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Performance Enhancement in Media Access Control (MAC) layer protocol on Wireless Sensor Network

Abu Raihan Mostofa Kamal*, M. Aminul Islam*, Md. Khaled-Ur-Rahman* and **Md. Zubairul Islam***

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ABSTRACT

The Media Access Control (MAC) layer is a part of the data link layer specified in the seven layer OSI model (layer 2). It provides addressing and channel access control mechanisms that make it possible for several terminals or network nodes to communicate within a multipoint network. The MAC sub-layer acts as an interface between the Logical Link Control (LLC) sub-layer and the network's physical layer. It provides an addressing mechanism called physical address or MAC address that is described by MAC address protocol or MAC protocol. An efficient Medium Access Control (MAC) protocol is very important for the performance of a Wireless Sensor Network (WSN), especially in terms of energy consumption. There are different existing MAC protocols for the wireless sensor network. We have analyzed those protocols and found the issues on which performance varies. Then we have tried to eliminate some of the demerits and finally proposed a new MAC protocol that performs better considering some attributes.

Keywords: *Wireless Sensor Networks, MAC Protocol, Energy Consumption, Logical Link Control, OSI Model.*

* *Department of Computer Science and Information Technology, Islamic University of Technology (IUT), Bangladesh. Email: raihanrcc@yahoo.com*

1 INTRODUCTION

Medium Access Control (MAC) layer is described by a MAC protocol, which tries to ensure that no two nodes are interfering with each other's transmissions and deals with the situation when they do. One fundamental task of the MAC protocol is to avoid collisions so that two interfering nodes do not transmit at the same time. Maximizing the network lifetime is a common objective of sensor network research, since sensor nodes are assumed to be dead when they are out of battery [1] and [4]. Under these circumstances, the MAC protocol must be energy efficient by reducing the potential energy wastes. Similarly to design a good MAC protocol for wireless sensor networks, the following attributes must be considered.

Scalability and Adaptability to changes: Some nodes may die over time, some new nodes may join later; some nodes may move to different locations. The network topology changes over time as well due to many reasons [2].

Latency: A packet may experience various delays at each hop of the network such as carrier sense delay, back off delay, transmission delay, propagation delay, processing delay, queuing delay etc [6]. Latency should be minimized as much as possible.

Throughput: Throughput of the sensor network should be increased during the lifetime of the network [1].

Bandwidth Utilization: Bandwidth utilization should be conserved during the lifecycle of the channel and with the sensor nodes [1].

2 EXISTING MAC PROTOCOLS

Several researches are done on MAC protocols with different perspective [5], [8] and [13]. The most well known MAC protocols for WSN can be divided in three main categories:

(i) Contention or Demand-based.
(ii) Time Division Multiple Access (TDMA).
(iii) Code Division Multiple Access (CDMA).

A major representative protocol of the first category is DCF (Distributed Coordinated Function) of the IEEE 802.11 [10]. It is based on the MACAW project and is well-suited especially for ad hoc networks because of its simplicity and robustness. However, it does not succeed in the area of energy conservation. But TDMA and CDMA based MAC protocols have the inherent advantage of the low duty cycle of the transceiver and the absence of collisions between neighboring nodes [7]. Still TDMA forces nodes to form clusters thus introducing complexity as inter clustering communication is not an easy task. Different types of MAC protocol that are proposed by different researchers are S-MAC (Sensor MAC) protocol, T-MAC (Timeout-MAC) protocol, EST (Energy saving Schedule for Target tracking sensor networks), DSMAC (Dynamic Sensor-MAC) protocol , Q-MAC (Query-based MAC) protocol , WISEMAC protocol, TRAMA (Traffic- Adaptive MAC) protocol, SIFT, DMAC, PMAC (Pattern MAC) protocol [13]. Among these protocols, S-MAC and T-MAC are considered most effective MAC protocol in the field of WSN.

