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Schedule based MAC Protocols in wireless sensor networks - A Survey

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Abstract— A wireless sensor network made up of huge amount of devices that are less in size as well as self-directed and distributed. These devices are known as sensor nodes that comprises of various components. Sensor nodes are low power battery devices. Energy consumption is a vital issue in wireless sensor networks (WSN).Various MAC protocols have been designed to lower the usage of energy in WSN. WSN-MAC protocols are categorized into two types: contention based and schedule based protocols. This paper discusses the challenges of WSN and Schedule - based MAC protocols and compare the various schedule based MAC protocols by highlighting their strengths and weaknesses.

Keywords— *Time division multiple access (TDMA); Wireless Sensor Network (WSN); MAC protocols*

I. INTRODUCTION

A network that consists of large number of devices that are distributed, self-directed as well as small in size is known as wireless sensor network. These small devices present within the WSN are known as sensor nodes. There can be around hundreds to thousands of sensor nodes present within the network. Sensor nodes keep track of the various conditions of the surroundings such as pressure, humidity, temperature. A sensor node comprises of various components which are a sensing unit, processing unit, communication unit and power unit. The various tasks such as collection of data, sensing, processing and transmitting of data to other nodes are performed by the various nodes [1]. The conditions of surroundings are sensed with the help of sensing unit further, the permutations of the sensed data are computed by the processing unit. This processed information can be exchanged further to the neighbouring nodes with the help of communication unit.

1) Architecture of a sensor node

The most important unit within the sensor nodes is a processing unit. The various tasks performed by components occur within the processor. The tasks are loaded within the processor. On the basis of functionality of the nodes, the rate of energy utilization can be computed. On the basis of various evaluation factors such as speed of processing, data rate, memory and so on, the changes within the performance of the processor can be computed.

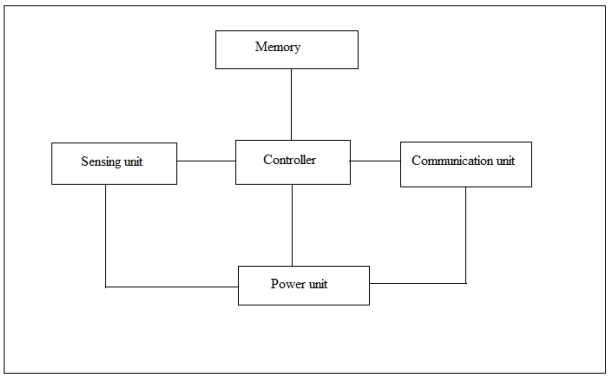


Fig 1. Architecture of sensor node [2]

2) Characteristics of Sensor nodes

The various characteristics of the sensor node used to assess the performance of WSN are:

- *Fault tolerance:* The failure of a node is a possibility within every network. In case when any node failure occurs within the network, the fault tolerance is the property that helps in controlling the functionalities of the network.[3]
- *Mobility of nodes:* The mobility of the nodes is free as there is a need to increase the communication efficiency of the network. The types of applications are an important factor to be considered.
- *Dynamic network topology:* There is a standard topology followed between the links of sensor

nodes. This can help the network to work in a dynamic nature.

- *Communication failures:* In case there is a need to exchange the data amongst other nodes, it is to be ensured that there is no delay occurring within the network towards the base station or the gateway node of the network.
- *Heterogeneity of nodes:* Various sensor nodes are deployed within the sensor networks. It is necessary for these nodes to work in cooperative manner in order to provide corrective mechanism.
- *Scalability:* There are innumerable sensor nodes present within the network. There is highly scalable network environment present within WSN.
- *Independency:* There is no central control point present within the wireless sensor networks.
- *Programmability:* There is a need of reprogramming or reconfiguring within WSN such that the random changes made within the network can be adapted in the network.
- *Utilization of sensors:* There is a need to provide maximum performance along with less energy within the sensors.

