International Journal of Recent Engineering Research and Development (IJRERD)
Volume No. 02 – Issue No. 05, ISSN: 2455-8761
www.ijrerd.com, PP. 25-37

Investigation on Energy efficient MAC protocols for Wireless Sensor Networks

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Abstract: Wireless sensor networks fundamentally contain large number of small sensor nodes consuming limited battery, storage and processing speed contending in network environment and synchronize with each other to achieve assigned target. Wireless sensor networks have a wide range of applicability such as environmental monitoring, trespasserigilant and tracing, manufacturing process monitoring, and strategic schemes. Due to limited available battery resource energy optimization and efficiency is really significant in WSNs. Energy management is desirable specially at MAC layer as MAC plays a significant role to regulate the operation of radio and it expressively affects the energy consumption of the whole network. Medium access control (MAC) confirms the effective operation of the network. Presenting efficient MAC protocol for Wireless Sensor Network (WSN) to prolong the network life time is challenging issue due to limited power constraint. In this investigation, we present MAC layer features, importance, challenges, taxonomies of various MAC protocols, sources of energy demolition, procedures to control energy losses, study of all the existing the energy efficient MAC protocols and in last there by explaining a relative analysis . Various parameters such as energy consumption, end to end latency, scalability, through put, average jitter, fairness, network lifetime are taken into consideration for relative analysis. This investigation will help in future finding and choice of a protocol in a particular scenario of WSN.

Index Terms: Wireless Sensor Networks, energy efficiency, Medium Access Control, Synchronous, Asynchronous, Contention Based, Schedule Based, Hybrid, Cross Layer.

1. INTRODUCTION

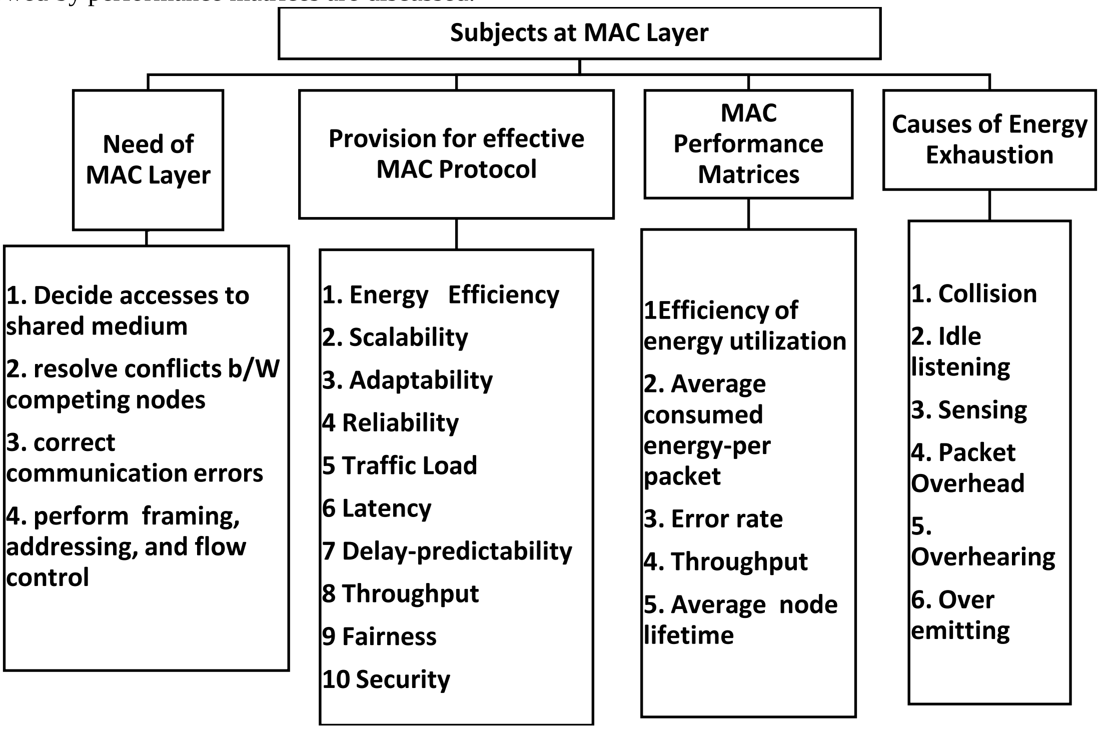
A Wireless sensor network comprises of dispersed independent sensor devices that cooperate to monitor physical or environmental situations, such as temperature, sound, vibration, pressure, pollutants in various site. These networks contain large number of sensing nodes with limited energy and processing capability to monitor the situation and gather the information along with transferring information to established communication network. Due to limited power, energy saving is crucial in wireless sensor network. In a network, MAC is responsible to make decision about channel, to provide access to the medium, scheduling, buffer management, and error control.

Contemporary MAC layer protocols designed for wireless devices such as MACA Wand IEEE 802.11are not suitable for sensor networks as considerable amount of energy is consumed when sensors continuously probe the medium. In addition, these schemes require nodes to transmit control packets in order to avoid collisions. The control packet sizes will be comparable to the size of data packets, which are small in most sensor applications. On the other hand, Bluetooth uses a TDMA based scheme assuming that all slave nodes are within transmission range of the master node, and thus it cannot handle the multi-hop mode of transmission usually employed in sensor networks for saving energy.

