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MAC PROTOCOLS FOR WIRELESS SENSOR NETWORK (WSN): A COMPARATIVE STUDY

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Data communication between nodes is carried out under Medium Access Control (MAC) protocol which is defined at data link layer. The MAC protocols are responsible to communicate and coordinate between nodes according to the defined standards in WSN (Wireless Sensor Networks). The design of a MAC protocol should also address the issues of energy efficiency and transmission efficiency. There are number of MAC protocols that exist in the literature proposed for WSN. In this paper, nine MAC protocols which includes S-MAC, T-MAC, Wise-MAC, Mu-MAC, Z-MAC, A-MAC, D-MAC, B-MAC and B-MAC+ for WSN have been explored, studied and analyzed. These nine protocols are classified in contention based and hybrid (combination of contention and schedule based) MAC protocols. The goal of this comparative study is to provide a basis for MAC protocols and to highlight different mechanisms used with respect to parameters for the evaluation of energy and transmission efficiency in WSN. This study also aims to give reader a better understanding of the concepts, processes and flow of information used in these MAC protocols for WSN. A comparison with respect to energy reservation scheme, idle listening avoidance, latency, fairness, data synchronization, and throughput maximization has been presented. It was analyzed that contention based MAC protocols are less energy efficient as compared to hybrid MAC protocols. From the analysis of contention based MAC protocols in term of energy consumption, it was being observed that protocols based on preamble sampling consume lesser energy than protocols based on static or dynamic sleep schedule.).

Keywords: Reserve Energy, Medium Access Control (MAC), Wireless Sensor Networks (WSN), Data communication

1. Introduction

A wireless sensor network (WSN) can be defined as a network which has a hundreds of sensor devices functioning collectively to accomplish a common objective [1]. A wireless sensor is a battery-operated device, able of sensing physical quantities, store and communicate data through wireless network. In wireless sensor network a node has a sensor, processor, radio and a battery. Structure of WSN and a sensor node is shown in Figures 1 and 2 respectively. Network of wireless sensor devices is being installed to monitor and circulate data/information about a variety of events of interest. The major role of a sensor in network is to gather and process information from an intended about the specific domain and send to defined location(s) [5].

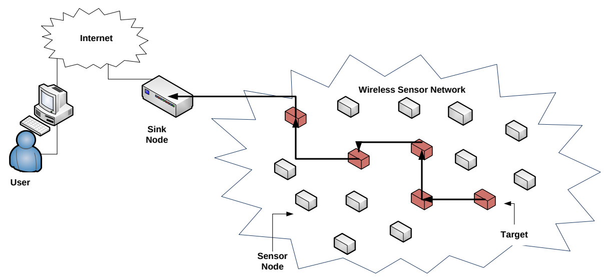

Figure 1. Wireless sensor network.

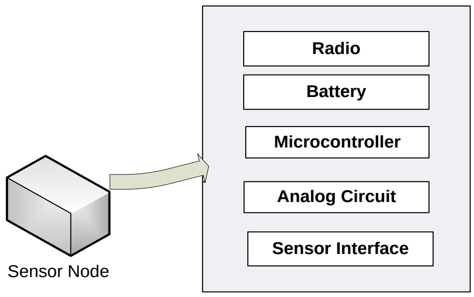

Figure 2. Sensor node view.

Over the past years, different researchers have proposed different design of Medium Access Control (MAC) protocols for WSN [4] addressing the specific needs. Data communication between nodes is carried out under MAC protocol which is normally defined at data link layer. The MAC protocols are responsible for coordination and message passing among nodes. The design of a MAC protocol should also address the issues of energy efficiency and transmission efficiency, discussed in detail in subsequent sections [2, 3].

The layout of the remaining sections of this paper are defined as, in Section 2 current state of the art MAC protocols for WSN are discussed. Section 3 focuses on classification of selected nine MAC protocols. The design issues and comparison between protocols are

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also discussed in Section 3. The last section concludes the paper, highlighting pros and cons of each protocol according to the defined parameters.

