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Medium Access Control Protocols for Wireless Body Area Networks: A Survey

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Abstract

Wireless Body Area Networks (WBANs) consist of a number of miniaturized wearable or implanted sensor nodes that are employed to monitor vital parameters of a patient over long duration of time. For medical applications, these devices are placed or implanted inside the human body to measure and transfer the real time data or audio signals. Resource efficiency is one of the most important factors that should be considered when developing a MAC protocol in WBAN. There are different approaches used to design MAC protocols to minimize energy consumption. Here explains a comprehensive survey of recent medium access control (MAC) Protocols for wireless body area networks (WBANs).Finally, we suggested that hybrid protocol is more useful to achieve high energy efficiency.

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Keywords: Wireless Body Area Networks (WBANs); Energy Efficiency; MAC protocols; Medium Access Control (MAC)

1. Introduction

Throughout the years, it has been proven that biomedical technology has greatly improved diagnosis, treatment and patient monitoring. Therefore the biomedical system has expanded the way of safeguarding human life. These systems are now getting smaller, more robust and comfortable for life of patient. So that these become more efficient for using. The current trend for biomedical system is there use in wireless technology for exchanging information which increases both the freedom of patient and health worker. Thus Wireless Body Area Network (WBAN)

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becomes an emerging technology which provides a real-time health monitoring.

One of the targeted applications of WBAN is in medical environments where conditions of a large number of patients are continuously being monitored in real-time. Wireless monitoring of physiological signals of a large number of patients is one of the current needs in order to deploy a complete wireless sensor network in healthcare system. Such an application presents some challenges in both software and hardware designs. Some of them are as follows: reliable communication by eliminating collisions of two sensor signals and interference from other external wireless devices, low-cost, low power consumption, and providing flexibility to the patients. A WBAN-based wireless medical sensor network system when implemented in medical centres has significant advantages over the traditional wired-based patient-data collection schemes by providing better rehabilitation and improved patients quality of life. In addition a WBAN system has the potential to reduce the healthcare cost as well as the workload of medical professions, resulting in higher efficiency.

Energy efficiency is an important issue in WBANs because sensor nodes damage human body tissue. More importantly sensor nodes connected to body are battery operated devices, they have limited life time. So, MAC protocols of WBANs needs to be energy efficient and supports medical applications. It allows integration of low power intelligent sensor nodes. They are used to stream biological information from human body and transmit it to a control device called coordinator. This procedure is very helpful while monitoring health of a person and in case of emergency providing proper medication. MAC protocol plays an important role in determining the energy efficiency of a protocol in WBANs. Traditional MAC protocols focus on improving throughput and bandwidth efficiency. However, the most important thing is that they lack in energy conserving mechanisms. By controlling the energy waste sources, maximizes the network lifetime.

2. Major source of energy waste

MAC is a sub layer of data link layer commonly known as layer two of Open Systems Interconnection (OSI) model. MAC sub layer is responsible for a number of functions including channel access control, scheduling of the transmission, data framing, error handling and energy management. Therefore the MAC layer is probably the most appropriate level to address the energy efficiency issues. Several MAC protocols for WBANs have been introduced to minimize the energy consumption and the main reason for energy waste in wireless networks are:

- Packet Collision: Occurs when more than one packet is transmitted at the same time. The retransmission of the packets that have collided requires additional energy consumption.
- Idle listening: This occurs when a node listen to an idle channel to receive data.
- Over hearing: Occurs when a node listen to the channel to receive packets that are destined for other nodes.
- Packet Overhead: Refers to the control packets and the information added to the headers. The number of control packets used to carry out the data communication process also increases the power consumption.

3. Requirements of MAC protocol for WBAN

Mostly the requirements of a MAC protocol are: energy efficiency, deployment and adaptability to changing the size, latency, the amount of flow, fairness, and network density. We detail below each requirement.