Power management of the radio has gained significant importance in sensor networks since the radio is a major consumer of sensor’s energy. The major part of power is consumed in radio (transmitter and receiver), which is controlled by the MAC protocol [1][2]. The effective MAC protocol proposes to reduce energy consumption, while supporting good scalability and collision avoidance resulting in improved lifetime of sensor networks. Security at Mac layer is another important concern because by attacking at a node, an attacker can waste the WSN node energy unnecessarily, steal, and interrupt data transmission. In the first part of our paper we will describe the design challenges of MAC layer WSN and then attributes of good MAC protocols are described. In the next section we will classify the types of WSN MAC protocols with the help of diagram. And then in the next part all the important energy efficient MAC protocols are discussed . After this we will try to differentiate all the energy efficient MAC protocol and will give a table based on attribute collision, overhearing, idle listening, latency etc. and then we will compare the protocols based on an application that is which type of protocol is good for which kind of application.

2. MAC-LAYER ISSUES FOR SENSOR NETWORKS

In this section, we investigate the practical views for designing efficient MAC protocols for wireless sensor networks. We first outline the provisions for effective MAC then sources of energy consumption followed by performance matrices are discussed.



2.1 Need of MAC

The Media Access Control (MAC) layer provides addressing and channel access control mechanisms that enable several terminals or network nodes to communicate in a network. Along with it, it resolve conflicts between competing nodes , tries to correct communication errors and also perform framing, addressing, and flow control.

2.2 Provisions for a Effective MAC Protocol in WSNs[2]

(a). Energy Efficiency: Energy is a scarce resource for sensor networks. energy-conscious medium access control (MAC) can save transmission and reception energy by preventing the probability for collisions, minimizing exchange of control messages, turning the radio into low power sleep mode when it is idle and finally, avoiding the excessive transitions among active and sleep states.

(b). Scalability: It is found that maximum applications of unattended sensor networks involve large number of nodes. Effective Protocol should gracefully accommodate these Variations in network size, node density and topology, resulting in fast and effective adaptation in order to avoid interference and connectivity matters.

(c). Adaptability: The MAC scheme should adapt to variation in network traffic and should allow medium access rescheduling to efficiently handle burst high-priority traffic.

(d). Reliability: To ensure reliability Packet delivery is guaranteed by the attentive choice of error free links, avoidance of overloaded nodes, and the detection and the recovery from packet drops.

(e). Traffic Load: It is duty of MAC protocol to confirm the nodes in network deliver traffic probably inspite of traffic load conditions(increase or decrease).

(f). Latency: The data collected and processed by nodes should be communicated to the network irrespective of factors such as traffic in the network, collision and retransmissions and bandwidth of the network.

(g). Delay-predictability: The active MAC protocol regulates the schedule for packet transmission not only for the individual node but for the entire network. Following time suitability of data response is typically affects efficiency of MAC protocol in communication.

(h). Throughput It signifies the amount of data transferred in unit time. Effective MAC empowers processing of available data without missing even a small detail and transporting to sink thereby resulting in high utilization of the medium.

(i). Fairness: It represents the measure of insurances that the sink node receives information from all sensor nodes in the network efficiently . Effective protocol minimizes the energy wastage in order to achieve high fairness.

(g). Security. By applying Security policies at Mac layer, unnecessarily energy wastes can be controlled that results because of attack on node energy, steal, and interrupt data transmission.

2.3MAC's Performance Metrics

To assess and compare the performance of energy-conscious MAC protocols, the following mix of metrics has been considered indicative by the research community:

1. Efficiency of energy utilization. It is ratio of energy wastage to total energy communicated. A protocol with low overhead, lesser collisions and low idle time would express small ratio of energy wastage.

2. Average consumed energy-per packet A protocol that has low average energy per packet typically encounters few packet retransmissions and suffers little contention-related collisions.

3. Error rate: A MAC protocol, which observes the buffer size limitations and employ an effective packet scheduling at the node and network level, would minimize packet drops.

4. Throughput: It is total number of packets received at the sink node per time unit. A high network throughput indicates a small error rate for packet transmission and a low level of contention for medium access.

5. Average node lifetime: This metric gives a measure of the overall network lifetime. A slow depletion rate extends the life of the sensor battery and lengthens the duration that a sensor can function.

2.4Causes of Energy Exhaustion [3]

Foremost sources of energy exhaustion in wireless sensor networks are [6][7]:

1.Collision: Due to interference, a transmitted packet has to be discarded and the retransmissions of same packet results in increased depletion of energy resources.

2. Idle listening: In idle listening nodes listen to receive possible traffic that is not sent. If nothing is sensed, the sensor node will be in idle state for most of the time. The main goal of any MAC protocol for sensor network is to minimize the energy waste due to idle listening, overhearing and collision.

3. Sensing: Sensing the target field for various parameters like temperature, humidity, flow, pressure etc. in several applications need energy from the battery.