2. Literature Review

2.1. S-MAC

S-MAC protocol is specifically designed for the adhoc WSN. The energy reservation is the main motivation and objective of this protocol. The main features of the S-MAC include periodic listen, avoidance of collision and avoidance of overhearing and fairness of message passing.

The periodic sleep and listen avoids the idle hearing which eventually saves significant energy. All the nodes are put to sleep mode periodically and radio of each node is also turned off during sleep. This reduces duty cycle to approximately 10%.

All nodes exchange their schedule using the SYNC packet which is broadcast periodically. The listen time is divided into two parts. One is SYNC which is used to send/receive to manage schedule and second is sending/receiving of data for actual communication as can be seen in Figure 3.

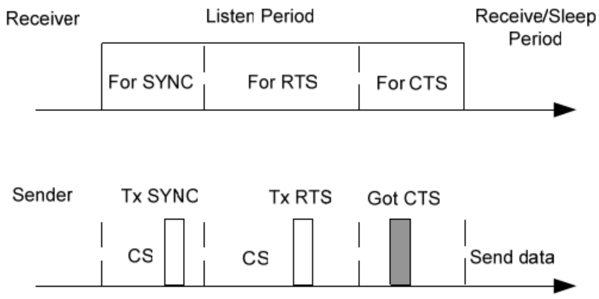

Figure 3. Two parts sending/receiving SYNC and data [15].

It allows adaptive listening which reduces the multi hop latency with the help of periodic sleep. At the end of each transmission, the wake up of the neighboring nodes is active for the limited short time.

It avoids the overhearing in such a way that all immediate neighbors of sender and receiver nodes are deactivated by putting them to sleep mode by receiving Request to Send (RTS) / Clear to Send (CTS). Hence neighboring nodes do not hear the information packets. The duration of the sleep is also added in the packet. S-MAC converts the longs messages into small messages and transmits in bursts. The receiver node receives each sub-message and sends ACK for the received data packet.

2.2. T-MAC

T-MAC which is defined as Timeout Medium Access Control [13]. This protocol is designed to avoid the idle listening overhead of S-MAC. The T-MAC uses the variable duty cycle based on the activity in the network. The activation of the node is happened based on the data packet transmission or some timer expiration. T-MAC transmits all messages by dividing them at variable length and sends them in bursts. In such way, the messages are sent at once and then nodes would be in sleep state between the bursts. The synchronization technique which is virtual clustering is same as in S-MAC. T-MAC uses fixed contention interval. It uses four steps exchange communication of RTS-CTS-DATA-ACK for collision avoidance and reliable data communication. In T-MAC, the node cannot go to sleep mode if its neighboring nodes are in message transmitting state.

In summary, Timeout MAC differs from S-MAC in such a way that all messages of variable length divided into variable length sub-messages and are transmitted in bursts and add sleep time between burst. It uses RTS/CTS/ACK scheme. It has same synchronization as S-MAC.

2.3. Wise-MAC

Wise-MAC is designed for the WiseNET [14]. It uses preamble sampling technique to avoid the idle listening and eventually to preserve the energy. In this network, all the connected nodes generate alerts for two different types of tasks. One, which checks whether the network is available for the data to transmit. The intermediate nodes acts as the listeners if the channel/medium is busy until the message is sent to the receiver or medium are free for the transmission. The second type of alert is generated for the receiver node to make sure the awake status of receiver node. This alert is added in front of the data packet to send the message to the receiver node for awake state till all the data packets of the message have been received. This wake-up preamble causes power consumption which is reduced using information of offset between sampling schedule of neighboring nodes and current node. Each node has sampling scheduling offset information of its neighboring node. This is adaptive to the traffic load because all nodes use this scheduling offset information for message passing. The repetition of data frames are detected by using the wake up preamble and data size information. The wake up preamble which is larger in duration compared with data frames indicates that frames are recurring and helps to avoid overhearing.