- Energy efficiency: With a large number of nodes powered by battery, it is very difficult to change or recharge batteries for these nodes.
- The deployment and adaptability to changing the size: As the networks may include many nodes, used protocols have to be able to manage change in number of nodes dynamically. These nodes must be programmable. In fact, when new jobs arise their programs must be changed during operation.
- Latency: In BANs, the importance of latency depends on the application. In applications, such as monitoring nodes, BAN will be vigilant for long, but largely inactive until something is detected. During this period of vigilance, there is little data flow in the networks. We note that low latency is essential to minimize consumption.
- The amount of flow: Refers to the amount of data transferred from a transmitter to a receiver in a given time. Many factors affect this rate, including the effectiveness of collision avoidance, the use of channel, and latency. Like latency, the amount of flow depends on the application. The applications of body sensor networks often require along life that accepts along latency and low throughput..

- Fairness: It is the ability of different users or nodes to share the channel fairly. It is an important parameter in networks; because each user wants an equal opportunity to send or receive data for his/her own applications. However, in WBANs, all nodes cooperate for a single common task. A node can have considerably more data to send to the other nodes. Rather than treating each node in the same way, success is measured by the performance of the overall application, and the equity of each node or each user becomes less and less important.
- Network density: Different applications have very different densities of nodes. Even within a given application, the density may vary over time and space because the nodes do not work or go in to sleep mode. Similarly, the density is not homogeneous across the network and the network must adapt to these changes.

4. Classification of MAC protocol

The medium access control protocols for the sensor networks can be classified broadly into following categories:

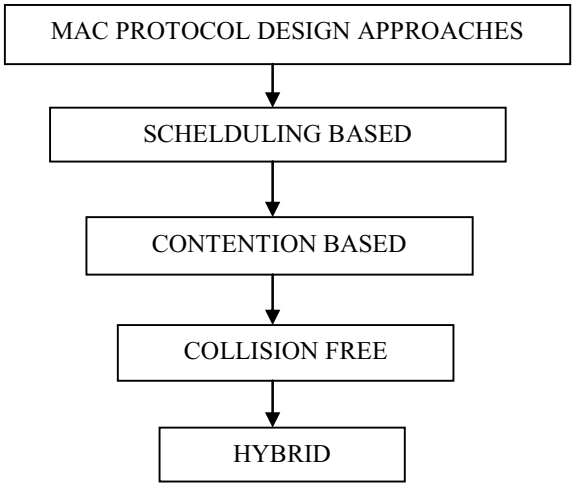

Fig.1. Classification of Mac protocol [7]

4.1. Scheduling based Mac protocols

In scheduling-based MAC protocols, the time at which a node can transmit is determined by a scheduling algorithm, So that multiple nodes can transmit simultaneously without interference on the wireless channel. The time is usually divided into slots, and slots are further organized into frames. Within each frame, a node is assigned at least one slot to transmit.

A scheduling algorithm usually finds the shortest possible frame so as to achieve high spatial reuse and low packet latency. TDMA allows several users to share the same frequency channel by dividing the signal into different time-slots. It has a natural advantage of collision free medium access. It supports low duty cycle operation: a node only needs to turn on its radio during the slot that it is assigned to transmit or receive. The limits with TDMA systems are synchronization of the nodes and adaptation to topology changes. The slot assignments, therefore, should be done with regard to such possibilities. However, it is not easy to change the slot assignment within a decentralized environment for traditional TDMA, since all nodes must agree on the slot assignments.

4.2. Contention based Mac protocols

The contention based protocols based on relax time synchronization and it is used when nodes are not assigned fixed time slot for sending request, and it is very useful when delivery of data is random rather than periodic. Contention schemes differ in principle from scheduled schemes since a transmitting user is not guaranteed to be successful. Contention based protocol usually carrier sense medium access /collision avoidance (CSMA/CA) are

easy to deploy and have been the most used ones in wireless sensor network due to their simplicity and flexibility and robustness. Nodes do not need synchronization information or global topology information in order to access the medium access and send their information. And also node can get in get out of the network without major complications. Contention protocol has several advantages compared to schedule protocols. First because contention protocols allocate resources on demand, they can scan more easily across changes in node density or traffic load. Second, contention protocols can be more flexible as topologies change. There is no requirement to form communication clusters, and peer-to-peer communication is directly supported. Finally, contention protocols do not require fine- grained time synchronization as in TDMA protocols. The major disadvantage of a contention protocol is its inefficient usage of energy.