4. Packet Overhead: Exchange of control signals that are used to reduce collision probability also results in energy depletion. So control packet exchanged should be minimum to avoid energy depletion.

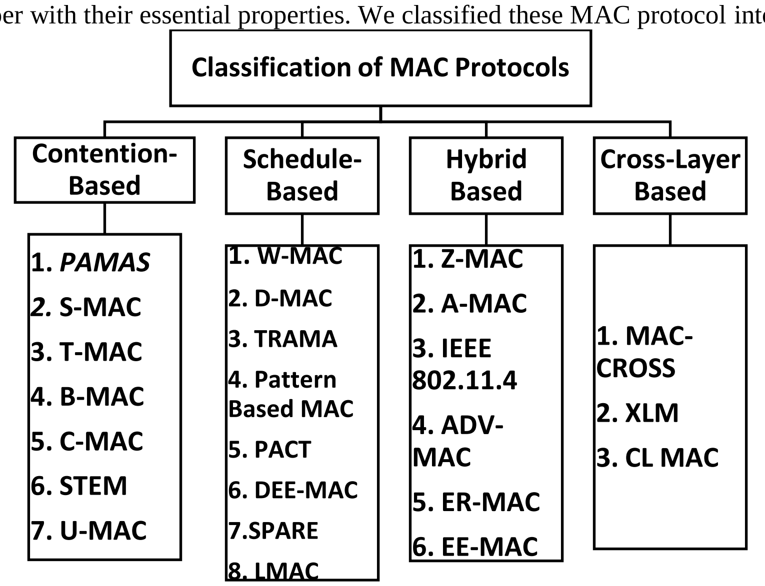
5. Overhearing: Overhearing occurs, when a node picks up packets that are addressed to other nodes.

While developing a new protocol, all these sources of energy wastage should be in mind along with security level of the protocol to result energy efficiency.

6. Over emitting- This is caused by transmission of message when destination node is not ready or sending rate is higher than receiving rate.

3 ENERGY EFFICIENT MEDIUM ACCESS CONTROL (MAC) PROTOCOLS in WSNs

Extensive range of energy efficient MAC protocols are present in the literature some of them are discussed in this paper with their essential properties. We classified these MAC protocol into four categories [1].



3.1 Contention based MAC protocol

The general approach of Contention based MAC protocols are Carrier Sense Multiple Access (CSMA)and Carrier Sense Multiple Access/ Collision Avoidance (CSMA/CA).To obtain wireless channel for sending data on network Mac protocol contend with each other to get wireless channel. The channel is accessed randomly so there is no need of coordination. When the chance of collision decreases in any network than it increases performance of network.

3.1.1 PAMAS (Power aware Multi-Access signaling

PAMAS [4] is a contention based(CSMA) energy efficient MAC protocol. For data and control packets, use of two different channels require two radios at each node increasing the cost, size and complexity of the sensor design but reduces the probability of collisions. In this protocol node goes to sleep mode which are neither transmitting nor receiving the data. The control channel is used for handshaking and the data channel for regular traffic. A node senses the data channel and responds to connection requests only if its neighbours are not transmitting or receiving. Senders that cannot establish a connection switch to sleep mode and retry later. The duration of a node stay in the sleep mode is determined based on the exchange of special probe messages on the control channel among nodes in close proximity. Although, the protocol requires the nodes to sense the medium to transmit but it does not eliminate collisions completely.

3.1.2 S-MAC (Sensor MAC) protocol

S-MAC[5]uses static duty cycle. Every frame has two parts: an active part and a sleeping part. By active part communicates with its neighbours and send messages queued during the sleeping part. S-MAC tries to avoid overhearing unnecessary traffic .It attempts to control energy waste and avoid collision by synchronization locally and periodically accomplish listen/sleep period schedules. All senders do carrier sense before start of a transmission. If the channel is busy, node goes to sleep mode and will try later. To reduce overhead Broadcast packets are sent without using control packets (RTS/CTS). Unicast packets follow the sequence of RTS/CTS/DATA/ACK between the sender and the receiver. To reduce node-to-node fairness, long message is divided into fragments and transmitted in burst through reserved medium simultaneously followed by only one RTS and CTS packet. Sender waits for an ACK from the receive for transmitted fragment. If there is any error, reserved transmission time is extended and retransmission followed. In S-MAC message passing technique is used to reduce contention latency for applications that require in-network data processing. S-MAC reduces the listen time by keeping nodes into a fixed sleep state. During rest time, the node keep its radio off, and fix a timer to aware itself later. All nodes are free to choose their own listen/sleep schedules. However, to minimize control overhead, neighbouring nodes are adjusted by exchanging their schedules periodically broadcasting a SYNC packet to their immediate neighbours.

Advantages: The energy is saved by using sleep and wake up technique.

- Time synchronization overhead may be prevented with sleep mode announcements.

