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

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Abstract—**This paper, explain a comprehensive survey of recent medium access control (MAC) Protocols for wireless body area networks (WBANs) and presents a comparison of the various approaches pursued. Apart for this, we outline the crucial attributes for a good MAC. Then, we investigate few MAC Based protocols devised for WBAN by emphasizing their Merit and Demerits. As a conclusion, we put forward a number of open research challenges with regard to prospects of medium access techniques and other issues.**

Keywords- **Wireless Body Area Network (WBAN); Energy-Efficiency; Research Issues, WBANs Application in real time, Body MAC Protocol, Medium Access Control (MAC)**

1. INTRODUCTION

The Main task in wireless body area networks (WBANs) is to make the entire network/system energy efficient .for this purpose we focus on a medium access control (MAC) layer which is the most suitable level to address the energy efficiency [1]-[4] of the any system. Medium Access Control layer is used to coordinate node access to the shared wireless medium. For achieving quality of service in any wireless networks the MAC Communication Protocol stack has been used.MAC protocols for WBAN are analyzed in this paper to observe the effect of changing the output power of nodes. Some popular MAC protocols are TMAC, ZigBeeMAC, SMAC and Baseline MAC. TMAC and SMAC are duty-cycling protocols Where SMAC is the previous version of TMAC.

ZigBeeMAC protocol can use CSMA/CA or TDMA schemes and gives better energy efficiency and throughput in simple WBAN having less number of nodes. The fundamental task in MAC protocol is to preserving maximum throughput, minimum latency, communication reliability and maximum energy efficiency by avoiding collisions and to prevent simultaneous transmissions. In this paper, some important aspect highlighting related to recent energy-efficient medium access control protocols for wireless body area networks and compare methods of the various approaches pursued. More specifically, in this paper we focus on different energy-efficient MAC protocol devised for WBAN. At first, we highlight the properties and functions that are crucial for the design of MAC layer protocols. And different Sources that contribute to the energy inefficiency are identified and comparisons of other MAC protocols are summarized. Apart for this, Here we mention Summarized detail of BodyMAC energy efficient Protocol. While Designing MAC Protocols some point keep into the mind that nodes are prone to failures, constrained capabilities and restricted energy resources.

The main contribution of this paper is summarized as follow:

- In this paper a substantial effort to analyze the various Medium access Control protocols for WBAN with based on their specific properties, merits and demerits.
- This paper explains the features of a medium access control for WBAN and identify the potential source of energy waste.

2. RELATED WORK

Gopalan et al. [4] review some most important MAC protocols for WBANs along with the comparison of four protocols based on different properties and parameters i.e., Energy Efficient MAC, MedMAC, Low Duty Cycle MAC, and BodyMAC [11]. And functional requirements and sources of energy wastage are also review. They also examine some open research issues in this survey. Quite a lot of task has to be done in data link layer, network layer and cross layer design. Sana Ullah et al. in [7] examine relatively a comprehensive study of MAC protocols for WBANs. Analogy of the low power heeding, scheduled contention and TDMA is provided.

MAC essentials, frame structures and analogy of different protocols and their trade-offs are discussed in detail. W. Ye, J. Heidemann, and D. Estrin [1] proposed to solve idle listening problem in S-MAC protocol by using fixed duty cycles concept. This study suggests that T-MAC[7,9], S-MAC, ZigBeeMAC[3], and Baseline MAC[5]protocols perform efficiently in case of WBAN [1].In another research work author analyzed MAC protocols to suggest the most energy efficient protocol for WBAN [3] [5] [6] [8]. In some research works T-MAC protocol is analyzed for its better performance than other protocols [7].

3. ATTRIBUTE OF MAC PROTOCOL AND POTENTIAL SOURCE OF ENERGY WASTE

a. Attribute of Good MAC

The primary of WBAN is energy efficiency and consumption. WBAN devices, being operated by a battery require stringent restriction on the use of energy resources. To achieve energy efficiency into the system, design of energy-aware communication protocol is required. Energy-efficiency and consumption can be increased and decreased by minimizing the energy wastes identified below .there are another important metrics like Fidelity, safety and security are considered important metrics besides energy efficiency. The QoS is also an important factor for designing of good MAC protocol. Other parameters of relevance include scalability, adaptability to changes in network topology, throughput, jitter, latency and bandwidth utilization. Throughput, jitter and latency requirements depend on the nature of the application. In summary, the attributes and properties of a good MAC in WBAN include energy-efficiency, reliability, heterogeneous traffic, safety and security in addition to QoS [6].

b. Primary Source of Energy Waste

As widely mention in the literatures, there are different sources contribute to the energy inefficiency as collisions, idle listening, overhearing, over-emitting, control packet overhead and traffic fluctuations etc.