The collision between two nodes can be avoided by using the reservation preamble of randomized duration which is also added in the frame packet. The collision which is caused by the effect of hidden node is avoided by adding the capacity of the node which is a costly operation. This helps to expand the sense range so that interference cannot occur. The data burst is used to transmit the data efficiently by using the a bit having label 'more'. This bit is ON which means there are more data packets to be received at receiver end so that node must be in listen state.

2.4. *μ-MAC*

μ-MAC [10] falls in the category of MAC protocols that are TDMA which stands for Time Division Multiple Access. It shares the architecture of Traffic-adaptive MAC (TRAMA) [16] which is a schedule based protocol with communication channel broken down two periods. Improvement in utilization of broadcasting depends on the information that is provided by the upper layers. This protocol also has a well-defined slot reservation method.

μ-MAC consists of a single time-slot channel. The protocol operations can either perform in a disagreement or disagreement -free stage. Disagreement-free stage transfers data between nodes. The spreading of information in the slots is programmed to evade collision. The intent of the disagreement phase is to put together a network topology and to start spreading the information between secondary-channels. This initialization refers to the collection of relevant slots in disagreement free phase.

Information is transported in group of windows/slots known as secondary channels in the disagreement-free stage. General traffic and sensor reports are two modules of secondary-channels.

General traffic consists of benefits beginning at the base station and direction-finding system for the collection of information of sensors. The secondary-channel of general traffic is formed by roughly the same spaced disagreement-free window. Depending on the flow of transfer, each node listens to the packets that are spread during the window. This secondary-channel must meet the bandwidth assigned to it for latency and energy utilization.

Sensor reports are compromised of data packets send out periodically during extended period and flows towards the base-station. These secondary-channels have varying bandwidth that is attuned depending on the probable traffic flow.

μ-MAC offers two commands for data communication: report and send. Data is transferred through the send command by means of general traffic secondary channels. Sensor report secondary channels are utilized by the report command. There are two commands provided by this protocol for the creation of sensor report secondary-channels which are reserve and register.

μ-MAC protocol operations can be divided in three stages. Figure 4, depicts the graphical representation of these stages. There are three nodes: s1 responds to the interests by reports generation, s2 is an intermediate node and Base station s3 originates awareness. The routing layer broadcasts this interest in the course of calls to send command. When the path between the entire network and base station is established, the MAC address of subsequent hop is registered by routing layer. The interest is bonded with the available sensor report of the secondary-channels through the register command. If a particular sensor is able to generate the required information, a command known as reserve is issued to μ-MAC. The sensor starts informing the base-station after the call for reservation is made. These types of reports are shifted through the command known as report.

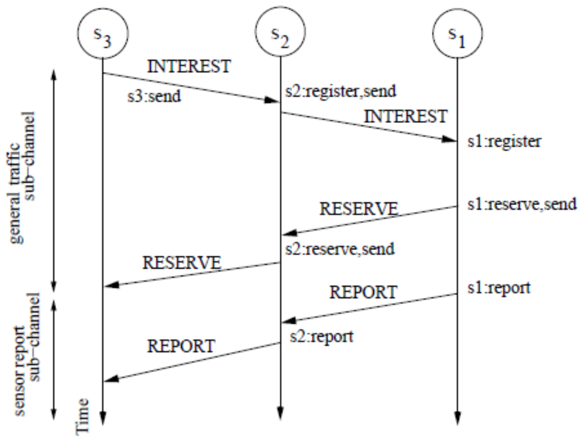

Figure 4. μ-MAC protocol operations [10].

2.5. *Z-MAC*

Another MAC protocol is Z-MAC [11] also known as Zebra-MAC. This protocol is a hybrid of TDMA and CSMA which stands for Carrier Sense Multiple Access. Z-MAC is known to attain low latency and high channel consumption under low contention similar to TDMA. It can attain high channel usage with the help of high contention and can reduce the impact between neighbors at a considerable small rate. Some of the unique characteristics of Z-MAC are that the execution is strong to window/slot task malfunctions, synchronization faults and time changeable channel circumstances.

Z-MAC protocol makes use of CSMA as the starting point idea but utilizes TDMA to improve disagreement decision. This mixing makes the protocol more powerful to instance malfunctions, time-divergence channel circumstances, topology alterations and slot transport malfunctions.

