A Review on Energy Efficient MAC Protocols in Wireless Sensor Network

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Abstract : Wireless Sensor Networks consists of various nodes of small size that are easy to install and extend in a very low cost. With advent in technology WSNs are being used in variety of applications such as healthcare, security, transportation, environmental applications. The main challenge faced in certain applications for deployment of WSNs in areas where human intervention is not possible is the non-replaceable and non-rechargeable nature of the battery. For this energy efficient protocols called MAC protocols are used to minimize the factors that cause wastage of energy like Idle listening, overhearing, packet collision, over emitting and maintaining metrics like delay, throughput, adaptability etc. So, MAC protocols help in regulating access of nodes to the transmission channel to decrease power consumption and hence increase the lifetime of the network. In this paper different MAC protocols are reviewed and are analyzed on the basis of technique used in the design of MAC protocol, findings and also the research gaps. This review gives a deep insight to the different MAC protocols that are designed over a time and also presents a comparison between state-of-the-art MAC protocols.

IndexTerms **- Wireless Sensor Network; energy efficient MAC; network lifetime; collision avoidance;**

1. INTRODUCTION

Wireless Sensor Network comprises of a large number of sensor nodes that can communicate with each other and have applications in different fields such as healthcare, security, transportation, environmental applications [1]. Power unit is an important component of sensor nodes as it is responsible for the lifetime of WSN. Every sensor node has a constrained energy due to limited battery life as battery is non-replaceable and non-rechargeable within sensor nodes as they are deployed in remote and hazardous areas. So, it affects the lifetime of Wireless Sensor Network. This is a critical issue in Wireless Sensor Networks.

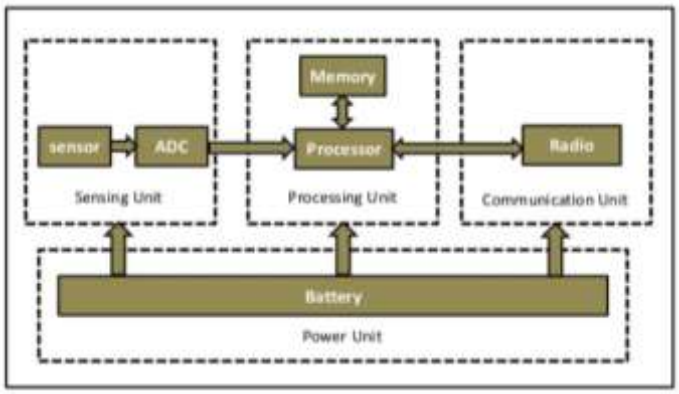

Fig.1 Components of wireless sensor node [1]

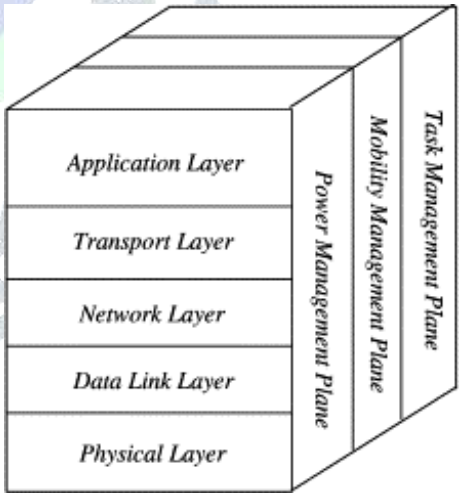

Fig.2 MAC protocol in WSN[4]

Solution for this challenge was first introduced in 2002 when MAC protocols were discussed [2].

1.1. Role of MAC protocols in WSN:

Media Access Control protocol popularly called MAC protocols serves two goals maintaining network infrastructure that is to establish links for communication between nodes and to efficiently share the communication medium among sensor nodes [3]. MAC protocols work on the Data Link layer of the WSN protocol stack. MAC protocols are responsible for efficient power consumption and increased lifetime of the network.