4.3. Collision free Mac protocols

There are some collision free MAC protocols developed by wireless sensor networks. An energy efficient collision-free channel access protocol for WSN reduces energy consumption by ensuring that uncast, multicast, and broadcast transmissions have no collisions, and by allowing nodes to switch to a low-power, idle state whenever they are not transmitting or receiving. E.g.: TRAMA assumes that time is slotted and uses a distributed election scheme based on intonation about the traffic at each node to determine which node can transmit at a particular time slot. TRAMA avoids the assignment of time slots to nodes with no traffic to send, and also allows nodes to determine when they can become idle and not listen to the channel using traffic information. In that no idle node is an intended receiver and no receiver suffers collisions.

4.4. Hybrid Mac protocols

Hybrid protocol is a grouping of contention based and Schedule based protocol. Several MAC protocols have been proposed to combine the features of CSMA and TDMA protocols with the aim to include the Benefits from both of them. In these hybrid protocols, Active/sleep duty cycles are applied by dividing time into frames during which a node spends a portion of the time for communication and sleep for the rest time to reduce the energy - wastage caused by idle listening.

Recently several medium access control protocols for the wireless sensor network have been proposed by the researchers using different approaches. We have studied the basic categories of MAC protocol; Contention Based, Collision Free, Scheduling Based and Hybrid in terms of reliability, latency, QoS and energy efficiency. Although several designs may have good energy efficiency and delay performance, for real time service support, there are still many challenges. The Hybrid MAC protocols show better and efficient features for real time applications but there are still many more challenges that need to be solved in the sensor networks there is still need to find out the suitable solution for real time communication and energy efficiency.

Table 1. Comparison [17]

Approaches	Reliability Support	Energy Efficiency	Real time communication
Contention based	Good	High	Moderate
Collision free	Good	Moderate	Moderate
Scheduling based	Good	Low	Low
Hybrid	Good	High	Good

5. MAC Protocols for WBAN

Many researchers have proposed various MAC protocols for WBAN. Some of them are IEEE 802.15.4 MAC Protocol, Battery-aware TDMA Protocol, Priority Guaranteed MAC Protocol, Energy-Efficient Low Duty Cycle MAC Protocol, A power-efficient MAC Protocol for WBANs Energy Efficient Medium Access Protocol etc. This section covers the pros and cons of some of these prominent MAC protocols proposed for WBANs. The protocols are introduced with emphasis on energy consumption and how they tackle energy inefficiency caused by collision, overhearing, idle listening, and control packet overhead.

5.1. IEEE 802.15.4 Protocol

The Institute of Electrical and Electronic Engineers (IEEE) approved the formation of a working group for IEEE 802.15.4 in September 2006 to draft a standard for Personal Area Network (WPAN) [6]. These Mac protocols are mainly designed for low data rate wireless applications, which use 68 MHz, 915 MHz and 2.4 GHz frequency bands. The 802.15.4 defines both PHY and MAC layers. The characteristics of the MAC layer management are beacons, channel access, management of GTS (Guaranteed Time Slot), validation of the frames, etc. There are two modes of operation of the MAC layer depending on the topology used and the need for guaranteed bandwidth, namely: non-beacon mode and beacon mode.

However, time-critical communication and high QoS requirements are needed for WBAN, for which IEEE 802.15.4 falls in short. To achieve the QoS requirements for time-critical application of WBANs, a number of protocols that are not based on IEEE 802.15.4 have been proposed.

5.2. IEEE 802.15.6 Protocol

The IEEE 802.15.6 [6] is a standard for WBANs, which operate in and around the human body. It appears to focus on functioning at relatively low frequencies, less than one megahertz, and short-range use, low cost, reliable wireless communication and especially an ultra low power. In this section, we try to present the medium access protocol described in the last draft standard. This draft specifies a medium access with different access modes and their access phases. In WBAN, the channel is separated into super frame structures. The super frame is of fixed length bounded by network beacons period of equal length. The IEEE 802.15.6 MAC layer can support three modes of operations, which are beacon mode with beacon period super frame boundaries, non-beacon mode with super frame boundaries, and non-beacon mode without super frame boundaries.

