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Enhanced TDMA Based MAC Protocol for Wireless Sensor Networks

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Abstract*— Wireless sensor networks usually contain large numbers of sensor nodes. Each node has a light weight and a low cost with three functionalities of sensing, on-board processing and transmission. Sensor nodes have limited battery power which leads to limited coverage and communication range. As sensor nodes are deployed in untethered and unattended environment, energy management is critical issue due to limited battery power. Our proposed work is to develop a MAC protocol known as ET-MAC protocol, an enhanced protocol of S-TDMA, In S-TDMA each node is assigned with consecutive time slots for data transmission. Due to consecutive time slots allocation, the last node in schedule have to wait for a long time even it has very few data for transmission. This static slot assignment is not advisable in the situations where nodes have different packet generation rate. In such situation, data loss is unacceptable, particularly, in applications are like surveillance and monitoring. Also, the applications with higher packet generation rate will face buffer overflow problem. Therefore ET-MAC protocol will take care of these issues by using dynamic slot-assignment scheme, where slot assignment depends on traffic density at different nodes and it uses largest remaining units first algorithm to assign the time slots .We are going to compare this protocol with static TDMA protocol and prove that this protocol is more efficient, has a better performance and no wastage of slots. Results shows ET-MAC protocol has better performance and channel utilization.

***Keywords*— Wireless Sensor Networks; MAC protocols, TDMA, Energy Efficiency, On Demand Slot Allocation.**

I. Introduction

Wireless sensor network *(WSN)* is an emerging technology. Sensor nodes are capable of sensing, on-board processing and transmission. These have large range of applications such as environment monitoring, earthquake detection, patient monitoring systems. Wireless sensor networks are also being deployed for military applications such as target tracking, surveillance and security management. These sensors have limited battery power to operate and have limited communication range. Hence energy management is crucial for wireless sensor networks. Thus conserving the energy in sensors is critical issue while designing the protocol of medium access layer of protocol stack, which is shown in Fig 1. Hence, lot of research is going on for developing the algorithms which increases the throughput of wireless sensor networks as well as reduces the energy consumption in nodes[6].

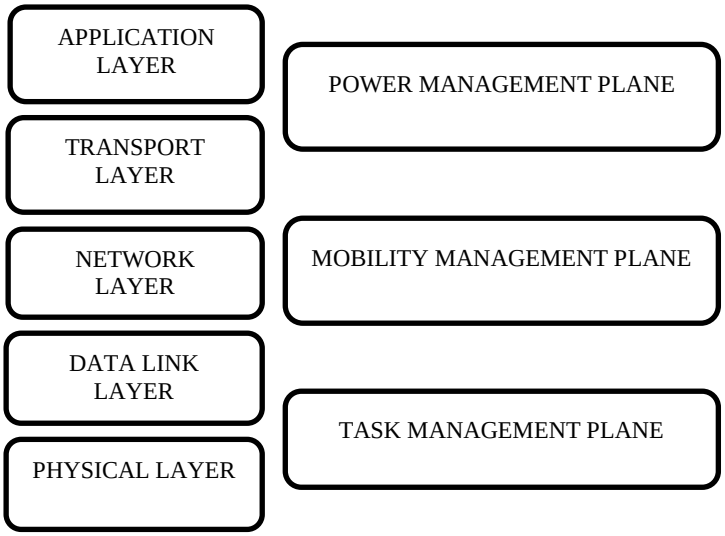

Fig. 1 protocol stack

In this paper, we proposed an ET-MAC protocol which is contention free MAC protocol. This protocol uses TDMA scheme. This is energy efficient protocol and is maximize the lifetime of sensor network by avoiding the major sources of energy waste such as, collisions, overhearing and idle-listening. In TDMA the time is divided into the number of frames and these frames are further divided into slots. These slots are assigned to nodes in a particular manner, in which

they do transmission and receiving activity exclusively. The aim of our project is to assign the slots to the nodes dynamically, because predefined or static assignment of slots leads to waste of bandwidth and increases waiting time for the last node even it have very little data to send. Second, if nodes do not have data to transmit it is wasting the time slot in the frame in static TDMA protocol , where as in our protocol we are going to assign a slot to a node which requests. Those who do not have anything will not be assigned any slot. Thus channel utilization will increase. Third our protocol will handle different traffic rate.