3) Challenges and Constraints of WSN

Although the wireless sensor networks and distributed systems are similar to each other, there are numerous challenges and constraints present within these networks. The architecture and designing of WSN is affected a lot due to this. This result in generating protocols and algorithms that are different from the other components within those networks.

a) Energy

There is huge energy consumption amongst various communication protocols due to intrinsic properties of the sensor nodes. Higher energy efficiency is provided with the help of various WSN communication protocols and applications. There are very limited power resources within the sensor nodes. Thus, in order to improve the performance metrics of these networks, there is a need to handle the power consumption.[4]

b) Node Deployment

In order to develop the WSN protocols, the WSN is deployed. There is no need to pre-determine the positioning of sensor nodes within the network. The networks are randomly deployed at the locations that are not accessible by humans or those are disaster prone. There is a need to self - manage these nodes which can further operate and collaborate with the other nodes and adapt to the failures occurring within the network. The changes occur within the network due to the mobility of the nodes in free manner. There is a need for the network to be adapted to the changes in order to provide better maintenance.

c) Wireless Medium

The sensor network designer faces numerable challenges during the communication within the wireless networks. The range of radio signals is limited when there is large and small-scale fading. There is a rapid increase in the distance between the sensor node and the base station. Thus, large distance is partitioned into various shorter distances. This result in challenging the support of multi-hop communications and routing through this mechanism.[5]

d) Hardware Constraints

There is an increase in growth of the traditional computing systems and the major issue within these networks is to design the network which is improved in terms of size, cost and other parameters. The designing of various protocols and algorithms is also affected due to the hardware constraints of the sensor. The entries of possible destinations in the network are to be stored within the routing tables. As the entries might be large in number it is difficult to store them within the memory of sensors. The redundant information can be reduced within the processing of these networks. The various sensor fusion and aggregation algorithms are required in order to increase the power of computation and the storage capacities of the network.

e) Security

The sensitive information is gathered from wireless sensor networks. There is an insecure transmission of data due to the wireless shared medium. All the data gathered from the network is sent to the sink of the network. If the sensor readings are missed, the correct execution of the actions or decisions controlled are provided. The attacks can be prevented or the effects caused by these attacks can be minimized with the help of various preventive mechanisms introduced. There is numerous computational, communications and storage related effects caused within the network which need to be handled.[6]

II. WSN- MAC

This section discusses the characteristics of various MAC protocols, major sources of energy waste in WSN, categories of MAC protocol, challenges of schedule-based MAC protocols.

1) Characteristics of MAC protocols[2]

There are various characteristics of MAC protocols can be summarized as follows :

- *Transmission Delay:* Transmission delay is the total time that is spent by single packet in the MAC protocol. It can be classified in two types deterministic delay (means total number of

state transitions) and probabilistic delay that allows only some part of the delay. There should be as less mechanisms as possible in this type of delay.

- *Throughput:* The rate at which messages are transferred is known as throughput. The throughput measurement can be done in terms of messages or symbols per second but mostly in bits per second. Our goal is to maximize the throughput.
- *Fairness:* If a MAC protocol allocates a channel to the competing nodes with some fairness criteria then it is considered as a Fair MAC protocol. However, in WSN fairness is a complex term. WSN is a distributed system so the channel allocation ratio between nodes may or may not be fair.
- *Scalability:* The ability of wireless communication system to meet some performance characteristics with the size of the network and the total competing nodes is known as scalability.
- *Robustness:* The composition of reliability, dependability and availability is known as robustness. It is the protocol sensibility over a continuous period of time for traffic load.
- *Stability:* Stability is refereed as how good a protocol handles fluctuation in the traffic load over a continuous period of time.

2) Categories of MAC protocols

MAC protocols are categorized in two basic categories: i) contention-based ii) scheduled-based protocols.[7]

a)Contention-based protocols: These protocols are based on a technique named as Carrier Sense Multiple Access (CSMA). In this channel is allocated to nodes on demand i.e. for a given transmit opportunity nodes try their luck for the channel and if channel is free, they starts transmission else can postpone the transmission until channel becomes idle and sense the channel to get the chance to transmit.

b) Scheduled-based protocols: These protocols are based on time-division multiple access technique (TDMA). In this channel is divided into fixed slots of time and their complete cycle is called as frame. TDMA MAC protocols minimize the energy consumption as they can reduce wastage due to collision, idle listening and over –hearing.

3) Reasons of Energy Waste in WSN

Following are the main energy wastage reasons in wireless sensor networks(WSN).[8]

- Collision: When more than one packet received by a node at the same time then they collide with each other, due to this those packets have to be rejected and there is need to retransmit those packets, which consume extra energy.
- Over - hearing: When a packet reaches to a node for which it is not destined, then it is known as over-hearing.
- Idle listening: When a node listens to the channel every time even if the data is not present on the channel causes idle listening, overhead and consumes more energy.
- Protocol overhead: Sometimes there is need to send extra control packets with actual data which causes protocol overhead and consumes extra energy.

