A Survey on MAC Protocols for Data Collection in Wireless Sensor Networks

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ABSTRACT
Data collection is the most basic task in wireless sensor networks. A wireless sensor network consists of large numbers of nodes which collects data and then forwards collected data to sink. An important area of research in WSN is energy conservation. Medium Access Control(MAC) protocols plays vital role in energy conservation. MAC protocols are either CSMA based or TDMA based. CSMA based protocols suffers from collision while synchronization among nodes is drawback of TDMA based protocols. In TDMA, the node becomes active only during the particular time slot which is allocated to it. In this paper, we first outline the basics of wireless sensor network, after that we present study of various CSMA based protocols like S-MAC, DSMAC, T-MAC, Wise-MAC; TDMA based protocols like D-MAC, LL-MAC, TRAMA, W-MAC and hybrid (CSMA+TDMA) protocols like Funneling MAC and Z-MAC for wireless sensor networks. At the end of discussion this paper also presents main advantages and disadvantages of these MAC protocols. This paper also presents some open issues related to these protocols and at the end we present conclusion.

General Terms
Wireless Sensor Networks(WSN), Medium Access Control(MAC), CSMA , TDMA

1. INTRODUCTION
A Wireless Sensor Network can be defined as a network of sensors which can communicate with each other wirelessly. Large numbers of nodes are present in any Wireless Sensor Network (WSN). Each of these nodes collects data and then forwards collected data to sink. Various characteristics of wireless sensor network are (1) Low cost, (2) Ability to handle node failure (3) Heterogeneity of nodes. Due to these characteristics WSN can be used in weather monitoring, disaster management, target tracking, homeland security. WSN can be also used in environmental monitoring and battlefield surveillance.

Data collection is basic task in wireless sensor networks. In data collection sensor nodes measures the attribute of nodes and sends to sink. Data is mainly collected in three stages: (i) Deployment stage: This stage deals with how deployment is done in sensing environment.(ii) Data delivery stage: It include how sensed data from each node is forwarded to the sink. (iii) Control message dissemination stage: This is the last stage where collection commands or control messages are disseminated from sink to all sensor nodes.

The medium access control (MAC) is the layer responsible for managing the shared medium access of all the nodes in the network. Main function of MAC is to avoid the access of two nodes to the medium at the same time. MAC protocols suffer energy waste due to overhearing, collision and idle listening.

MAC protocols can be categorized into contention based and TDMA based.

a) CSMA-based MACs: CSMA-based protocols are robust to the hidden problem so they are mostly used in ad hoc wireless networks. Example is the standardized IEEE 802.11 distributed coordination function (DCF). Energy waste problem occur in contention based protocol due to packet collisions.

b) TDMA-based MACs: These kinds of MAC protocols are based on the mechanism of reservation and scheduling. TDMA protocols present the advantage of no collision, while synchronization among nodes is major drawback. In these MAC protocols radio's duty cycle is reduced and no collision, so TDMA based protocol are energy conservation as compared to contestation based protocol.

Following attributes should be considered for designing useful MAC protocol for the wireless sensor networks.

(a) Energy efficiency: Sensor nodes are mostly battery powered and it is very difficult to recharge or change batteries for the sensor nodes.

(b) Latency: At the time of detection of an event, sensor nodes should have capabilities to report results to sink node in real time so that suitable action can be taken.

(c) Throughput: Requirement of throughput depends on application. Some application requires large data received at the sink node, while in fire detection application single report is enough for the sink node.

In this paper Section II, first we discuss about various CSMA based protocols like S-MAC [5], DSMAC [6], T-MAC [7], P-MAC [9], Wise-MAC [12], thereafter some TDMA based protocols like D-MAC [10], LL-MAC [13], TRAMA[15], W-MAC [18] also hybrid protocols like Funneling MAC [14] and Z-MAC [17]. At the end of section II one table shows various advantage and disadvantage of some of the protocols. Section III describes open issues about MAC protocols. Section IV is about conclusion.

2. LITERARURE REVIEW
The Medium access control is a wide research area. There are various MAC protocols like S-MAC [5], T-MAC [7], D-MAC [10], P-MAC [9], LL-MAC [13], Funneling MAC [14], etc. Here is brief introduction about these protocols.