S-MAC: S-MAC protocol reduces the listen time by letting node go into periodic sleep mode [2] and [3]. To maintain this sleep-listen period each node goes to sleep for some time and then wakes up and listens to see if any other node wants to talk to it. During sleep the node turns off its radio and sets a timer to awake it later. The duration of time for listening and sleeping can be selected according to different application scenarios. For simplicity these values are the same for all the nodes. However, all nodes are free to choose their own listen/sleep schedules. So to reduce control overhead, we prefer neighboring nodes to synchronize together. That is, they listen at the same time and go to sleep at the same time. To accomplish this, the whole network is segmented into number of clusters and nodes within the same cluster follow the same sleep-listen schedule. If two neighboring nodes reside in two different virtual clusters, they wake up at the listen periods of both clusters [2] and [3]. **Fig.1** shows that two neighboring nodes A and B may have different schedules if they each in turn must synchronize with different nodes, C and D respectively as shown in **Fig.2**.

Schedule exchanges are accomplished by periodic SYNC packet broadcasts to immediate neighbors [11]. The period for each node to send a SYNC packet is called the synchronization period. If multiple neighbors want to talk to a node, they need to contend for the medium when the node is listening. The contention mechanism is the same as that in IEEE 802.11, i.e., using RTS (Request to Send) and CTS (Clear to Send) packets. The node who first sends out the RTS packet wins the medium and the receiver will reply with a CTS packet. After they start data transmission, they do not follow their sleep schedules until they finish transmission [1]. **Fig.2** represents the sender-receiver communication according to S-MAC protocol based on contention mechanism.

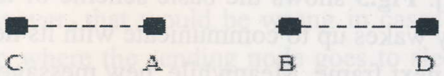

Figure 1: Neighboring nodes A and B have different schedules and synchronize with node C and D respectively.

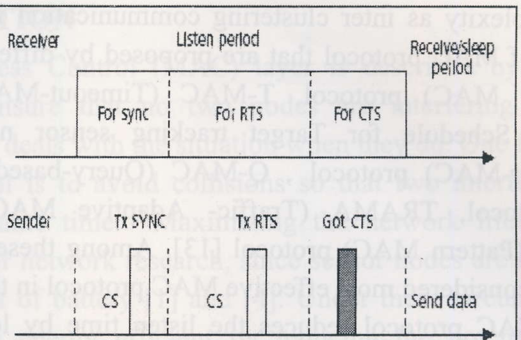

Figure 2: S-MAC message Scenario.

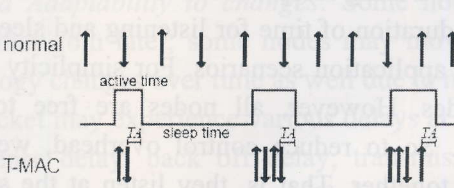

Figure 3: T-MAC message scenario.

The amount of time need for SYNC packet, RTS packet and for CTS packet for sender and also for receiver node will be active otherwise the node will remain in sleep mode. S-MAC also includes the concept of message passing, in which long messages are divided into frames and sent in a burst. With this technique, one may achieve energy savings by minimizing communication overhead at the expense of unfairness in medium access [8]. Collision avoidance is also considered by achieving carrier sense represented as CS in the **Fig.2**. Furthermore, RTS/CTS packet exchanges are used for unicast type data packets [9]. In case of S-MAC, long messages are divided into frames so that retransmission due to any unfairness in the network takes less overhead and less power consumption.