4) Challenges of Scheduled based MAC protocols

Schedule based MAC protocols reduces collision, idle listening and over hearing, still there are various challenges in schedule based MAC protocols.[7]

- There is need of time synchronization between the neighbouring nodes and due to mobility of nodes resynchronization is requires.
- When network traffic load changes than it becomes difficult to adapt the schedule.
- To record or to keep the node and its neighbour's schedule , memory is needed.
- Maintenance of scheduling protocols causes extra packet overhead during network set up and at the time of change in the topology.

III. Various Schedule based MAC protocols

1) TRAMA (Traffic Adaptive MAC protocol)

TRAMA is a TDMA based MAC protocol. This protocol saves more energy by providing collision free scheduling of nodes. In TRAMA, nodes goes into idle state when they don't have any data to send on the channel therefore, it consumes less energy. TRAMA comprises of three components: neighbourhood protocol (NP), adaptive election algorithm (AEA), schedule exchange protocol (SEP). TRAMA divides time into two slots: a) random access also called signaling slots, b) scheduled access also called as transmission slots.[9]

In initial stage, it is in random access mode in which each node picks up a slot randomly. Nodes indicate the intended receiver by exchanging their two hop neighbourhood information. A node can join the network at the time of random access period. AEA allows all the other nodes to go into idle state by using schedule information for current time slot.

Advantages: TRAMA has less collision during packet transmission than the contention based protocols. Due to this

maximum throughput is possible and energy efficiency is improved.
Disadvantages: Because of maximum sleep time in TRAMA there can be high delay in packet transmission than the contention based MAC protocols.

2) EMAC (Eyes MAC)
EMAC is a TDMA based protocol comprises of self - organizing and distributed system for transmitting data in wireless sensor networks. Each node actively listens to the channel at regular intervals and send control messages to all other nodes. Data is transmitted in time slots and each node can transmit data in its intended time slot. A schedule table is maintained by each node in which it stores its schedule and neighbours' schedule. There are three parts of a time slot in EMAC protocol: Communication request (CR), Data Part and Traffic Control(TC). In CR part, nodes ask to tell about the accessibility of data for a time slot controller node. Those nodes that do not receive a request during this time will turn their transceiver on for the entire time of CR part. Node that has the time slot sends its schedule for its data part and broadcasts schedule table to TC part. All nodes will be in sleep mode during a time slot that is not used by any node. If there is no addressing of a node in TC, and if its request is also not accepted, then node will be in stand by state during the entire time of data part. After the TC part, actual data is transmitted either by uplink or downlink transmission.[10]

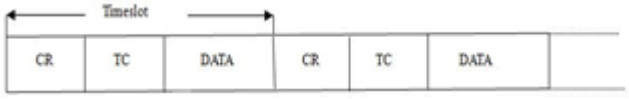


Fig 2. Time slot structure for EMAC[7]

Advantages: EMAC is a scalable protocol having dynamic configuration. This protocol reduces the packet overhead thus maximizing the energy efficiency and minimizing the power consumption.
Disadvantages: Some energy consumption in CR part of the protocol due to idle listening and also this protocol is not suitable for higher bandwidth utilization.

3) L-MAC (Light Weight Medium Access Protocol)
LMAC is an energy efficient scheduling protocol that provides collision free communication by using TDMA. LMAC is mainly designed to minimize the number of state transitions and minimize the protocol overhead. By reducing the radio state transitions sensor nodes become adaptive to heavy traffic loads and implementation cost also becomes less. This protocol has two parts: control message part and data part. Time slots will kept small so that no wastage of energy in idle listening. In LMAC, nodes selects their time slots based on their own local information.[11][12]

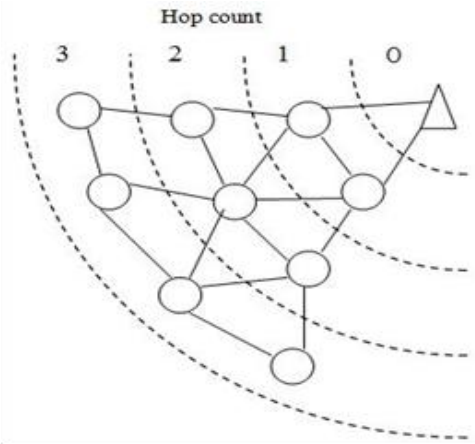


Fig 3 . Hop distance tracking by nodes in LMAC[7]

Advantages: Nodes self-organize their time slots based on their local information and synchronized their schedule even in case when nodes are mobile. This property minimizes the protocol overhead. State switching reduction decreases the energy consumption, hence increases the network lifetime.
Disadvantages: High delay from source to sink. Bandwidth utilization is less and throughput is less.