1.2 Classification of MAC protocol:

Broadly MAC protocol can be classified into three categories:

1.2.1 Contention based MAC protocols

In this protocol network node competes with its neighbors to get the channel. Node senses the channel before getting involve in transmission of data. If it is idle, then node transmits the data otherwise node differs its transmission for some time. These protocols are used in Event driven WSN applications. Contention based MAC protocols do not require clustering or topology information. So, each node in the network can independently decide for contention without controlling the frame exchanges. Disadvantages of using these protocols include collisions, overhearing, idle listening and less throughput. CSMA is the example of contention-based MAC protocols.

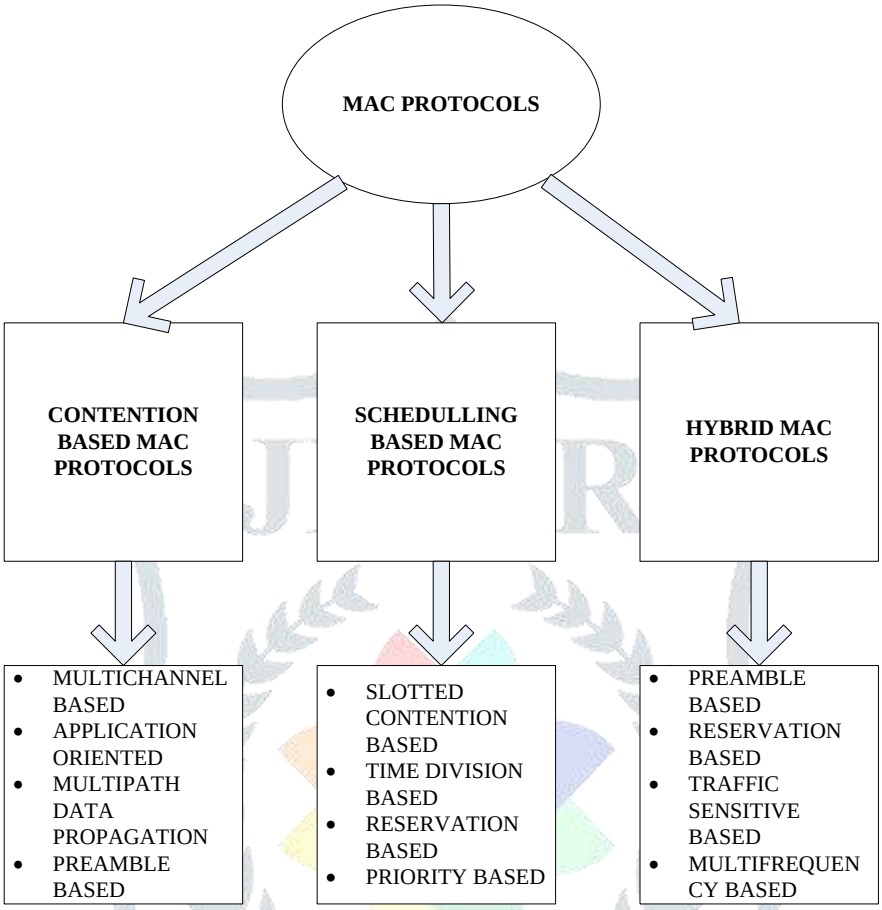

Fig.3 classification of MAC protocols based on Access method

1.2.2 Scheduling based MAC protocols

These are contention free protocols, in these protocols each node is allocated a Guaranteed time slot called GTS to access the medium. In this protocol collisions are avoided but energy consumption is not avoided as node keep its radio on during its allocated GTS even if it has no data to send. The main advantages of scheduling-based MAC protocols include less collisions, less overhearing and avoidance of idle listening. These protocols also provide deterministic end to end delay which is of great importance in certain applications. Examples includes Flow Aware Medium Access Control protocol and Lightweight Medium Access Control protocol.

1.2.3 Hybrid MAC protocols

These MAC protocols exhibit the advantages of two or more different MAC protocols. Generally, they combine the technique of synchronous MAC protocol with that of asynchronous MAC protocols. They are more complex. Zebra MAC protocol is a hybrid MAC protocol that consists of the advantages of TDMA and CSMA.