T-MAC: The novel idea of the T-MAC protocol is to reduce idle listening by transmitting all messages in bursts of variable length and sleeping between bursts. To maintain an optimal active time under variable load, we dynamically determine its length [5]. **Fig.3** shows the basic scheme of the T-MAC protocol. Every node periodically wakes up to communicate with its neighbors and then go to sleep again until the next frame. Meanwhile, new messages are queued. Nodes communicate with each other using a Request-To-Send (RTS), Clear-To-Send

(CTS) and Data acknowledgement scheme which provides both collision avoidance and reliable transmission. This scheme is well known and used, for example, in the IEEE 802.11 standard a node will keep listening and potentially transmitting, as long as it is in an active period. An active period ends when no activation event has occurred for a time *TA*. An activation event is:

(i) The firing of a periodic frame timer;
(ii) The reception of any data on the radio;
(iii) The sensing of communication on the radio, e.g. during a collision;
(iv) The end-of-transmission of a node's own data packet or acknowledgement;
(v) The knowledge, through overhearing prior RTS and CTS packets that a data exchange of a neighbor has ended.

A node will sleep if it is not in an active period. Consequently, *TA* determines the minimal amount of idle listening per frame [12]. The described timeout scheme moves all communication to a burst at the beginning of the frame. Since messages between active times must be buffered, the buffer capacity determines an upper bound on the maximum frame time.

In the T-MAC protocol, every node transmits its queued messages in a burst at the start of the frame. During this burst, the medium is saturated: messages are transmitted at maximum rate. A node may expect to be in a fierce fight for winning the medium every time it sends an RTS. An increasing contention interval is not useful, since the load is mostly high and does not change. Therefore, RTS transmission in T-MAC starts by waiting and listening for a random time within a fixed contention interval. This interval is tuned for maximum load. The contention time is always used, even if no collision has occurred yet.

When a node sends an RTS but does not receive CTS back, one of three things has happened:

(i) The receiving node has not heard the RTS due to collision; or
(ii) The receiving node is prohibited from replying due to an overheard RTS or CTS; or
(iii) The receiving node is asleep.

When the sending node receives no answer within the interval *TA*, it might go to sleep [5]. However, that would be wrong in cases (i) and (ii): we would then have a situation where the sending node goes to sleep, while the receiving node is still awake. Since this situation might occur even at the first message of the frame, the throughput would dramatically decrease.

3 PROPOSED ARCHITECTURE

We proposed an improved way to transmit packet though wireless sensor network as shown in **Fig.4**. Our main goal is to increase network performance mostly by increasing lifetime of sensor node. In case of existing MAC protocol especially in S-MAC the sensor nodes are put to sleep periodically to save energy. In such protocols, idle listening happen in this way that, nodes are in listen mode but no data to transmit. So nodes lose their energy without data transmission or reception. Also at a certain moment number of nodes is in listen mode. Some of them are transmitting and some nodes don't have anything to transmit. If some how we can activate those nodes having packets to transmit, then no idle listening will happen and wasted of energy will be reduced. To avoid idle listening nodes have to know prior when to go to listen mode.

In our proposed improvement with the RTS packet each node will be informed the arrival time of message and the whole length of message so that node can calculate how long the nodes have to be in listen mode. When RTS is received by the receiver, the whole path between sender and receiver is specified and after completing of transmission a CTS packet will end of the transmission process.

(i) *Calculation of duration*: When RTS packet will depart any node, then it will keep track the departing time and also the arrival time when to arrive to the receiving node. Suppose $T_{duration}$ is the duration of transmission from one node to another node, $T_{arrival}$ is the arrival time to any node and $T_{departure}$ is the departure time. So

$$T_{duration} = T_{arrival} - T_{departure}$$

This $T_{duration}$ will be added to the next hop duration and the total duration will be calculated.

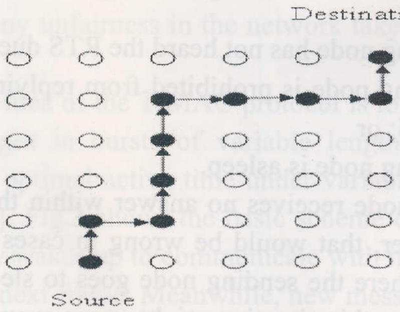

Figure 4: Network architecture of Proposed Architecture.