Primarily there are two types of medium access control (MAC) protocols. (1) contention-free and (2) contention-based MAC protocols. In contention-free MAC protocol the channel which is among all nodes used such a way that collision never happen. Because, at any point of time only one node has access to the channel. Contention-free protocols are further divided into two categories. First is Fixed Assignment and second is Dynamic assignment. Our protocol comes under Dynamic Assignment category. Second is contention-based protocol. Here channel is assign such way that collision will occur, because all nodes allowed to access the channel simultaneously. But protocol is design in such a way that it will reduce the probability of collision and also have mechanism to recover from it. Fig.2 shows the category as well as example of this protocol. There are some protocol exist which called hybrid protocol which uses the advantages of both categories and try to avoid the weaknesses of both.

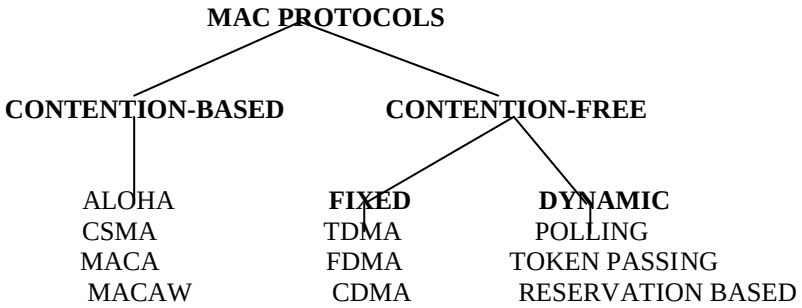

Fig.2 categories of MAC protocols

In this paper, we proposed an ET-MAC protocol which is contention free MAC protocol. This protocol uses TDMA scheme. This is energy efficient protocol and is maximize the lifetime of sensor network by avoiding the major sources of energy waste such as, collisions, overhearing and idle-listening. In TDMA the time is divided into the number of frames and these frames are further divided into slots. These slots are assigned to nodes in a particular manner, in which they do transmission and receiving activity exclusively. The aim of our project is to assign the slots to the nodes dynamically, because predefined or static assignment of slots leads to waste of bandwidth and increases waiting time for node when it have very little data to send.

II. Related work

Studies revealed that the main sources of energy waste in wireless sensor networks are collision, control packet overhead, idle listening and overhearing. These are common problems in shared wireless channel. These problem tackled by Medium Access Control protocol.

A. *Contention-Free mac Protocol With TDMA Scheme*

TDMA scheme naturally avoids above problems of collision, overhearing and idle listening with perfect scheduling. So, TDMA becomes natural choice for MAC protocol when it needs to conserve energy. Recent researches have proposed some TDMA-based MAC protocol for wireless sensor networks [1], [2], [3], [4] and [5] which uses TDMA approach.

The authors in[1] has proposed E-MAC protocol for wireless sensor networks. This protocol is based on self-organizing and fully distributed approach. There are two kinds of nodes in network, active and passive. Active node periodically listen to channel and broadcast a short control message, which is used for MAC operation and piggybacking. This information used to create maximal independent set of nodes, which creates a connected network of active nodes. Here each node can have one of the three modes of operation.(1)Active mode- nodes forwards the packet to destination.(2)Passive mode- nodes keep track of one of the active nodes.(3)Dormant mode- nodes put in low power state for a greed amount of time. Here time slots are reused in at least 3 hop neighbour nodes. This protocol works well only in limited network traffic.

Hoesel et al. presented the Lightweight *MAC* protocol (*LMAC*) [2].This protocol inherits the idea of E-MAC. L-MAC uses distributed algorithm for slot assignment. Slot consist two parts. (1) Control message (2) Data unit. Upon receiving message receiver will decide to stay awake or not. By combining message from all neighbouring node is able to determine unoccupied slots. Process starts from base station, during each frame it continuous throughout network. Node cannot select a slot which is in two hop neighbour. Problem with this protocol is, if collision occurs in control message during selection of slots, process needs to be restarted.

Heinzelman et al. [3] propose a Low-Energy Adaptive Clustering Hierarchy (*LEACH*), which generates clusters based on the size of the sensor network. In LEACH protocol, the nodes are organized in the clustered form. Each cluster has one cluster head which is responsible for deciding the schedule and assigns the slots. Here duration of slot is constant.

LEACH rotates the responsibility of cluster head randomly so that energy level in cluster remains balance and no single node will drain out of it is energy by serving as cluster head alone.

Samra Boulfekhar et al. [4] propose S-TDMA protocol, which generates cluster using LEACH protocol. Here cluster head does the slot allocation. Account query message sent by cluster head and Response query is by other nodes in cluster. With response query nodes sends number of data units they have in buffer. Slots are assigned as per number of units. If nodes do not have data units, slot will not be assign to it. Thus slots are not wasted.