- **Over Hearing**: Overhearing occurs when a sensor node receives packets that are destined for other nodes. Overhearing such packets results in unnecessary waste of energy and such waste can be very large when traffic load is heavy and node density is high.

- **Control Overhead**: A MAC protocol requires sending, receiving, and listening to a certain necessary control packets, which also consumes energy not for data communication.

- **Idle listening**: Idle listening occurs when a sensor node is listening to the radio channel to receive possible data packets while there are actually no data packets sent in the network. In this case, the node will stay in an idle state for a long time, which results in a large amount of energy waste.

- **Collisions**: Collision occurs when two sensor nodes transmit their packets at the same time. As a result, the packets are corrupted and thus have to be discarded.

4. MEDIUM ACCESS CONTROL PROTOCOLS FOR WBANS

In this section, a huge range of MAC protocols are described by stating the primary properties of the protocols, wherever possible. The main categories of MAC protocols for WBANs are grouped into firstly contention-based and contention free or secondly scheduled-based protocols. Contention-based MAC such as (CSMA/CA) protocols which helps to the nodes to competes for the channel to transmit data. Before transmission of data nodes performs CCA (Clear channel assessment) concept. If the channel is busy, the node defers its transmission till it becomes idle.

CSMA based MAC protocols such as S-MAC [1,10], T-MAC [2], B-MAC [6], P-MAC [5], D-MAC [9] and Wise MAC [3] are known to be not energy efficient for Wireless body area network. And CSMA/CA is not a efficient protocol for WBAN due to its collision issues and unreliable CCA. Time Division Multiple Access (TDMA) mechanism on the other hand, is an attractive solution for WBAN applications because of its energy-efficiency. TDMA is a schedule-based multiple access technique where time frames and time slots are used for managed transmission of packets. In a TDMA, the channels are divided into different types of time slots such as fixed time slots and variable time slots which are assigned to a particular sensor node to transmit during its slot period. Since slots are pre-allocated to individual nodes at initialization time, they are collision-free.

4.1 S-MAC Protocol

S-MAC [1,10] for WBANs. In S-MAC to reduced idle listening problem used the concept of fixed duty cycles. For fixed duty cycles nodes wakeup after a peculiar time/schedule, as assigned by coordinator, sends data and again goes back to sleep mode. So all nodes are synchronized; therefore, collision can also be bypass. S-MAC gives considerably low latency. In this protocol, due to sleep schedules concept time synchronization overhead problem may be prevented.

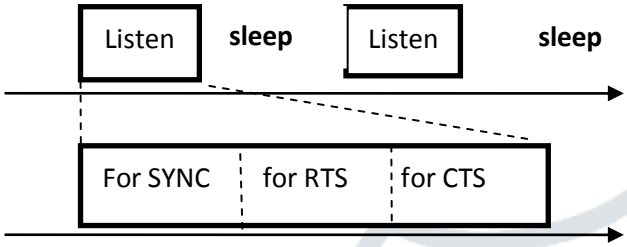


Fig 1 Periodic listens and Sleep in S-MAC [1]

To reduce idle listening, S – MAC [10] introduces a periodic listen and sleep mechanism to establish a low - duty - cycle operation on each node. In S – MAC [1], all nodes are free to choose their own listen and sleep schedules .To reduce control overhead, however, neighboring nodes coordinate their sleep schedules and try to adopt the same schedules to listen and sleep, rather than randomly sleep on their own. To establish coordinated or synchronized sleep schedules, each node exchanges its schedule with other nodes by periodically broadcasting a SYNC packet to all its immediate neighbors and maintains a schedule table that stores the schedules of all its known neighbors for listening and sleeping.

Advantage: simplicity, high latency. time synchronization overload may be prevented due to sleep schedules.
Disadvantage: overhearing, collision may cause and low throughput, if packet is not destined to listening node.

4.2 T-MAC Protocol

T-MAC [2] suggested Time-out MAC (T-MAC) for WBANs. It uses flexible duty cycles for rising energy efficiency. In T-MAC, the node wakes up after time slot assignment, send pending messages. If there is no activation event for TA, the node goes back to sleep mode again. If a node sends RTS and does not receive CTS, then sends RTS two more times before going to sleep. To solve early sleep problem, it uses future RTS for taking priority on full buffer.

