-beacon mode with super-frame boundaries: The super-frame duration is covered either by a type I or a type II access phase but not by both phases as given in Figure 6.

Non-beacon mode without super-frame boundaries: The coordinator provides unscheduled Type II polled allocation only as given in Figure 7. The access mechanisms used in each period of the super-frame are divided into three categories: 1) Random access mechanism, which uses either CSMA/CA or a slotted Aloha procedure for resource allocation, 2) Improvised and unscheduled access (connectionless contention-free access), which uses unscheduled polling/posting for resource allocation, and 3) Scheduled access and variants (connection-oriented contention-free access), which schedules the allocation of slots in one or multiple upcoming super-frames, also called 1-periodic or m-periodic allocations. These mechanisms are comprehensively discussed in the standard [2].

Beacon mode with beacon period super-frame boundaries

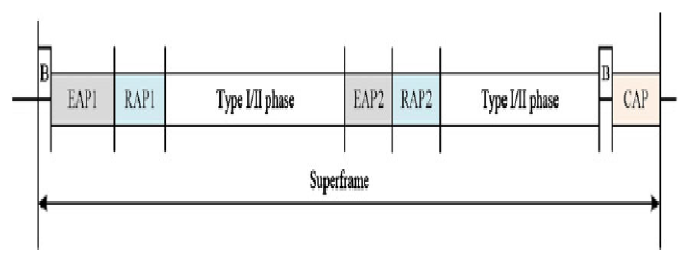

Figure 4: Beacon mode with beacon period super-frame boundaries

Non beacon mode with super-frame boundaries

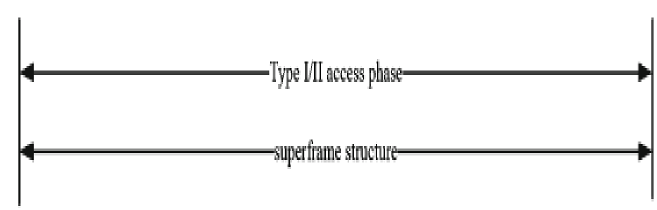

Figure 5: Non beacon mode with super-frame boundaries

Non beacon mode without super-frame boundaries

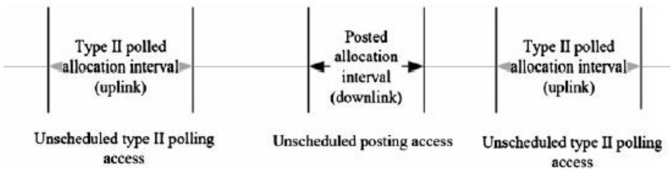

Figure 6: Non beacon mode without super-frame boundaries.

6. CONCLUSION

WBAN is a promising technology and will play a significant role in enabling ubiquitous communication in medical and non-medical fields, this work is intended to understand the working and significance of both IEEE 802.15.4 MAC and IEEE 802.15.6 MAC with respect to WBANs. WBAN brings out a new set of requirements and considerations, which are necessary in developing a WBAN MAC protocol. The WBAN system requirements and WBAN architecture are discussed here. Also, the super-frame structure of both protocols, for beacon mode and non-beacon mode are separately investigated. This paper presented a brief overview of the IEEE 802.15.6 standard and the IEEE 802.15.4 standard.. We studied the MAC layers specifications and identified their key points. As a solution to the challenge of the body area network, the IEEE 802.15.4 standard would provide a limited answer in its non-beacon form. This paper can be used to quickly understand the key concepts of both IEEE 802.15.4 and IEEE 802.15.6 without reading the whole standard.

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