Shafiq U. Hashmi et al. [5] propose An Efficient TDMA Scheme with Dynamic Slot Assignment in Clustered Wireless Sensor Networks. Here, cluster is deployed such a that CH can accommodate only some of the nodes at a time.Which will save the wastage of channel bandwidth and reduces energy consumption. DSA requires nodes with dual band transceivers. When any sensor wants to send data, it communicates with its CH and sends a request for connection. CH gives next slot in frame and node submits it data followed by connection termination.

III. Network model

A. Basic Framework

Network is deployed in a clustered form. Network is divided into number of clusters. Cluster consists of cluster head(CH) and others are Cluster members(CM). Cluster node has a duty of assigning the slots to the Cluster members of its own cluster. Cluster members have a fixed sized buffer space, where they store the sensing data. Each node has unique id and has different data rate. We are assuming the situation, where we are finding some area from our deployed network. From these areas we need more frequent packet or data then other part of network. These areas are more sensitive. So, different packet rate we are going to assume. There is a base station to whom cluster heads will submit their data. Here, we assume that most of the time sensors have data available but in different number.

B. ET-MAC slot assignment scheme

The main stress kept here is on assigning slots. Here sensors are keep sensing and keep gathering data in their buffer space with a different rate and so traffic load can be different time by time during data submission. As describe earlier network is divided into number of cluster. Cluster Head(CH) will take responsibility for assigning slots and receiving data from other nodes in cluster.

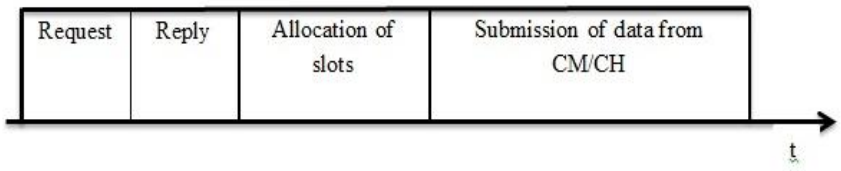

Fig.3 frame format

For this protocol frame format is shown in Fig.3. Here submission of data from cluster members(CM) to CH will not be fixed and which is explain below.

1) *REQUEST*

Initially cluster head(CH) will broadcast a request message to all of its members called cluster members (CM). CH wants to know that, how many packets are in the buffer space of each and every node?

2) *REPLY*

Each node has a counter(CNTR) value which will increment each time when data is stored in a buffer space. Buffer space is nothing but a queue.

$$CNTRcmi = CNTRcmi + 1; \quad (3.1)$$

Each node who receives this broadcasted message, will reply with a single packet to its base station. Each node will know the unique id of base station from the information of the REQUEST message and puts its own unique id in REPLY message.

If any REPLY message is not received by CH from any node, it will again send a unicast message to it only.

3) *ALLOCATION OF SLOTS*

Now, CH collects the information from the messages sent by cluster members and execute *largest remaining data first* and calculate number of slots for each member and sends slot numbers to them one by one.

$CNTR_{CHi}$ (total no of packets from all the members).

$$CNTR_{chi} = \sum_{i=1}^{n} CNTR_{ch}; \quad (3.2)$$

The time length of next part is calculated by,

$$TL = CNTRCHi * Ts; \quad (3.3)$$

Where T_s is the time necessary for send or receive data of length X.

As it will receive all message it executes the algorithm called *largest remaining data first*(LRDF).

STEPS followed by Algorithm:-

1. After collecting reply messages from cluster members, cluster head comes to know that what number of slots needed by each member, which is extracted from packets.
2. Then CH will sort those integer values from maximum to minimum and stores those values in an array.
3. Now, two dimensional array is used, where number of column will be same sa number of nodes and number of rows will be a (max integer value + 1) or we can say first element of sorted array.
4. First row of two dimensional array will be same as sorted array.
5. Next in each column one by one a single slot will be assigned and at the same particular value in first row will be decremented by one.
6. When values in first row become zero then no slot will be put in those particular columns afterwards.
7. When all values in first row becomes zero, first column leaving first element copied into a temporary array and send to the node which wants maximum slots.
8. One by one all cluster members will receive their slots in array form.

4) *SUBMISSION OF DATA FROM CM/CH*

After receiving the slot numbers from CH each node will extract their data from packet and submit them to the CH in their allocated slot.

E. *ILLUSTRATIVE EXAMPLE OF ET-MAC PROTOCOL*

V_i = a global variable which stores value of pointer sent by node i.

Assume node from V1 to V5 with the no of data in their buffers 1, 3, 4, 2, 5 respectively. Algorithm for assignment shown in Fig. 4.