Advantage: delay minimized and outperforms other MAC protocols under variable load.
Disadvantage: sleeping problems.

4.3 P-MAC Protocol

PMAC [5] 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 signaling. The second contribution is to effectively remove anticipatory characteristic of MAC layer by removing idle listening altogether. This has implications on energy efficiency.
Advantage: high throughput
Disadvantage: adaptation to changes might be slow

4.4 D-MAC protocol

D - MAC [9] is an energy - efficient and low - latency MAC protocol by Lu et al. [9] for data gathering in WSNs. This protocol address the data forwarding interruption problem in multi hop data delivery and its primary goal is to achieve

both energy efficiency and low latency. To deliver data from a source sensor node to the sink through a multi hop path, most MAC protocols that use active – sleep duty cycles (S - MAC) suffer from a data forwarding interruption problem, where some nodes on the multi hop path cannot be aware of the on - going data delivery.

To minimize this problem, D – MAC[9] employs a staggered wake - up schedule to enable continuous data forwarding on a multi hop path. To enable continuous data forwarding on a multi hop path, D - MAC staggers the schedule of the nodes on the multi hop path and allows the nodes to wake up sequentially like a chain reaction.

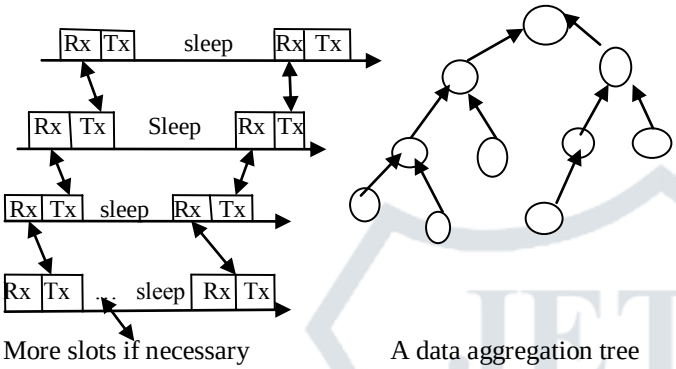


Fig2. Aggregation tree in D-MAC and its implementation [9]

In the schedule, an interval is divided into three periods (or states): receiving, sending, and sleeping. In the receiving period, a node is expected to receive a packet and send an ACK packet back to the source address. In the sending period, a node tries to send a packet to its next hop and receive an ACK packet for that node. In the sleeping period, a node turns off its radio to redeem energy. The receiving and sending periods have the same length of μ , which is long abundant for transmitting and receiving one packet. Depending on its depth d in the data gathering tree, a node sets its wake-up schedule $d\,\mu$ ahead from the schedule of the sink.

Advantage: good delay performance and energy efficient

Disadvantage: collision avoidance not utilized and leading to collision

4.5 Wise MAC Protocol

The Wise MAC [3] protocol LPL mechanism is used. In this, a non-persistent CSMA and a preamble sampling method used to minimize idle listening. The preamble is used to alert the receiving node of a packet arrival. All the nodes in a network sample the medium periodically. If a node pattern a busy medium, it continues to listen until it receives data or the medium becomes idle.

Advantage: mobility support, scalable and adaptive to traffic load
Disadvantage: Decentralized sleep-listen scheduling Mechanism

4.6 FLAMA Protocol

FLAMA [4],an energy-efficient- MAC protocol designed for wireless sensor networks. FLAMA achieves energy efficiency by minimizing idle listening, preventing data collisions and transmissions to a node that is not ready to receive packets. It comply medium access schedules to the traffic flows exposed by the application. FLAMA is simple enough so that it can be run by nodes with defined processing, power efficiency, memory, and communication.

Advantage: Low delay, Better end to end reliability and significant energy saving
Disadvantage: lack of multiple channels, time synchronization

4.7 HEED Protocol

Hybrid, Energy - Efficient, and distributed [8] (HEED) clustering approach for ad hoc sensor networks. The elementary goals of HEED [8]: (1) prolonging network lifetime by distributing energy utilization, (2) abort the clustering process within a constant number of iterations, (3) minimizing control overhead and (4) producing well - distributed cluster heads and compact clusters.