The time window or slot management is executed at deployment which results in high overhead in the beginning. The owner of the window always has high precedence than its non-owners. This helps to reduce the probability of impact as the owners are given chances to spread and the windows are programmed beforehand. When a window is not used by the owner, then the non-owners can take and use that slot. This priority mechanism has an implied effect when controlling among CSMA and TDMA.

Z-MAC protocol runs certain procedures in succession that are: neighbor finding, slot/window allocation, local frame swap and universal instance management. These procedures execute just one instance through the system to compensate the cost. This improves throughput and efficiently utilizes the energy during data transmission.

The first task for a node start up is to check for neighbors through a neighbor finding protocol by occasionally broadcasting a ping to the neighbors. Every node collects the information from the ping which comprises of its two neighbor data.

The neighbors listing are used by the time time/window assignment procedure. Time slots are allocated to every node in a manner that no two blocks/nodes inside a two-hop region are allotted the similar window/slot.

As soon as the slot is picked for a node, the node has to make a decision on the period of use for spreading.

At the end, each node has the size of the frame and number of the window/slot of its two-hop neighbor to forward this information when required. All nodes coordinate to slot 0 and then are prepared to execute the spreading. In Z-MAC the local clock management amongst senders is done through a method RTP/RTCP which is the short form of Real-time Transport Protocol. A node can have two level modes. A node is in HCL mode as it obtains a precise disagreement note from two-hop surrounding/neighbor; else it is in mode LCL.

2.6. A-MAC

A-MAC [12] protocol also known as Alternative MAC protocol is a power efficient procedure intended for inspection and supervising applications that is spanned over a long period of time. This protocol provides collision free, low idle listening and less overhearing transmission services.

To reduce idle listening in A-MAC protocol, the nodes are informed before hand when they will get the packets. Therefore, the node needs to be on the go only when it is the sending or receiving data. A-MAC uses the nodes into episodic sleep that become accustomed to active duty phase to preserve energy. When putting the sensor nodes into periodic sleep mode this might interrupt forwarding of information which adds to communication/transferring latency. To reduce this, A-MAC lets nodes on different heights to wake up in sequence.

For collision avoidance, the wakeup schedule lessens the likelihood of collision. Collision occurs when neighbor nodes broadcast data concurrently. This can be reduced by keeping the nodes from coming around at the similar time.

2.7. D-MAC

In WSN applications most well-known traffic pattern is collection of data from a number of source nodes to a sink node through a unifacial tree. So, there is need to design a medium access control protocol that utilizes energy efficiently and result into minimal latency in data gathering trees in WSN. The key objective of D-MAC (Data Gathering MAC) [9] is accomplishment of incredibly short latency period, withal it is energy efficient. D-MAC makes use of its data garner tree formation to attain two main features i.e. low latency for packet delivery and efficient energy consumption. D-MAC stages the wake and sleep plan of the sensor node in the data collection tree par rapport to its position or depth in the data tree. It results into nonstop data packet furtherance flow in which each and every one node on the multi-hop pathway can be informed of the data transfer on the way along every duty-cycle changes. D-MAC is form of an enhanced algorithm named as Slotted Aloha where each slot is allotted to the set of nodes depending on a data collection tree as depicted in Figure 5.

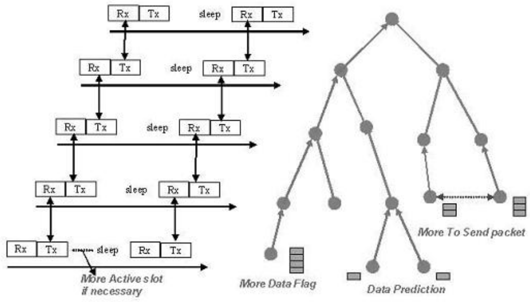

Figure 5. Data gathering in D-MAC [9].