(ii) *Calculation of listen duration*: RTS packet will contain the whole length of the total packet and each node will receive the copy of that information and will calculate the amount of time the node has to be activated. If the departing rate of the node is $D_{departure}$ *kb per ms*. And if total message is M_{total} .Then the listen duration D_{listen} will be:

$$D_{listen} = M_{total} / D_{departure}$$

So each node will be activated D_{listen} amount of time. But the network designer can keep the node activated some more time for security because of the calculated time may not be the same as the actual transmission time.

In case of multicast or broadcast transmission, our proposed architecture performs differently which is shown in **Fig.5**.

We will follow the periodic sleep-listen schedule in multicast and broadcast transmission.

4 PERFORMANCE EVALUATION

The parameters that are used in our simulation are shown in **Fig.6**. In this experiment, nodes send messages to a single sink node at the corner of the network. No data aggregation is used. In our improved protocol we have enforced mostly on energy saving of network node. We have analyzed the used energy on each node on different network issue. On our performance analysis we have found some performance improvement with respect to S-MAC.

Instead of periodic sleep and listen period, our improved protocol listen the node at the time when the data arrive to it and no idle listen on it. So definitely the energy wastage is very less. In the graph we see when the message length is 20 at that time our improved protocol show better performance. We have analyzed this performance when massage transmission occur on unicast transmission. Through this graph we see the energy used in the improved protocol is less than S-MAC at a certain level of load but if load increases the node of the network remain busy for more time and require more energy. So with high load high amount of energy is needed as shown in **Fig.7**.

Now, if we increase the message length (i.e. 100 *bytes*), the performance differs from the performance at massage length 20. The main reason of that is that, in our improvement the number of dropped packet is less than S-MAC. So retransmission is less and required energy is less as shown in **Fig.8.**

According to our improved protocol for each transmission of data RTS and CTS packet is transmitted. So if hop count is large then each node will receive the RTS and CTS packet. This RTS and CTS require some amount of energy. So after a specific number of hops with the increase of hop length the required energy is increasing at very small amount. This characteristic is applicable when the network is running on low traffic as shown in **Fig.9**.

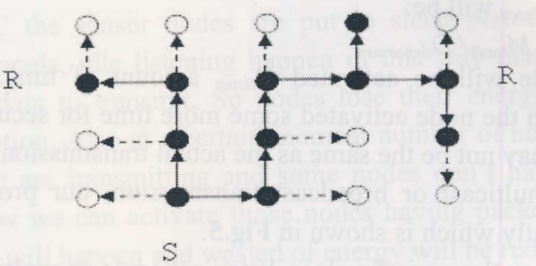

Figure 5: Proposed Architecture's network Broadcast.

Parameters	Values	Parameters	Values
Transmitting power	10 mA	Nodes	100
Receiving power	4 mA	Neighbors of each node	8
Power consumption in sleep mode	20 μA	Frame length	1 sec
TA for TMAC	15 ms	Message length	6 bytes

Figure 6: Simulation Parameters.

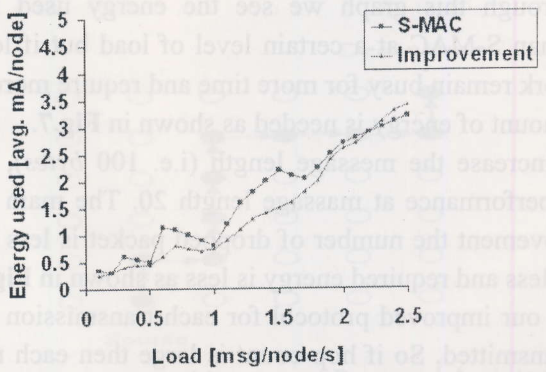

Figure 7: Homogeneous local unicast, message length = 20 *bytes*.