Disadvantages: Broadcast data packets do not use RTS/CTS which increases collision probability. Adaptive listening incurs overhearing or idle listening if the packet is not destined to the listening node. Sleep and listen periods are predefined and constant, which decreases the efficiency of the algorithm under variable traffic load. The listening period of S-MAC is of fixed duration, that is, if there is only little traffic, this will result in wasting usefulenergy. On the other hand, if traffic is heavy, the fixed duration is just not enough

3.1.3 Timeout-MAC (T-MAC)/(Dynamic Source MAC)

T-MAC[6] implements adaptive duty cycle in which messages are transmitted in dynamic length bursts. T-MAC improves S-MAC by reducing energy consumption in idle listening phase and under variable traffic load due to static sleep-listen periods. Nodes wake up during the beginning of a slot to listen for activity and returns to the low power sleep mode when no communication sensed. In T MAC, nodes communicate with each other using a Request To Send (RTS), Clear To Send (CTS), Data, Acknowledgement (ACK) scheme, which provides both collision avoidance and reliable transmission. Clustering and Frame synchronization is inspired by virtual clustering. When a node comes to life, it starts by waiting and listening. If it hears nothing for a certain amount of time, it chooses a frame schedule and transmits a SYNC packet, which contains the time until the next frame starts. If the node, during start up, hears a SYNC packet from another node, it follows the schedule in that SYNC packet and transmits its own SYNC accordingly. When a node either transmits or receives or even if it overhears a message, it stays awake for a short period of time adapting itself to traffic density and after completion of the message transfer checks for more traffic. The timeout period lets a node to change to the sleep mode rapidly. In this way duty cycling reduces energy and increases latency. To reduce potential collisions, each node waits for a certain period of time within a fixed contention period before the medium is accessed.

Disadvantages :Both S-MAC and T-MAC concentrate message exchanges to small length of time, which results in inefficiencies under high traffic loads. In T-MAC, nodes that are not required to exchange data also stay awake and waste energy. Finally, intended receivers stay awake using messages that indicate future transmissions, which can significantly increase the idle listening times and therefore energy consumption of nodes.

3.1.4 B-MAC

B-MAC[7] is a carrier sense multiple access with collision avoidance MAC protocol for WSN. It uses the asynchronous duty cycle mechanism and sends a long continuous preamble for communication. Berkeley Media Access Control implements adaptive preamble scheme for low power wireless sensor network that provides a flexible interface to obtain ultra low energy operation, essential collision avoidance, and good channel utilization. When a sender has data to send, the sender transmits a preamble that is at least as long as the sleep period of the receiver. The receiver will wake up, detect the preamble, and stay awake to receive the data. It performs CCA (Clear Channel Assessment) before communication. B-MAC outperforms S-MAC in energy efficiency but does not produce fairness of packet delivery. In this protocol overhead of sending control messages before sending every data packet is reduced by sending a preamble [12]. B-MAC is a good protocol for low traffic network. But if traffic on the network increases, sending preamble before every message transmission is a overhead. It is more energy efficient for the duration of no traffic. The preamble sampling technique may be more costly than sleep\active schedule protocol for high traffic networks.

3.1.5 C-MAC

CMAC [8] supports low latency and avoids synchronization overhead. it improves energy efficiency and the latency by applying aggressive RTS, Anycast and convergent packet forwarding mechanisms. The three important procedures that are implemented by CMAC are: Aggressive RTS containing double channel check for medium assessment, anycast based forwarding, and minimizing the anycast overhead by onwards connecting the packets. CMAC implements unsynchronized sleep scheduling and permits operation at very low duty cycles in no packet to transmit in network. In the situation of traffic, CMAC first anycast packets to wake and discover forwarder and then converges from route- suboptimal anycast (with unsynchronized duty cycling) to route-optimal unicast (with synchronized scheduling). For flow initialization it use anycast and for flow stabilization it uses convergent Packet Forwarding. CTS transmissions are ranked considering the routing metrics of local nodes. The Nodes which have better routing metrics can send CTS packets faster, and the other overhearing nodes cancel their CTS transmissions. After convergence, nodes can use Synchronized Wake-up Schedule to save more energy.

3.1.6 STEM (Sparse topology and energy management)

In wireless sensor networks, a node spends major part of energy for sensing an event and promoting details into the network. STEM[9]decreases the energy in monitoring state and reduces the latency between monitoring and transferring states. STEM uses two radios to save energy of a wireless sensor network. One is a data radio and the other is a wake up radio. The wake up radio lets the data radio remain in sleep state until it finds an event to transfer or to operate. The wake up radio uses a low duty cycle and it periodically listens for events. If there is any event which has to be processed, then it activates the data radio. Instead of heaving two radios one radio can be used and switch between the wake up and transfer state using different frequencies. This can lead to a problem if a target node transferring data wishes to wake up another node. It has to postpone the current information and latency will increase. STEM is an event generated protocol used for applications where nodes spend most of the time in waiting for an event. If any event occurs then it forwards the data to the desired nodes.

3.1.7 Ultra wide band MAC (U-MAC)(())

U-Mac [13] is use to reduce energy consumption for wireless sensor network. It uses concept of SMAC protocol by which there are three improvements in this protocol. For example selective sleeping after broadcast, various duty-cycles, and utilization based tuning of duty-cycle.