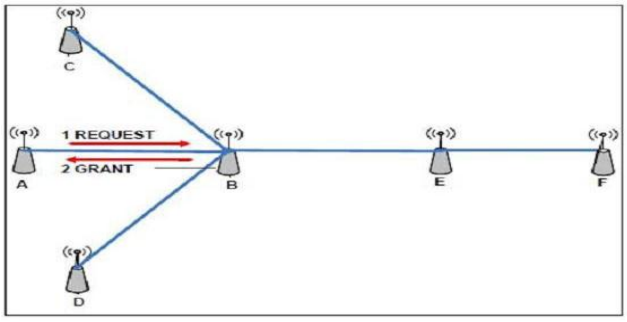
4) D-MAC (Data Gathering MAC)
DMAC is an energy efficient MAC protocol having low latency and converge-cast communication. The main goal of DMAC is to reduce the delay in data gathering and thus increasing the energy efficiency. This protocol allows transmission of packets continuously because all nodes are notified of the continuing transmission. Nodes are assigned with the adjacent slots to reduce the latency in the data aggregation tree. This protocol adjusted the duty cycle according to the traffic load. In DMAC, time interval is having three parts: sending, sleep and receiving period. Length of sending and receiving interval is same in the tree. A node selects its wakeup schedule by finding the depth of node to sink node. When there are large amount of packets to send, then there is need to maximize the node and other hops' duty cycle time by using extra data flags in the header part of MAC.[13]

Advantages: End to end delay is less in DMAC. It increases throughput during high traffic and solves interruption problem in data forwarding.
Disadvantages: It is not reliable for end to end delivery of data so cannot use for real time applications. It does not provide fairness in scheduling.

5) DRAND (Distributed Randomized TDMA protocol)
It is a distributed randomized time slot scheduling algorithm. DRAND increases the energy efficiency as it schedules nodes in a conflict free manner. In DRAND at the start node A is in idle state, then a request is sent by A to B based on some probability (tossing a coin and probability of getting a

head or tail is 1/2) . Node B gets the time slot of A and add it to the list. If during this time, node B doesn't get any request from its one hop neighbours before A then it sends a grant message. By getting grant message node A allocates its time slot. If any one hop neighbour of B sends a request message to B before A then node B gives a release message to node A. In both scenarios node A has to wait for a time period Ta (time delay). Node A broadcasts a fail message to all its neighbours and move to idle state. After Ta time node A again gives a request message.[14][15]

Advantage: DRAND works efficiently in large networks. It provides collision free scheduling by doing slot assignment locally for each node.



.Fig 4. Slot assignment by DRAND[14]

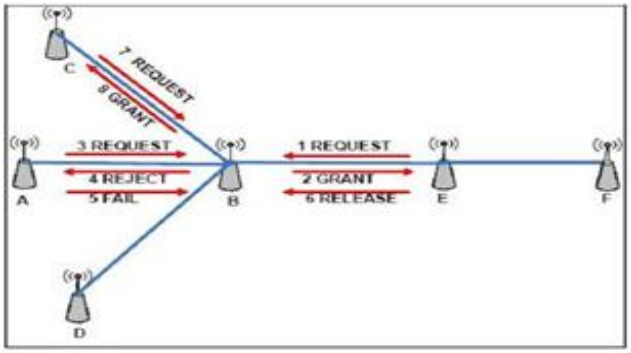


Fig 5. Unsuccessful slot allocation by DRAND[14]

Disadvantages: Sometimes it includes extra message overhead because of fail message, it consumes more energy in sending unnecessary messages.

6) Fair Scheduling TDMA protocols

It is a distributed slot -scheduling algorithm. Each node has four states IDLE, GRANT, REQUEST and RELEASE. In this algorithm, node A gives a request message to node B. If node B doesn't get any request from any of its one -hop neighbours then it sends a Grant message to A and also it sends request to all its two hop neighbours indicating about the time slot of A. If any other request comes from node E before A to B then node B store requests in its queue and gives a WAIT message to all nodes which have sent requests then node B assigns the grant to nodes according to priority of requests.[14][16]