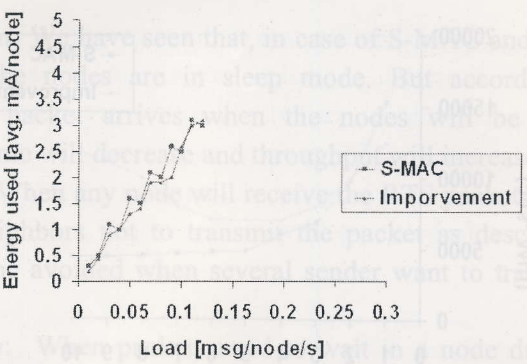

Figure 8: Nodes-to-Sink at larger (100 *bytes* data) message length.

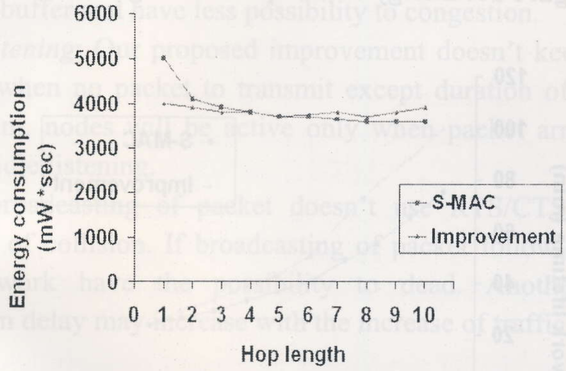

Figure 9: Energy consumption for low traffic.

In case of high traffic the performance of new improvement is reducing. Because with the high traffic most of the node is in active mode and when the node is in active mode, it requires some energy. Also RTS and CTS node uses some amount of energy. By considering all of those used energy, the energy used in the new improvement is more compared to S-MAC as shown in **Fig.10**.

Whenever all the nodes and the network connections are available for long time, we referred it as the lifetime is longer. But the lifetime of node depends on its energy, how much is used and how much is remaining. If due to more transmission node reduces its energy then the lifetime is decrease. So in our improvement nodes are in listen mode when the packet arrives. If more packets arrive, nodes remain active for long time and reduce more energy. In the performance figure with the increase of number of packet is transmitted the lifetime also decrease. But at a level, lifetime becomes equal with the S-MAC as shown in **Fig.11**.

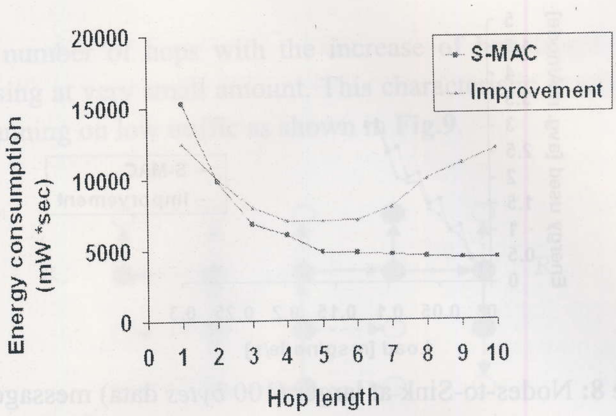

Figure 10: Energy consumption for high traffic.

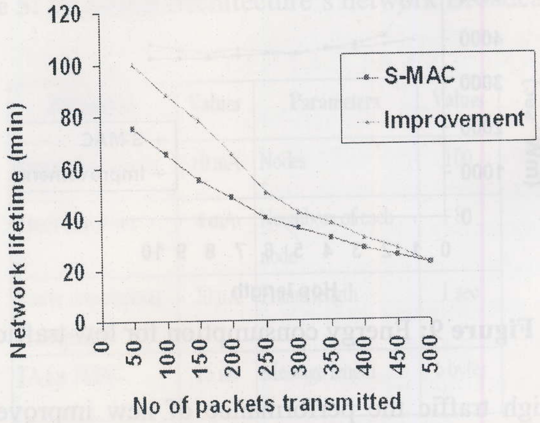

Figure 11: Network lifetime .Vs. packet traffic.