3.2 Schedule Based Protocol

In scheduling-based MAC protocols, the time at which a node can transmit is determined by a scheduling algorithm, so that multiple nodes can transmit simultaneously without interference on the wireless channel. The time is usually divided into slots, and slots are further organized into frames. Within each frame, a node is assigned at least one slot to transmit. A scheduling algorithm usually finds the shortest possible frame so as to achieve high spatial reuse.

3.2.1 Wise MAC

W-MAC[11] follows synchronized preamble sampling and attempts to resolves the problem of energy depletion due to insignificant sending the preamble and loosing energy while every node has affixed wakeup schedule. It provides very low power consumption when the channel is idle. This scheme schedules the start of preamble packet, and save energy, by having a wakeup schedule of all the neigh boring nodes. It leads to the instant transmission right at the time with a wake-up preamble of minimized duration. The access point keeps an up-to date table with the sampling schedule of all sensor nodes. In high traffic conditions, the duration of the wake-up preamble being smaller than the sampling period. When the traffic is low, the length of the wake-up preamble can exceed the length of the data packet. The wake-up preamble is composed of padding bits followed by repetitions of the data frame. In the header of the data frame, this sensor node will see whether the packet is destined to itself or not. If the packet is destined for another node, it goes to rest. If the destination is itself, it waits for the end of the transmission and sends an acknowledgement. The disadvantages of this technique is that the (long) wake-up preambles cause a throughput limitation and large power consumption overhead in reception.

3.2.2 D-MAC

DMAC [12], low latency optimized MAC involving data gathering trees in wireless sensor networks. The node communication path is unidirectional. DMAC proposes a staggered active/sleep schedule to solve the interruption problem. A data prediction mechanism reduces the channel contention and collisions. DMAC is focused at both energy efficiency and low latency by delivering data along the data gathering tree.In DMAC, stagger the activity schedule of nodes on the multi hop path to wake up sequentially like a chain reaction. In this structure, data delivery can only be done in one direction towards the root. Intermediate nodes have a sending slot immediately after the receiving slot. In DMAC, RTS/CTS control packets are not employed because as they would add unnecessary overhead given the relatively small packet size in most sensor applications. To recover lost packet due to harsh quality wireless channel and contention , link layer ARQ through ACK packet and data retransmission is needed. It also includes a slot-by-slot renewal mechanism to react quickly to traffic rate variations and to maintain low data delivery latency. In the Modified DMAC protocol [14], leaf nodes go into a full sleep state for one cycle in heavy traffics, which means that they turn off their transceivers for one cycle. All leaf nodes have a full sleep state every n cycle in heavy traffic load.

3.2.3 TRAMA (Traffic-Adaptive MAC protocol)

TRAMA[13] is a schedule based traffic adaptive, collision free protocol that selects receivers based on schedules announced by transmitters. TRAMA increases the energy efficiency by increasing the time spent in the sleep mode. In addition TRAMA decreases the collision rate. However significant amount of end to end delay is occurred. TRAMA consists of four main phases: Neighbourhood discovery through NP (neighbourhood protocol), Traffic information exchange through SEP and AEA (Schedule exchange protocol and adaptive election algorithms), and data transmission. These phases uses neighborhood and schedule information to select the transmitters and receivers for the current time slot, leaving all other nodes in liberty to switch to low-power mode. TRAMA is shown to be fair and correct, in that no idle node is an intended receiver and no receiver suffers collisions.

3.2.4 PAMAS (Pattern Based MAC)

Pattern[13] based MAC is improvement of TRAMA protocol. In this protocol schedule is determined on the basis of comprehensive information exchange. The collision probability of data is zero in this protocol that increases the energy efficiency in the low traffic network. Still collision of schedule reservation message packets is possible, and exchange of global messages for schedule reservation will incur heavy traffic the network.

3.2.5 PACT (Power Aware Clustered TDMA)

PACT uses passive clustering in which one node act as a communication back bone within a cluster. It selects nodes as gateways which are members of one or more clusters, where communication between the cluster heads is possible. PACT selects nodes as cluster heads and gateways based on their energy level. PACT uses adaptive duty cycle with respect to traffic and it turns off the radio of the nodes during inactive period or when there is no traffic to transmit. It uses a simple scheme to select the active gateways between neighboring cluster heads. PACT considers both the space and time domain to minimize the energy consumption and communication cost. In the space domain, PACT uses the passive clustering structure to minimize the communication cost, while it saves the energy by allowing the nodes to use only active slots and sleep during in inactive slots [45]. The PACT protocol is a TDMA-based protocol in which each node has pre-assigned time slots to provide collision-free communication. If we look at this protocol with respect to surveillance application, it will give better results because it provides collision-free communication. It uses the passive clustering technique to make nodes energy efficient by only allowing gateways and cluster head nodes to participate in data forwarding. On the other hand, each node has to listen to the mini slots or control packets from other nodes in order to get the control information. This may lead to some energy consumption.