The IEEE 802.15.6 standard does not define any priority QoS architecture. Therefore we need to propose a priority architecture that is designed to accommodate all types of traffics namely the emergency and the normal traffics in the sensor node, and the normal and on-demand traffics in the coordinator.

5.3. Battery-Aware TDMA Protocol

Battery-aware TDMA protocol [11] is one of the protocols designed for WBANs to maximize the lifespan of the network using cross-layer approach. A number of parameters are considered to design this protocol, which include: time-varying wireless fading channel, electrochemical properties of battery, and packet queuing characteristics. Periodic beacons are transmitted by the coordinator just as IEEE 802.15.4 does. The time axis is divided into three time slots: (1) active time slot, (2) inactive period, and (3) beacon slot. To support different applications of WBANs, the frame structure is adaptive and can be changed. Periodic wakeup mechanism is introduced to avoid idle listening of nodes. A dedicated time slot *Ts* is assigned to each node, where data is transmitted by end node when it receives beacon from the coordinator. Dedicated GTS assigned to each node improves reliability and timely delivery of packets. End nodes remain in sleep mode for the inactive period of time to avoid extra consumption of energy. However, the lack of mechanism to accommodate emergency data and holding of data packets in buffer for long intervals are the two drawbacks of this proposed solution. In addition, packet buffering might result in high packet delay and packet drop rate.

5.4. Priority-Guaranteed MAC Protocol

Super frame structure plays an important role in the design of MAC protocols. A new super frame structure is introduced for the priority-guaranteed MAC protocol. Time axis is divided into two main portions: active and inactive periods. Active time period is further divided into five parts to accommodate various kinds of data flow.ControlChannelAC1 and ControlChannelAC2 are used for uplink control of life-critical medical applications and consumer electronics applications, respectively. Two different times slots are reserved for period and burst data known as Time Slot Reserved for Periodic traffic (TSRP) and Time Slot Reserved for Burst traffic (TSRB), respectively. Beacon is used for synchronization on nodes. For uplink control, randomized ALOHA is used by AC1 and AC2. However, TDMA is used to assign GTS to end nodes for data communication in the two data channels. The performance of this mechanism is better than IEEE 802.15.4 in terms of energy consumption. Un adaptability to emergency data traffic and complexity of super frame are the major shortcomings [12].

5.5. Energy-efficient Low Duty Cycle

Energy-efficient Low Duty Cycle (ELDC) [13] is one of the TDMA-based protocols proposed to accommodate streaming of large amount of data. Network life is maximized with efficient utilization of TDMA approach for medium access. In the proposed network topology, master node (MN) is responsible for on -body network coordination and synchronization. The time axis is divided into multiple time slots. Acceptable packet drop, packet error rate, and number of sensor nodes are the parameters used to decide the number of reserved channels for on-demand traffic. Guard band time slots are inserted between two consecutive time slots to avoid collision of data transmission caused by clock drifts. ELDC performs better in terms of energy efficiency, high data rate, and accommodation of short burst of data. However, period synchronization will cause extra energy consumption.

5.6. A Power-Efficient MAC Protocol for WBANs

Researchers have proposed a power-efficient MAC Protocol [14] to accommodate the normal, on-demand, and emergency traffic in WBANs. Two wakeup mechanisms are introduced to improve the network performance for not only normal traffic but also for on-demand and emergency data traffic. The data traffic generated by routine monitoring of physiological is categorized as normal traffic. In life-critical applications, some of the in/on or around the human body sensor nodes initiate emergency traffic. End nodes are requested by coordinator for on-demand traffic to acquire information if needed. To accommodate all these three types of communication patterns, the time axis in super frame is divided into three parts: a beacon message, a configurable contention access Period (CCAP) to accommodate short burst of data where slotted ALOHA is used for channel access, and a contention-free period (CFP) where GTS are assigned to end nodes for collision-free communication. However, low power listening is not an optimal solution for improved efficiency in on-body or implanted sensor nodes.