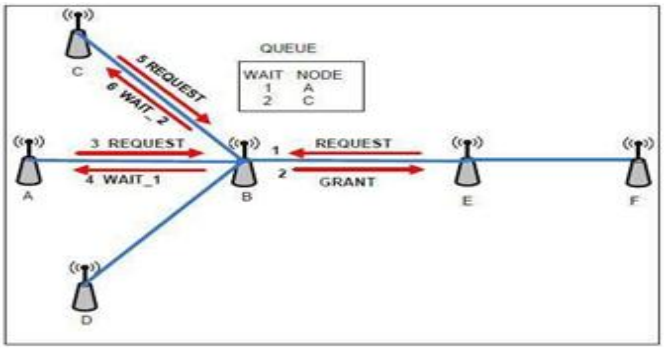


Fig 6. Fair scheduling in wireless sensor networks[14]

Advantages: Message overhead is less than that of DRAND, due to this it is more energy efficient than DRAND.
Disadvantages: The main disadvantage is that it needs extra memory to store the requests coming from the nodes. It increases space complexity of the algorithm.

7)DICSA (Distributed and concurrent link scheduling algorithm for data gathering in wireless sensor networks)

DICSA gives distributed link scheduling even without getting any pre-assumption about the network. It allocate slots to the nodes by considering two algorithms: (i) Primary State Machine: in this, each node performs its own slot reservation (ii) Secondary State Machine: in this, there is concurrent participation of each node in the slot assignment of its neighbours. DICSA gives the concurrent slot reservation of the nodes. It reduces the energy consumption by providing collision free slot allocation. Both algorithms access a list of forbidden slots.[17] In DICSA, nodes allocate their slots without considering the time and their neighbours' reservation status. A slot reservation can pass or fail, but nodes cannot update their list of forbidden slots immediately until reservation is completed.

Advantages: DICSA is more energy efficient than DRAND and also in terms of slot assignment. It provides more efficient packet forwarding than DRAND. It is used in data gathering applications, improves the performance of data gathering applications.
Disadvantages: Sometimes it incurs message overhead due to packet collision.

8)AEH-MAC (Adaptive Sleep Efficient Hybrid MAC protocol)

AEH – MAC adjust the sleep time of nodes dynamically to increase energy efficiency by reducing the idle listening, increasing the sleep time and reducing the collision. The nodes' sleep time is calculated dynamically in accordance with the traffic load of requests and wakeup time is coordinated with the neighbour nodes. In this, each node

reserves a conflict free slot for itself up to their two hop neighbouring nodes. In case of heavy traffic load in the network, at that time sleep time of nodes is reduced to reduce the energy consumption due to switching. [18]Each node in the network reserve its slot based on their local track of data instead of depending on the neighbouring nodes and seeking for Grant messages. Each node has their one and two hop neighbours' IDs and their slots information. When traffic load decreases, sleep time of nodes is maximized to save the energy due to idle listening. AEH- MAC fairly allocates the bandwidth to all the nodes in the network. It reduces the hidden and exposed terminal problem.

Advantages: It reduces the packet collision and energy consumption. It helps in concurrent slot scheduling without increasing extra message overhead.
Disadvantages: This algorithm is not highly synchronized due to which there may be collision. It doesn't work efficiently with highly mobile networks.

Table 1. Comparison of various MAC protocols

Protocol	Category	Type	Adaptivity to changes	Overhead
TRAMA	Schedule based	TDMA	Good	Neighbour Protocol, Schedule Transmission
EMAC	Schedule based	TDMA	Good	Selection of time slot and TC,CR of each time slot
LMAC	Schedule based	TDMA	Good	Network setup and control message and DDT
DMAC	Schedule based	TDMA	Weak	Synchronization, unnecessary data flag in header, idle listening, MTS clear/request
DRAND	Schedule based	TDMA	Moderate	Message overead
FAIR SCHEDULING	Schedule based	TDMA	Good	Extra Memory requirement
DICSA	Schedule based	TDMA	Good	Unnecessary packet overhead
AEH-MAC	Schedule based	Hybrid	Moderate	Minimum control overhead

IV. CONCLUSION and Future Scope

Wireless sensor networks are energy restricted and network lifetime is less. Therefore, to enhance network's lifetime, MAC protocols are required. In this paper, various TDMA based MAC protocols have been discussed with their merits and demerits. Time is partitioned into slots and each node is allocated a different time slot to send/receive the data to enhance the energy efficiency of the network. TDMA has the property to minimize the collision in the network. A comparative study of various protocols are also discussed in this paper. In spite of these positive aspects, there are few drawbacks like strict time synchronization, adaptivity to changes etc. With all these tradeoffs, various researches are going on to propose optimum distributed energy efficient MAC protocols for wireless sensor networks.

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