1.3 Research issues in MAC protocol

There are following research issues that are reported in MAC protocol.
The performance metrics given below:

a) **Transmission delay:** Transmission delay is the time spent by data in the channel after it has been sent from transmitting node till the time it reaches receiving node. MAC protocol designing principles have to comprise on simplicity and low delay with error control, retransmissions and collision avoidance.
b) **Throughput:** It is the measure of the rate at which messages are served and the goal is to maximize it.
c) **Scalability:** This is the ability of the MAC protocol to be applied on wireless sensor network with any number of nodes.
d) **Collision**: collision occurs when packets are send at the same time and the packet is discarded and gets corrupt and there is a need for retransmission.
e) **Latency:** waiting time of sender for receiver to wake up increases Latency.
f) **Reduction in energy wastage:** There are many reasons of energy wastage like collisions, idle listening, overhearing, over emitting that has to be minimum for a better MAC protocol.

g) **Deterministic and bounded delay:** For time critical applications where there is a need of predictable delay and bounded delay some specific types of MAC protocols are needed that can fulfill this condition.
h) **Fairness:** MAC protocol should be able to allocate a channel with a fair criterion.
i) **Lifetime of nodes:** Some nodes in the network die early. So, to increase their lifetime is also a challenge that can be solved by MAC protocol and taking their residual energy into consideration.
j) **Bandwidth utilization:** designing of MAC protocol should be aimed to efficiently utilize the bandwidth to avoid Energy wastage.
k) **Time synchronization:** Time synchronization among nodes is an essential requirement for which many MAC protocols are designed.

We have reviewed various techniques that are used in previous research work and have mentioned the research gaps so that a comparison can be drawn among various MAC protocols.

2. Related work

The efficiency of MAC protocol directly effects the performance and lifetime of Wireless Sensor Networks. A number of MAC protocols have been proposed in past years that have contributed towards improved lifetime of Wireless Sensor Networks while maintaining other characteristics of WSNs. Table1 gives deep insight into different types of proposed MAC, technique used, key findings and also highlights the research gaps:

2.1 MAC protocols in WSN

Akyildiz et al. in [1] discussed that MAC protocols works on Data Link Layer of WSN protocol stack. MAC protocols serve two important tasks that are to establish communication link among sensor nodes and to fairly and efficiently share the communication channel.

Ye et al. in [5] advised a new energy efficient MAC protocol called SMAC that is Sensor MAC protocol. This protocol uses both contention and scheduling scheme. In this protocol, the concept of periodic sleep and listen is used and half of the total frame duration is allocated to sleep and half to listen thus reducing the duty cycle to 50%.This protocol avoids overhearing and adjust the sleep time according to traffic patterns. But more energy is consumed by SMAC compared to IEEE802.11 in case of heavy traffic as SMAC has synchronization overhead of sending and receiving SYNC packets and also more latency to transfer the data.

Ren and Liang in [6] proposed ASCEMAC protocol (Asynchronous Energy- efficient MAC protocol). Free running scheme and schedule broadcast is utilized for phase switch schedules. In this protocol the need for time synchronization is removed by using rescheduling method. It uses the Time slot allocation method. As compared to existing Energy efficient MAC protocols data packet waiting time is less. It is a adaptable to traffic strength and network density. Network lifetime is extended but no detailed information is given about energy consumption form other sources of energy wastage.

Manesis et al. in [4] proposed Variable Load Adaptive MAC protocol. This is an advantageous protocol for variable traffic load as it provides energy efficiency and low latency which is proved through MATLAB simulations. This removes the problem of idle listening as data packets are transmitted in bursts in high load conditions.

Sahoo et al. in [7] proposed DGRAM (Delay Guaranteed Routing and MAC protocol). The design of protocol is based on slot reuse to reduce latency of a node in accessing the medium. DGRAM guarantees the Deterministic delay. Packet average delay and total energy spent in the network are much less than in the case of TDMA MAC.