5 PERFORMANCE ANALYSIS

In all wireless sensor networks, network performance depends upon how efficiently and fairly the nodes can transmit as compare to the wired network. Wireless network have restricted power source and other restriction. So wireless network is necessary to design carefully. Our proposed improvement of MAC protocol handles the several network issues by following ways:

Energy saving: Our proposed improvement will follow the periodic listen and sleep schedule until receiving the RTS packet. After that each node knows the activation time for transmission. So nodes will not be activated more time when no packet to transmit.

Throughput: We have seen that, in case of S-MAC and T-MAC, packet may arrive when the nodes are in sleep mode. But according to our proposed improvement, packet arrives when the nodes will be in listen mode. So transmission time will decrease and throughput will increase.

Collision: When any node will receive the RTS packet this node will prevent each of its neighbors not to transmit the packet as described in T-MAC. So collision will be avoided when several sender want to transmit packet to same destination.

Congestion: When packets need to wait in a node during long time, then buffer in the node has possibility to overflow. So due to overflow packet will be lost and have to overflow. But in our proposed improvement, packets need not to wait in the buffer and have less possibility to congestion.

Idle listening: Our proposed improvement doesn't keep the node active for long time when no packet to transmit except duration of *TA*. In our proposed improvement, nodes will be active only when packet arrives. So our protocol avoids the idle listening.

Also broadcasting of packet doesn't use RTS/CTS, which increase the probability of collision. If broadcasting of packet follow the proposed rule the whole network have the possibility to dead. Another thing is that the transmission delay may increase with the increase of traffic

6 COMPARISON AMONG S-MAC, T-MAC AND PROPOSED ARCHITECTURE

Consider the periodic sleep-listen schedule of S-MAC of wireless sensor network that is considered the better MAC protocol mostly in case of power saving.

In S-MAC, periodic listen and sleep schedule reduce 50% of energy consumption. But the node become in listen mode when no packets to transmit and occur idle listening. Energy saving MAC protocols tries to minimize the length of the idle listening. Burt our proposed improvement shows only very few time *TA* the nodes become in idle listening mode. This amount is very less than compared to idle listening of S-MAC.

In T-MAC, sensor nodes have to wake up periodically even when there may have any packet to transmit but if there are packets to transmit then transmit but if no packet then wait *TA* amount of time. If no packet arrives then go to sleep. But this process increase the time to transmit as following in **Fig.12**. If packet arrives during the sleep period then the packets have to wait until to wake up the node and increase the waiting time as well as transmission time.

In case of our propose protocol, packet will follow periodic listen time to get RTS packet. But after getting RTS packets, nodes will wake up on time of transmission, so waiting time will be reduced also energy wastage due to *TA* will decreased and will show the better performance.

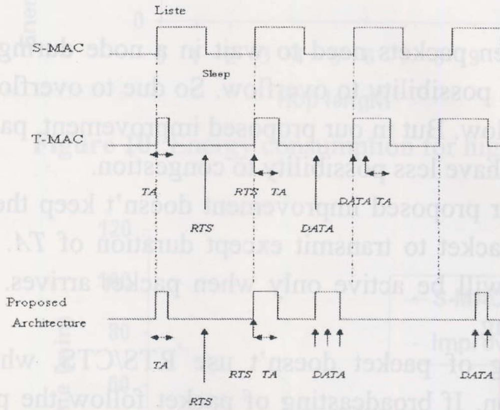

Figure 12: Comparison with S-MAC and T-MAC.

7 CONCLUSIONS

According to the available research papers, an efficient MAC protocol is critical for the performance of a Wireless Sensor Network (WSN), especially in terms of energy consumption. There are different MAC protocols that are defined for the wireless sensor network. Each of them has some advantages and disadvantages. The main task was analyzing those protocols; improve them to find out the most efficient protocol. Our proposed improvement shows a significant amount of energy savings and potentially increases the network lifetime. The activities of our proposed improvement are shown and the energy efficiency is proved by simulation results. However, we hope that our research will have a great impact on designing an efficient MAC protocol for WSN.

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