3.2.6 DEE-MAC

DEE-MAC[14] implements the concept of clustering and operations of DEE-MAC built rounds. These rounds consist of two phases: cluster formation phase and a transmission phase. Cluster formation phase, decides that whether the node become the cluster head or not and it is based on remaining power and in the transmission phase consists of a different types of sessions and every session comprises of two type of period a data transmission period and other is contention period. This protocol implements reduced energy consumption by synchronizing cluster head and enforce the idle listening modes to sleep mode. Cluster is based on the knowledge of remaining power as all nodes contend to be the cluster head which is done dynamically.

3.2.7 SPARE MAC

This protocol is used for data diffusion in WSN. By avoiding, overhearing and idle listening SPARE MAC [14] is used to sustain the available energy. Distributed scheduling solution is taken to implement this, in which we assign each sensor node to a specific time slots. This protocol reduces the problem of collisions and idle listening.

3.2.8 Lightweight Medium Access Protocol (LMAC)

LMAC[15] is TDMA-based protocol which tries to minimize the transceiver switches and make the switching-state traffic adaptive. It allows the nodes to sleep when there is no data to transfer. The LMAC protocol is based on Eyes Medium Access Protocol (EMAC) described in [49]. The EMAC protocol is a TDMA based protocol in which each node has one slot to transmit the data in a frame and it can reserve the slot in the next frame. It divides the frame into three parts: Communication Request (CR), Traffic Control (TC) and The LMAC uses a distributed algorithm to find free slots. The LMAC protocol allows the node to select the slot that is not in use within two-hop neighbouring nodes. The new node selects the time slot before sending data. It has to listen all control messages in a complete frame to find a free slot, as each control message has information about the time slot it contains. The new node will operate 'OR' to all received occupied slots and then it can find which time slots those are free.

3.3 Hybrid MAC

It is integration of contention-based MAC and TDMA-based MAC. We take all the advantages of these two methods and make a better solution which is hybrid MAC. TDMA (Time Division Multiple Access) is a schedule based MAC protocol which has been reviewed to be best during high traffic condition avoiding much of colliding problems whereas it suffers certain disadvantages as it needs global synchronization ,does not easily adapt to changes in network topology and it is difficult to ascertain interference among neighborhood nodes (interference irregularity). CSMA (Carrier Sensing Multiple Access) is a contention based MAC Protocol which provided fine results during less traffic levels whereas experienced hidden terminal problems and hence chance of packet collision is more. Hybrid protocol divides the channel into two parts, one channel for control packets and other for data packets. Through control channel , control packets are sent in the random access and in data packets data are transmitted in the scheduled channel. The hybrid protocols can save higher energy and supply better scalability and flexibility in comparatively. Hybrid protocols are A-MAC, IEEE 802.15.4 and Z-MAC.

3.3.1 Z-MAC

Zebra MAC emphases on choosing suitable mechanism out of CSMA or TDMA approaches as per requirement of circumstances in the network. It adjusts easily to the level of contention in the network Z-MAC applies CSMA for two hop neighbours overcoming the hidden terminal problem using RTS/CTS. It implements a channel reuse scheduling algorithm using Distributed RAND, which allocates slots for all the nodes in the network. A single slot can be owned by many nodes but only the owner can transmit at first the next priority is given to non owners. In topology change scenarios, a local slot assignment is accepted without troubling the main slot. It permits multiple node to own a time slot. It does not need global time synchronization thus local synchronization information about the neighbour nodes is enough. Z-MAC has two phases a set up phase and a

Z-MAC phase. During the set up phase it runs the following steps: discovering the neighbours, assigning slots, local frame exchange and global time synchronization. During the Z-MAC phase, nodes forward the frame size, slot number to two hop neighbour and maintain synchronization. Each node has its own local time frame. Z-MAC works under two modes namely a Low Contention Level (LCL) which implements CSMA approach to access the channel and a High Contention Level (HCL) which uses TDMA approach. It finds better efficiency during high contention level, providing better channel utilization at variable loads. A major drawback is it does not compromise for energy inefficiency during low contention levels.

3.3.2 A-MAC

It is proposed for no-overhearing, collision-free and fewer idle-listening transmission services. This is used in the applications like long-term surveillance and monitoring. A-MAC [15] is based on the concept in which when receivers wants to receive the packets nodes are notified in advance. When the nodes want to receive, or send the packets they are activated and during other time they go to sleep mode. By this method, Wastage of energy is unseen on idle listening and overhearing. It is also enhancing the accessibility of the wireless channel.

3.3.3 IEEE 802.15.4

It is a low-rate Wireless Personal Area Networks (WPAN). To maintain the synchronization of time-frames it takes coordinator which is operating in the beaconed mode. It has concept of super frame structure, in this we use TDMA-based period for access, and we use a contention-based period for non-guaranteed access. All nodes enter into the sleep state when they are not used. It can also work in ad-hoc based mode [18]. For energy conservation there is no special design method xcept a typical duty cycle controlling scheme.