V_1= 1 , V_2= 3 , V_3= 4 , V_4= 2 , V_5= 5;

5	4	3	2	1
1	2	3	4	5
6	7	8	9	0
10	11	12	0	0
13	14	0	0	0
15	0	0	0	0

Fig. 4(slot assignment)

Hence according to the algorithm slots will be allocated to the nodes.

V_5 = 1 , 6 , 10 , 13 , 15;
V_3 = 2 , 7 , 11 , 14;
V_2 = 3 , 8 , 12;
V_4 = 4 , 9;
V_1 = 5;

And slots assignment according to the above example is shown in Table 1.

Hence, node V_5 need not wait for others to complete transmission. Where as in Traditional fixed TDMA it have to wait for 10 time slots.

1) *Slot Allocation*

Table. 1 (Slot Allocation)

SLOT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
NODE ID	5	3	2	4	1	5	3	2	4	5	3	2	5	3	5

This slot assignment is done using Largest Remaining Units First algorithm. where each node initially getting a single slot according to priority. The nodes with maximum data units will have maximum priority. Then remaining slots will be allocated by same procedure. Last CH will send packet which contains list slots for particular node.

2) *Schedule Table*

Table 2 (Schedule Table)

NODE ID	SLOT NO
1	5
2	3,8,12
3	2,7,11,14
4	4,9
5	1,6,10,13,15

This schedule table shown in table-2 is sent to all nodes and nodes will send their data to cluster node only in their time slot which are instructed in table.

IV. Simulator Results

Simulation results are carried out on Tossim simulator. Results compares ET-MAC and traditional TDMA protocols. Comparison is shown in form of graphs.

A) *RF POWER VS PACKET DELIVERY RATIO*

Packet delivery ratio is a ratio between total number of packets receive and total number of packet sent. This describes what percentage of packet are successfully delivered.

Rf power is a measurement of signal power. Its unit is dbm (Decibel-milliwatt).

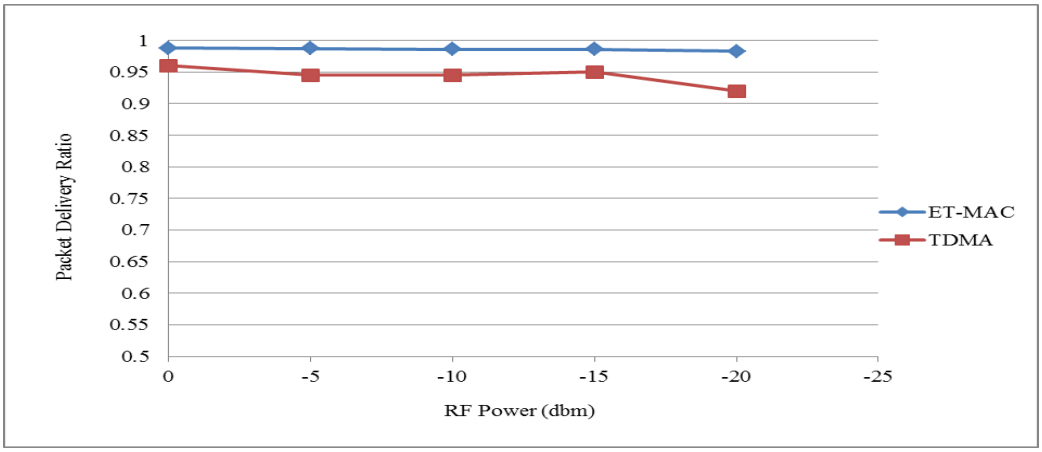

Fig. 5(Packet delivery ratio VS Rf power)

Graph presented in Fig.5 shows that up to -20 dbm values the packet delivery ratio is 98% where traditional TDMA has less delivery ratio than ET-MAC.

B) *SOURCE DATA RATE VS PACKET DELIVERY RATIO*

Source data rate suggests that the rate at which the nodes in network is generating packet or sending the packet.