The Sensor-MAC (S-MAC) [5] is a CSMA based protocol which consists of periodic sleep and listen in that each node goes into sleep period for some time and after that time node becomes active to see if there is any other node intends to talk

to it, though latency is increased due to periodic sleep of each node. In message passing first step is to divide long messages into frames and then sent in a burst that can cause longer delay. This protocol is not useful for variable kind of traffic, as it involves predefined and constant periods of sleep and listen intervals. DSMAC (Dynamic Sensor MAC) [6] is a CSMA based protocol. In DSMAC, listen interval is kept as it is but sleeping interval can be changed dynamically. In DSMAC [6] receiver node makes a decision to double the original duty cycle by shortening the sleep time period length accordingly without changing the listen time period if latency becomes intolerable. DSMAC [6] solves the high latency problem which was presented in SMAC protocol for high traffic load. Timeout MAC (TMAC) [7] protocol is a CSMA based protocol which uses adaptive duty cycle. TMAC [7] protocol reduces idle listening time by transmitting all the messages in bursts of variable lengths, and sleeping between bursts. The node goes to sleep, if no activity is there in the neighbourhood of a node for a time TA . TMAC [7] is not suitable for high traffic loads.

Berkley Media Access Control (B-MAC) [8] is CSMA based protocol which can adjust the sleep schedule of the nodes to adopt the changes in traffic loads, though B-MAC [8] suffers from the overhearing problem. Pattern MAC (PMAC) [9] is CSMA based protocol. PMAC [9] determines the sleep-wake up schedules of nodes adaptively with the help of its own traffic and traffic pattern of its neighbors, a sensor node gets this information through patterns. Bit 1 in the string suggests that node wants to stay awake during a time slot, while 0 indicates that node wants to sleep. Main drawback of PMAC [9] protocol is that it is not suitable for various kinds of traffics like convergecast, broadcast, and point-to-point.

DMAC[10] is a TDMA based protocol. Above discussed MAC protocols suffer from data forwarding interruption problem. DMAC [10] presents active/sleep schedule mechanism of a node to solve this problem which depends on its depth of the tree. In DMAC [10] nodes which are present at the same are having the same slot for data transmission, so collision may occur. X-MAC [11] is CSMA based protocol which introduces short preamble approach that retains the advantage of low power listening like low power communication and simplicity. WiseMAC [12] is a CSMA based protocol, it is based on aloha. This protocol uses same technique like B-MAC [8], but major difference is that sender can schedule its transmission according to schedules of receiver awake periods.

WiseMAC [12] protocol solves many problems which are related to low power communications. Drawback is that this protocol does not provide a mechanism by which a node can adopt to changing traffic pattern.

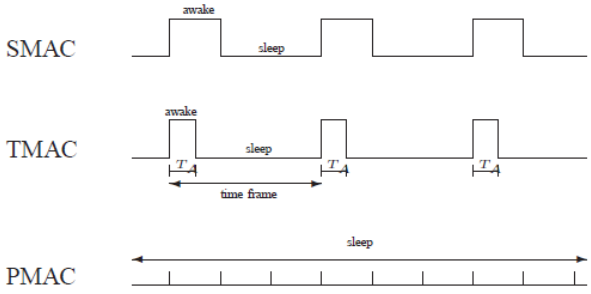

Fig. 1. SMAC [5], TMAC [7] and PMAC [9] with their idle listening periods lengths with no traffic. (Image from [9])

On the other side LL-MAC (Low Latency MAC) [13] is TDMA based protocol. LL-MAC [13] protocol periodically collects data from all nodes present in the network and sends collected data to the sink through multi-hop paths. LL-MAC [13] evades hidden terminal problem, as it is TDMA based protocol it offers collision free approach, though it causes high memory usage.

Funneling MAC [14] is a hybrid (CSMA/CA + TDMA) protocol. In this protocol first task for all the sensor nodes is to perform CSMA unless they receive a beacon. Funneling MAC [14] reuses the same slot if two nodes are more than 2 hops away from each other. As this protocol is hybrid in nature throughput and loss performance of sensor network can be improved. Other TDMA based protocol is TRAMA (Traffic-adaptive medium access protocol) [15]. This protocol avoids assignment of time slots to nodes when there is no traffic. TRAMA [15] supports unicast, broadcast and multicast traffic. MERLIN [16] divides the network in time-zones and after that uses combination of TDMA and CSMA technique to decrease number of collisions and node activity. MERLIN [16] suffers from hidden terminal problem.

Z-MAC (Zebra MAC) [17] is a hybrid MAC protocol which combines the strengths of CSMA and TDMA but offsetting their weakness. Main feature of Z-MAC [17] is that under low contention this protocol behaves like CSMA and under high contention it behaves like TDMA. Z-MAC [17] is robust to dynamic topology changes, time synchronization failures, slot assignment failure which commonly occurs in wireless sensor network. Though, in worst case it falls back to CSMA.