3.3.4 ADV-MAC

ADV-MAC practices the concept of advertising for data contention and later attempts to lessen the energy waste in idle listening without compromising for throughput and latency. It also provides synchronization during transmission. ADV-MAC has four periods. A fixed sync period and an Advertised period then a variable data and sleep period. During the ADV period, the node transmits ADV packet which intimates the receiver about the data transmission and during the DATA period only the intended receivers will be awake to accept the data and the rest of the nodes are in the low power sleep mode. As we increase ADV period, every node gets an equal chance to transmit data thus avoiding idle listening period. ADV-MAC had two major draw backs.

• Since every node were assigned slots in the ADV period, time remaining in the data period of the frame is not enough to accommodate all the nodes that successfully transmitted ADV packets.

• Since no ACK is sent for ADV packets, in case of any collision the transmitting node and receiver node is not intimated, hence transmitting node is awake and receiver is in sleep mode, hence data is sent only in the next frame.

3.3.6 ER-MAC

ER-MAC (Emergency-MAC)[17] is gives precedence to emergency packets giving up latency and delivery ratio of low priority ones during emergency period. ER-MAC uses two queues, high priority packet queue and low priority packet queue. Low priority data is sent only if the higher priority queue is empty. Under normal mode of ER-MAC, if there is no data available to transmit, then the nodes go to low power sleep mode. During the initial start-up phase, the sink node initiates tree construction using simple flooding mechanism. During usual situations it functions following CSMA/CA. ER-MAC gives better results regarding energy efficiency when compared with Z-MAC, because in Z-MAC, nodes have to contend for the channel but in case of ER-MAC as soon as emergency is detected, it immediately transmits data. At the time of emergency, it switches on to emergency mode, emergency flag is set in both the packets and all nodes are scheduled to wake up allowing contention in
TDMA slots. A major drawback of ER-MAC is that it consumes more energy during normal mode than compared to the emergency mode.

3.3.7 EE-Hybrid MAC[18]

It is a low latency MAC protocol that allots priority to the nodes which handles critical loops of industrial process control domain by following interrupt mechanism. The procedure starts by identifying the onehop neighbors using broadcast of ping messages. The nodes collects the data from their respective region and transfer it to the sink using CSMA mechanism. When the node in the high priority region is to be transferred, that particular node id information is available, using that information, the neighboring nodesstop their transmission and change over to TDMA giving the first slot to the node that is in high priority region. If two nodes are present in the same high priority region ,then slots are assigned to the nodes one after the other. The node id information is available in the packets and then this information is passed along with the other packets, which enables them to transfer data from one node to the other faster.

3.4 Cross layer MAC

To accomplish flexibility, efficiency and reliability, coordination of all layers is essential. *Cross-layer MAC protocols* is a recent new generation of MAC protocols *that uses two or more than two* layers to augment energy depletion .The layers can liaise into two modes: *interaction* or *unification*. In the interaction mode, the MAC protocol is designed by operating the data generated by other adjacent layers. On the other hand, unification mode involves the change of only one layer together with functionalities of pre decided controlled layers at the same time.

3.4.1 MAC-CROSS

MAC-CROSS Protocol [19] is an example of Cross-layer approach which permit the routing information of the network layer to be collapsed by MAC layer thereby resulting a collaboration between MAC and network layers. It allows only the communicating nodes in action and rest of the nodes not concerned by this communication pushed into Sleep mode. To avoid collisions, MAC-CROSS uses the control messages *RTS/CTS/ACK*. This protocol improved energy efficiency by combining the characteristics of MAC layer and routing layer. Here main emphasis is to feat direct interactions between the application layer and the MAC/Physical layers.

3.4.2 XLM protocol (A Cross-Layer Module)

The communication in XLM is different compared to traditional approaches. In this module , if A node has a packet to send, it initiates the process by transmitting an *RTS* packet to his neighbourhood to announce about it. Upon receiving an *RTS* packet, each neighbourhood node performs the following conditions test to participate in communication process:

1. Each node confirms reliability links for the communication.
2. After that congestion prevention by limiting the transmitted traffic by a relay node,
3. Next phase assures no buffer overflow occurs for all the node participating in communication.
3. Last step confirms that the residual energy of a node do not exceed a minimal threshold.

The module of local congestion control of XLM ensures energy efficiency and a reliable communication. XLM is better than one-layer protocols in terms of communication processing and implementation complexity considerations.

3.4.3 CLMAC

In Cross-Layer MAC, MAC layer follows an adaptive Wake-up/Sleep cycle to access to the medium. In it periodically synchronisation is done in the local zone. Each node holds information about neighbouring nodes like identifier, position, and calendar. The routing table is maintained by a routing agent in adjacent network layer. CL-MAC operates at MAC layer level by exploiting routing information using a similar mechanism adopted by MAC-CROSS protocol. For this reason, weak modifications are made in RTS and CTS message structures following the guidelines of the IEEE 802.11 standard. The Sink node address is supposed to be known at the level of each node of the network.