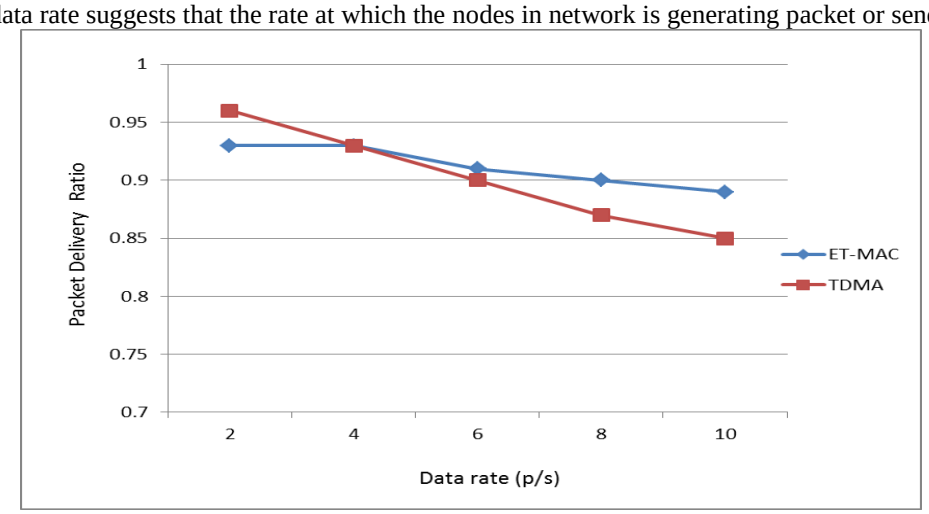

Fig. 6(Packet delivery ratio VS Data rate)

Fig. 6 shows that packet delivery ratio is not varying much while increasing the data rate, whereas for traditional TDMA has more packet loss than ET-MAC.

C) *TIME SLOT UTILIZATION*

Following graph is shown to explain how our protocol ET-MAC has 100% time slot utilization and TDMA's utilization can be varying.

For example,

Here we are assuming that 1 slot is for transmission of 1 byte. So, in traditional or fixed TDMA each nodes are assign with some predefine number of slots. Let say 3 slots are assigned to all nodes. So, there is a possibility that a node can transmit 0 or 1or 2 or 3 bytes. Hence, if nodes have less bytes than 3 or zero bytes to transmit slots are not utilized properly and getting wasted. Fig.7 green color suggests the unused slot, blue and red suggests used one.

In ET-MAC protocol nodes will find what number of data(in terms of byte) available in its buffer space and ask for same number of slots. And only that number of slots will be assigned to it by cluster head. If 1 is needed 1 will be assign, If not needed of any slot, no slot will be assign.

Hence, there is not fixed number of slot assign so that the wastage of slot can occur.

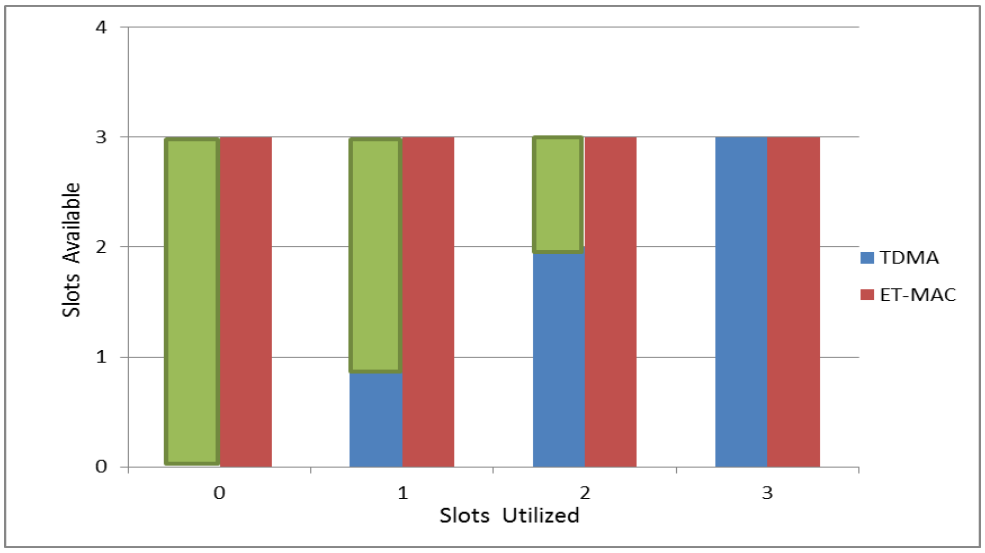

Fig.7 (Time Slot Utilization)

V. Conclusion

We have successfully implemented the MAC protocol which is enhancement of S-TDMA and reached to that ET-MAC protocol is comparatively performs better than fixed TDMA. From graphs we can conclude that ET-MAC has better packet delivery ratio against RF power and as well as different data rates than fixed TDMA. Also, slot utilization is much higher than TDMA. We implement buffer space at each node for storing data which is useful when data rate is high. Data stored here. Nodes counts how many number of data are in buffers and demands slot for it and cluster head assigns it successfully. Applying LRUF algorithm no node will wait for other nodes to finish transmission and as well as takes care of high and different data rates with better delivery ratio.

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