Other TDMA based protocol is W-MAC (Workload Aware MAC) [18]. Above discussed MAC protocol for convergecast operation in WSN assumes that every single sensor node in network should generates the equal amount of data at same rate, but in real, this assumption is not true sensor nodes may generate different amount of data in one convergecast operation. This kind of operation can be also known as heterogeneous convergecast. W-MAC [18] protocol is based on the assumption of each sensor node should knows its parent node and also the generation of amount of data. To minimize power consumption and to offer low data latency to nodes, this protocol employs two major steps namely workload collection and time pool allocation mechanism. Main advantage of this protocol is that it performs better as compared to D-MAC and LL-MAC as it is heterogeneous in nature and also it can support data aggregation. This protocol assigns a unique time slot to each node for convergecast operation, rather than assigning unique time slots to each node we can reuse the same time slots in different level. So if any large network is formulated, in that network it is feasible to use W-MAC protocol with reusing of time slots for convergecast rather than using unique time slot for each node.

Table 1. Comparison of various CSMA & TDMA based protocols

Protocol	Type	Advantage	Disadvantage
S-MAC[5]	CSMA	Due to sleep schedule energy waste problem caused by idle listening is reduced	Under variable traffic load, efficiency can be decreased as sleep and listen periods are constant and predefined.
		Due to dynamic sleeping	For longer messages data

T-MAC[7]	CSMA	schedule variable load can be easily handled.	may get lost due to early sleeping problem.
B-MAC[8]	CSMA	Sleep schedules are adjusted so as to adopt changes in traffic.	This protocol suffers from overhearing problem.
WiseMAC [12]	CSMA	Performs under variable traffic condition its dynamic preamble length adjustment.	Hidden terminal problem accompanies WiseMAC.
D-MAC[10]	TDMA	Provides very good latency as compared to other sleep/listen methods.	When a number of nodes which are having the same schedule try to send data to the same node, collision will occur.
LL-MAC[13]	TDMA	Evades hidden terminal problem.	This protocol causes high memory usage.
TRAMA[15]	TDMA	As compared to CSMA based protocols, less collision and higher percentage of sleep time are achieved.	Duty cycle of this protocol is considerably very high.
W-MAC[18]	TDMA	As it is heterogeneous in nature it performs well as compared to above all protocols.	Main drawback is that it does not support concurrent transmission.

3. OPEN ISSUES

We have discussed various MAC layer protocols, among all these protocols there is no standard protocol because choice of the MAC protocol depends on type of application. While using CSMA based protocols additional mechanism is needed to avoid or detect the collision. Though, this drawback is solved in TDMA based protocols. TDMA protocols are based on assignments of time slots to nodes, but it is not simple to change the assignment of time slots to nodes within an environment which is decentralized. Other scheme that offers collision-free medium is FDMA. Like FDMA, CDMA also offers collision-free medium, but high computational requirement is major drawback of CDMA methods. Various issues found in above discussed protocols are as described below.

[5] assumes that sensor network should be dedicated to only a single application or it should be dedicated to a few collaborative applications, but still more study is required on the latency as well energy consumption. Also in case of topology changes still more work is required. In [7] experiment is done only on static and non-mobile network. In this protocol virtual clustering technique is also discussed but this technique has not been researched thoroughly. Multi-hop synchronization and virtual clustering are very interesting for further studies. As [9] is not suitable for various kinds of traffics such as point-to-point, convergecast and broadcast, in these areas still more work is required. For variable bit-rate data transfer P-MAC can be combined with other protocols like D-MAC and T-MAC. Still work is required in improvement of data transfer latency and energy efficiency of P-MAC. In [10] assumption is made that sensor nodes are fixed, mobility of the sensor nodes is not considered, so work can be done in this direction. Still work is required in scheduling to reduce latency by using off-sets/phase differences. In [11] latency can be measured with more data points. In this protocol very less nodes are used, so we can implement with more number of nodes. Though, key feature of MAC protocol is fairness, which is not evaluated. In [15] only one single, time-slotted channel is used for both data and signal transmission. In this protocol still work is required in the use of channel, rather than using one single channel for data and signal transmission two different channels can be used for transmission. In [16] mobility of nodes is not considered, so still work is required to cope up with the mobility of the nodes. [17] can be extended to mobile ad hoc networks and mesh networks. In [18] concurrent transmissions are not supported, but if we reuse the same time slot again we can support the concurrent transmissions. In this protocol tree formation is not established but it is assumed, so rather than assuming the tree formation, we can construct the whole tree and then start assigning time slots to the nodes.

4. CONCLUSION

This paper presents the study of various CSMA based, TDMA based and hybrid (CSMA+TDMA) medium access control (MAC) protocols, however there is no any protocol is accepted as a standard. Among all the discussed protocols W-MAC (Workload Aware MAC) is better as compared to all the other discussed protocol, as no other protocol supports heterogeneous convergecast. This paper also presents advantages of various other CSMA and TDMA based protocols and open issues of above protocols. In future work can be done to overcome the drawback presented in W-MAC[18] protocol, which assigns unique time slot to each node but this protocol does not support concurrent transmissions, though by reusing the same time slot in different level the concurrent transmission can be supported in this protocol.

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