HEED periodically selects cluster heads based on a hybrid of two clustering parameters: The first one is the residual energy of each sensor node and the secondary parameter is the intra cluster communication cost as a function of neighbor proximity or cluster density. The first parameter is used to probabilistically select an initial set of cluster heads while the secondary parameter is used for breaking ties. The clustering process at each sensor node requires several rounds.
Every round is long enough to receive messages from any neighbor within the cluster range. In LEACH, an initial percentage of cluster heads in the network, ***C* prob**, is predefined. The parameter ***C* prob** is only used to limit the initial cluster – head announcements and has no direct impact on the final cluster structure.

***CH* prob = *C* prob. *E* residual / *E* max**

Where **E residual** is the estimated current residual energy in this sensor node and **E max** is the maximum energy, which is typically Xerox for homogeneous sensor nodes. The **CH prob** value must be greater than a minimum threshold **p min**. A cluster head is either a tentative cluster -head, if its **CH prob** is < 1, or a final cluster - head, if its CH prob has reached 1 .
Advantage: low overhead, scalable prolonged network lifetime
Disadvantage: cannot guarantee optimal set of cluster heads

4.8 ZigBeeMAC protocol

ZigBeeMAC (802.15.4) 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.
The power saving mode of ZigBeeMAC [9] is considered for comparison with the proposed MAC protocol. To determine energy consumption, we have taken the data communication scenario when a node uploads data to the coordinator.

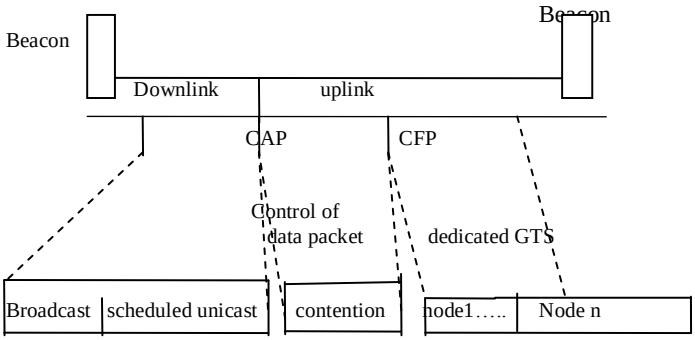
Advantages: high data packet rate, average throughput
Disadvantage: more energy consumption

5. ENERGY EFFICIENT TDMA BASED MAC PROTOCOL

5.1 Body MAC Protocol

Fang and Dutkiewicz [11] examine energy efficient TDMA-based MAC protocol for WBAN. In this protocol, control packet overhead, idle heeding, packet strike problem have been reduced by allocating different bandwidth management schemes such as Burst, Periodic and reconcile Bandwidth is used to improve energy efficiency and latency.

An efficient sleep node is introduced to turn off a node's radio, especially for the nodes supporting low duty cycle applications. The MAC frame in BodyMAC [11] protocol has three parts: Beacon, downlink and uplink sub frames.



CAP : contention access period
CFP: contention free period
GTS : Granted time slot

Fig 3 Body MAC Frame structure [11]

For MAC layer synchronization purpose beacon is used. For transmission data from gateway to node downlink frame is used, which can hold on-demand jam. The uplink frame consists of two sub-parts: *CAP* and *CFP*. Most important criteria of WBAN MAC design is the inclusion to support time critical event reporting. Sleep mode has to support time critical events that may come at any time. An event report packet can be sent either in CAP or GTS. The simulation results reveal that the BodyMAC [11] protocol shows better performance than IEEE 802.15.4 in terms of end-to-end delay and energy saving.
Advantages – end-2 end delay, flexible bandwidth allocation and energy saving.
Disadvantages – unreliable CCA and collision issues

6. OPEN RESEARCH ISSUES

Most of the work primarily focuses on the energy efficiency and power consumption. Apart for this a lot of work has to be done in other areas such as physical layer ,data link layer, network layer and cross layer design. Apart for this we can also use multiple Energy efficient MAC Protocols in single window to overcome the idle listening, overhead and collision avoidance problems like (S-MAC+T-MAC) or (B-MAC+LEACH) . However, still a lot of work has to be done in **Body MAC** [11] Protocol based on some Criteria as Bandwidth Allocation, energy saving, Packet transmission etc. Therefore, data link layer, network layer and cross layer optimization are another promising research area that needs to be addressed more extensively in the future.

7. CONCLUSION

This paper presents a survey on MAC & energy Efficient 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. It's believed that this paper will inspire researchers/scholars to develop effective energy efficient MAC Protocols and less energy-consumption MAC protocols for WBANs.

Note: In this paper we have mentions limited MAC Layer Protocols which supports Wireless Body Area Networks. Apart for this there is lots of another MAC Protocols available for BAN.

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