4 CONCLUSION

The paper presented a study of all types of MAC protocols that helps wireless sensor networks to obtain energy efficiency in order to prolong network life time. This study analysed the strength and weaknesses of these discussed protocols. The focus was on comparative assessment and identifying the relevance of these protocols. we organize all existing MAC protocols for energy efficiency into four categories and found the following understandings

- In Contention-based MAC protocols, energy is wasted due to vast control packet overhead and idle listening.
- The schedule based protocols results in huge latency and control packets due to strict clock synchronization is required.
- The hybrid MAC associating two approaches achieves better energy efficiency but difficult to achieve due to difficulty in transition method among contention-based and TDMA-based

- Cross layer approach formulate detailed use of information in protocol stack and could gain energy conservation intensely. However, it increase the design effort and reduce the compensation of layered technique so it wants wide study.

This paper gives the better comparative analysis of energy efficient MAC protocols, which further help in selecting desired protocol for the particular application. Although in our investigation energy efficient MAC protocols and their designs illustrates that, despite many proposals, no sound proposal has been presented. However adaptive and cross layer designs solutions can lead to achieve both high performance and low energy consumption at the same time.

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Contention Based MAC Layer Protocols							
Name of protocol	**Key Features**	**Energy Efficiency**	**Throughput**	**Latency**	**Collision**	**Advantages**	**Disadvantages**
PAMAS	Two channels &Two radio used	Low	Low	High	High	reduces the probability of collisions	costly & complex design ,
S-MAC	Adaptive listening, Fixed duty cycle, virtual cluster, CSMA ,	Medium	Low	Low	High	Low duty cycle to save energy Overhearing avoidance	-High latency due to periodic sleep, -Fixed duty cycle not adaptive to dynamic traffic loads
T-MAC	Future request to send Adaptive duty cycle, overhearing,	High	Low	High	High	Save more energy by the adaptation to dynamic traffic	Adaptive duty cycle increase latency and reduce throughput
B-MAC	Low power listening channel assessment software interface	Low	Medium	High	High	Low overhead when network is idle, simple to implement, Consumes less power	Overhearing, bad Performance at heavy traffic. Long transmission latency
C-MAC	Avoids synchronization overhead, convergent packet forwarding	High	High	Low	High	High throughput, low latency & consumes less energy	Mainly designed for low duty cycles
STEM	event generated protocol, uses two radios: data radio & wake up radio	low	low	low	High	decreases energy in monitoring state, reduces latency b/w monitoring and transferring states	spend most of the time in waiting for an event
U-MAC	Less synchronization overhead	low	low	low	Medium	selective sleeping after broadcast, utilization based duty-cycle	various duty-cycles
Schedule Based MAC Protocols							
D-MAC	Staggered schedule	Low	High	Low	High	Energy saving and low latency	Aggregate rate is high
TRAMA	Adaptive	Low	High	Low	low	Higher	Time is divided

	assignment TDMA					energy efficiency & throughput	into random access period
W-MAC	Synchronized preamble sampling	Medium	Medium	High	High	Low synchronization Overhead due to decoupling	Overhearing problem in nontarget receivers - End-to-end delay over multihop path
Pattern Based MAC	Adaptive assignment TDMA	High	High	Low	Very low	energy efficiency in the low traffic network	exchange of global messages for schedule reservation will incur heavy traffic
PACT	adaptive duty cycle, passive clustering	High	high	low	Very low	surveillance application, it will give better results	Mini slots may lead to energy consumption
DEE-MAC	clustering	High	high	low	Very low	High energy efficiency	exchange of remaining power for subsequent clustering
SPARE MAC	Data diffusion	High	low	Low	Very low	reduces collisions and idle listening	End-to-end delay over multi-hop path
LMAC	Eyes Medium Access Protocol	Medium	Medium	High	High	adaptiveswitching-state traffic	Slow in heavy traffic
Hybrid Based MAC Protocols							
Z-MAC	Chooses best out of CSMA /TDMA, local framing and synchronization , uses Distributed RAND	High	High	Low	Very Low	providing better channel utilization at variable loads	energy inefficiency during low contention levels.
A-MAC	Used for no-overhearing, collision-free and fewer idle-listening transmission services	High	High	Low	Very Low	long-term surveillance and monitoring	enhances accessibility of the wireless channel
IEEE 802.15.4	low-rate Wireless Personal Area Networks , ad-hoc based mode	High	High	Low	Very Low	Uses super frame structure	typical duty cycle controlling
ADV-MAC	advertising for data contention, synchronization during transmission	High	high	low	Low	minimize the energy lost in idle listening, Effective large networks involving high traffic	No ACK, Short data period of the frame

ER-MAC	precedence to emergency packets	High	high	Low during emergency	low	enhancing better delivery ratio and latency, Effective for disaster management	it consumes more energy during normal mode
EE-Hybrid MAC	handles critical loops of industrial process control, follows interrupt mechanism	High	high	low	Low	Industrial applications targeting critical process	Not suitable for heavy traffic
Cross Layer Based MAC Protocols							
MAC-CROSS	collaboration between MAC and network layers	High	high	low	Low	improved energy efficiency, direct interactions between the application layer and the MAC/Physical layers	Slow in heavy traffic condition
XLM	neighbourhood announcement	High	high	low	Low	Better Implementa-tion complexity	increased design effort
CLMAC	adaptive Wake-up/Sleep cycle	High	high	low	Low	periodically synchronisation in local zone	enhances channelaccessibility