5.7. Energy-Efficient Medium Access Protocol

The Energy-efficient Medium Access Protocol (EMAP) [15] is a prominent protocol designed for WBANs to maximize energy efficiency. Central control mechanism is used for periodic sleep and wakeup scheduling. Cross-layer optimization is being utilized to reduce power dissipation caused by control packet overhead. Star network topology with a single coordinator (i.e., master node) is considered to coordinate with eight on-body/implanted sensor nodes. Master nodes are responsible for most of the activities and processes. It is observed from the simulation results of different physiological signs that the power consumption depends upon the number of retransmissions and sleep intervals. Centrally controlled idle listening and overhearing reduce energy consumption efficiently. However, there are some limitations in implementation which include, e.g., complexity, limited number of nodes in a cluster, lack of mechanism for on demand data, and link establishment process where only one node can establish a link at a time.

5.8. P-MAC Protocol

PMAC [9] protocol defines a fixed time interval which is called frame. It is a fixed time duration period. At the start of each frame, nodes turn on their radio and listen to the channel for a brief duration. If no packets arrive in that time, nodes switch off their radio and go to sleep till the start of the next frame. The first one is the proposal of PMAC (Proper MAC) for the wireless sensor networks that deploy a basic scheme of data transmission followed with ACK (acknowledgement) packets by the receiver. This is achieved reliably without the use of any sort of additional control signalling. The second contribution is to effectively remove anticipatory characteristic of MAC layer by removing idle listening altogether. This has implications on energy efficiency. One of the main advantage is it has a high throughput and its disadvantage is adaptation to changes is might be slow.

5.9. Body MAC

TDMA is one of the most reliable and widely used channel access mechanisms for WBANs. Body MAC [16] utilizes the TDMA channel access mechanism to define uplink and downlink sub frames to improve power efficiency. End nodes use periodic sleep scheduling when they have no data to communicate. Burst Bandwidth procedure, Periodic Bandwidth procedure, and Adjust Bandwidth procedure are the three procedures used to accommodate different data streaming. Improved network stability and control packet transmission are achieved with this flexible and efficient bandwidth management. The simulation results reveal that the Body MAC protocol shows better performance than IEEE 802.15.4 in terms of end-to-end delay and energy saving. It also has flexible bandwidth allocation and energy saving. Disadvantage is it has collision issues.

5.10. HEH BMAC

A hybrid polling Medium Access Control (MAC) protocol with Human Energy Harvesting capabilities, called HEH-BMAC [18], designed for Wireless Body Area Networks (WBANs). The proposed protocol uses a dynamic schedule algorithm to combine User Identification polling (ID) and Probabilistic Contention (PC) random access, adapting the network operation to the random, time-varying nature of the human energy harvesting sources. HEH-BMAC offers different levels of node priorities (high and normal), energy-awareness and flexibility. Extensive simulations have been conducted in order to evaluate the energy efficiency and throughput of our scheme compared to IEEE 802.15.6 standard in energy harvesting conditions.

6. Open research issues

Most of the research is focused on the energy efficiency and power consumption of WBAN. Apart from this a lot of other works are done on the following areas such as physical area, data link layer, network layer and cross layer design. To overcome the idle listening, overhead and collision avoidance problems we can use multiple

Energy efficient MAC Protocols in single window. In the case of hybrid MAC protocols, protocols based on CSMA/CA and TDMA access mechanisms give better performance compared with MAC protocols-based CSMA/CA mechanisms. So works are also going on to purpose a hybrid protocols that are most suitable for WBAN networks.

7. Conclusion

Energy efficiency is one the most important goals to be achieved in WBAN. Healthcare applications over WBAN include data streaming of critical and noncritical physiological signs sensed by in/on or around the human body sensor nodes. It has been the focus of researchers to improve the performance of WBAN in terms of reliability and energy efficiency at the MAC layer. However, other techniques including, e.g., cross-layer approach, antenna design, and RF communication and propagation models also affect the performance of WBAN. This paper presents a survey on MAC protocols for WBAN. The requirements of a good MAC protocol for WBAN have been identified, and various approaches of WBAN MAC protocols are comparatively analyzed based on merits and

demerits. At this level, a hybrid and cooperative MAC Protocol is required to satisfy WBANs requirements such as guaranteed QoS, multiple physical layer support and adaptability to traffic variations, etc. So as a future work, we have to propose a hybrid MAC protocol that takes into consideration the requirements of WBANs networks.

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