Tang et al. in [8] advised PW-MAC (Predictive – Wakeup MAC protocol) A prediction-based retransmission mechanism and on demand error correction mechanism is used. Average sender duty cycle is very less that is 11% when compared with other protocols. Packet delivery ratio of 100%. The chances of idle listening increase due to prediction and collisions.

Berder et al. in [9] proposed TDAMAC (Traffic – aware dynamic MAC protocol) Wake-up interval is adapted dynamically based on traffic status register bank so that interval may converge to a steady state in variable or fixed traffic. Lifetime was found to increase 3-6 times the other protocols. Other factors like packet delivery ratio, collisions are not discussed.

Lim et al. in [10] suggested ASMAC (Asynchronous Scheduled MAC protocol) in which Wakeup time of neighboring nodes is scheduled periodically and asynchronously. The advantage includes reduced energy consumption and delay. Limitation of this protocol includes the Overhead for broadcast and need to store one hop neighbor table.

Barac et al. in [11] proposed Priority MAC High priority traffic is enabled to use dedicated bandwidth for low priority traffic at the time of critical traffic. Highest priority traffic is handled more efficiently with different latency requirement without bandwidth wastage. Lifetime of the network has not been discussed and collisions may occur at the time of dealing with higher priority traffic.

Khurana et al. in [12] Multilayer MAC protocol that is based on the technique that reduces the energy consumption to a level not achieved by SMAC and is self-organizing protocol that do not need a central node to have control over all nodes. In this protocol the frame duration is divided into 50% listen and 50% sleep just as in SMAC. Further the listen time is divided into different layers and nodes are distributed over them according to their energy. In these layers the active or listen mode is further divided into active and sleep mode and width of active duration is same in all layers and the active region is non-overlapping. This protocol reduces Idle listening and probability of collisions and hence the energy consumption is reduced and the duty cycle becomes extremely low but there is one limitation that the nodes with low power die early due to the same quantity of work performed as done by high power nodes.

Alvi et al. in [13] advised BEST-MAC (Bitmap Assisted efficient and Scalable TDMA – based MAC protocol). Size of time slots is small but their number is more than member nodes. This protocol considers the short node address. Knapsack algorithm is used for scheduling. Adaptive traffic load is handled in an efficient manner and job completion time is reduced with decreased packet delay which are the main advantages of this protocol. More than 70% and 80% efficiency are achieved in transmission delay than BMA-RR and E-TDMA respectively. Energy consumption is also reduced. But there is no detailed information about parameters

like collision, network lifetime.

Zheng et al. in [14] proposed WirArb (Wireless Arbitration) in which to provide a priority to a user, a channel access is provided. Order of channel access is decided by predefined arbitration frequency. Discrete Markov Chain is used to have efficient utilization of bandwidth and real time communication. Use of Markov chain helps in time critical applications and deterministic delay. Channel utilization comes out to be 100%. It can be used for real time applications. Energy consumption is not discussed.

Rai et al. in [15] proposed JRAM (Joint Routing and MAC protocol). The technique used is that the network nodes is partitioned into k disjoint sets and then a cycle structure is applied. More than one chances are provided to node to succeed in scheduling in a cycle. Energy consumption is reduced in periodic broadcast with low end-to-end delay and reduced idle listening specially in many to one communication. Network lifetime and collisions are the factors that are not discussed.

Farang et al. in [16] discussed DBMAC (Delay bounded MAC protocol). This protocol guarantees the deterministic delay and collisions. At the time of time critical data to be send the priority is given according to Channel Access Order. Same priority is resolved using a Super frame and channel access order. Better performance in case of delay is observed than TDMA MAC with a deadline delay. This protocol is applicable to the network with maximum node 50. No clear information of energy consumption comparison are given.

Siddiqui et al. in [17] discussed ADPMAC (Adaptive and Dynamic Polling based MAC protocol). Different polling distributions along with incoming traffic patterns are varied to improve the energy efficiency and so the lifetime of network. When the arrival of incoming traffic and polling interval distribution are in accordance with each other energy efficiency improves compared to SCP-MAC and is degraded when there is mismatch. Polling may cause delay when there are many nodes to be checked. So factors like end to end delay, packet delivery ratio and collisions are not discussed.

Liu et al. in [18] advised QT-SAC (Quorum Time Slot adaptive condensing) in which nodes wake up times are scheduled adaptively by selecting more Quorum time slots and QTs are allocated only when data is transmitted to further decrease the latency. Duty cycle is prolonged due to more number of Quorum time slots. Energy efficiency increases by 24.64-82.75 % and latency is reduced significantly This protocol is applicable to restricted number of nodes so the scalability of the network is a limitation.

Jha et al. in [19] suggested Multi-Layer MAC protocol that is ML MAC protocol. In this the author showed that the node power consumption was less as compared to SMAC and that of TMAC also by considering some assumptions. Also, some specific parameters were taken into account. The results were verified using MATLAB simulations.

Sokullu and Demir in [20] compared the MAC protocols for Linear Wireless Sensor Networks. The MAC protocols discussed are MFTMAC, DiSMAC, WiWi. MFTMAC is a contention-based protocol and is suitable for applications that involves collection of data through nodes and that is sent to the nodes through Multiple Hopes. DiSMAC is a protocol that avoids collisions and helps in solving hidden node problem for this purpose it uses Directional Antennas. WiWi is a contention free protocol. In this protocol, there is a synchronous communication between nodes. This protocol provides deterministic latency as well as throughput but power consumption issue is not considered for this protocol. In addition to this there is a comparison of other protocols namely LINE-MAC and LC-MAC. LINE-MAC reduces the Energy Consumption as it uses ACK packets which helps in reducing collisions, whereas LC-MAC uses the method of booking of Relay Nodes and use of bursts for transmission. With the help of simulations, it is proved that LCMAC is suitable for lesser number of nodes that is lesser than 20 but LINEMAC even works well with larger number of nodes.

Wang et al. in [21] proposed the protocol called DSMAC (Demand Sleep Media Access Protocol). Through this node are able to adjust their Sleep cycle with respect to the received data packets. A short packet is transmitted to wake up the node. In this way the problem of Overhearing is solved. This protocol is based on Asynchronous Duty Cycle. This devised a way through which the neighboring nodes can know the wake-up time of their neighboring nodes in next duty cycle. This protocol is proved better than SWMAC protocol in terms of heavy traffic conditions which gives lower delay, low energy consumption and less idle listening.

Jang et al. in [22] suggested MCAS-MAC (Multichannel Asynchronous Scheduled MAC protocol). The technique used in this protocol is that the multiple channels that donot overlap are used for efficient utilization of bandwidth. Packet delivery ratio is improved in dense environment in both single hop as well as multi hop networks as that of ASMAC. An additional dwell time is used immediately after the reception of data packets. But this protocol leads to a decreased lifetime.

Ramadan et al. in [23] purposed a Node power based MAC protocol with Adaptive learning period for Wireless Sensor Network. This protocol is an enhanced version of ML-MAC protocol described in [19]. In this protocol the width of active period in sublayers in [23] is varied for low power nodes, high power nodes and medium power nodes. The Back off Algorithm used is binary Backoff Algorithm which reduces the number of collisions. So that the energy consumption can be decreased accordingly according to the power of nodes. In this way the idle listening is reduced and power consumption becomes low ultimately increasing the lifetime of the network and the low power nodes can be save from dyeing early.

3. Conclusion and future scope

In the recent years network lifetime along with the other factors has been the area of concern so has been the MAC. Challenges of MAC protocol are explained in detail to have a deep insight in the past research work. In this paper, we have also tried to bring out the key findings of the different MAC protocols that are discussed in previous years along with the technologies used and the research gaps in Table1 by comprehending the literature. The existing MAC protocols targets the optimal solution of low energy consumption but there are other factors of the WSN that are needed to be explored more like priority, predictable delay, bandwidth utilization, very low duty cycle etc. This paper gives an idea about some of the open research issues that can be resolved by MAC and provides a direction in which further development can be initiated.

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