D-MAC is intended to resolve the interruption dilemma and consent to nonstop packet transferring by giving the sleep plan of a node an offset in reference to its position or depth in the tree. In addition D-MAC, regulates the duty cycles adaptively with respect to the load of traffic in the network. Data prediction scheme is another important point in D-MAC. In this protocol in the receive epoch of a sensor node, all of its decedent sensor nodes has send out periods and compete for the transmission medium. Subsequent slots of the node results into achieving low latency.

D-MAC accomplishes really nice latency in contrast to other sleep and listen time assignment schemes. Networks where latency is essential D-MAC could be a strong candidate to resolve this issue.

One drawback of D-MAC protocol is that collision evasion techniques are not used. So, when several nodes that have the same active and sleep plan (same depth or level in the tree) endeavor to transmit to the same target node, collision will take place. It is a likely situation in event triggered wireless networks having sensors. In addition, the data broadcast paths might not be well-known before hand, which thwart the formation and arrangement of the data gathering tree.

2.8. B-MAC

It is a CSMA-Carrier Sense Multiple Access protocol that makes use of very less power listening and an adapted preamble to attain low power communication [8]. A preamble is the sequence of bits which does not contain significant information and is only used to inform receiver that some node wants to communicate. In B-MAC protocol nodes wake-up for a limited time period and test out channel activity, if no activity is observed they return to sleep. In case a sender node desires to pass on a message, it passes a stretched preamble to ensure that the receiver node is listening for the data packet and a preamble has the size equal to sleep interval.

Low-Power Listening (LPL) or periodic channel sampling is the most important technique that B-MAC utilizes. B-MAC is very dynamic and robust, no synchronization is requisite and it has instant upturn after channel distribution. One main problem with the B-MAC protocol is overhearing i.e. every node in the locality of a sender wake up and hangs around for the packet resulting into the energy wastage. Another issue is that communication cost is typically paid by the sender and the preamble span can be much longer than the actual data length. This overhearing issue is later on resolved by Wise-MAC and B-Mac+ discussed in this section.

2.9. B-MAC+

It is an enhanced version of B-MAC [8] protocol. B-MAC+ [6] try to cut down energy utilization wasted during the long preamble of B-MAC. The basic idea of B-MAC+ is to change pattern of wake up preamble with small numbers of blocks containing some information related to the address of destination node and number of remaining blocks. This information is helpful in context of receiver node to shun wait states in considerable segments of the preamble broadcast time period i.e. intending to sleep and waking-up while the data consignment is actually transmitted.

The wake-up preface of B-MAC+ is acquired by splitting the chunks of B-MAC. So, B-MAC+ saves more energy than B-MAC with same latency and throughput [7]. B-MAC+ is more energy efficient because, when receiver receives early preamble it can turn off its radio for remaining preamble blocks and wait for time of data arrival to turn radio on. It would again wake up when data arrives.

3. Methodology

According to the design of MAC protocols, protocols can be categorized into two main categories, scheduled based and contention based. Scheduled based protocols allocate each node an exclusive time slot for communication. These protocols guarantee collision free medium access. Contention based protocols use CTS/RTS to avoid the risk of collision of transmitted data. Whereas hybrid protocols use features of scheduled based and contention based design. Classification of MAC protocols according to design options is given in [13]. [7] Classify MAC protocols as contention based, reservation based, hybrid and cross layer. In this paper, classification of MAC protocols and place of each protocol in this hierarchy is shown in Figure 6.

To establish a WSN using hundreds/thousands of sensor nodes, to get the desired information is a challenging task, due to the management of sensor nodes for efficient utilization of battery power. The recharging of the battery after establishment of the network is a difficult task. Hence, for any WSN protocol, energy is a critical concern. Usually, two parameters have been used to evaluate the WSN MAC protocols.

1. Energy Efficiency
2. Transmission Efficiency

The Energy efficiency is a measure using three parameters.

1. Collision which normally occurs at the receiver end when more than one data packets from the sending nodes reached at the same time, the destination node may lose the data packet and cause increase in latency.
2. Overhearing means that current node normally acts as the medium to transfer the data from source to other target nodes causing unnecessary energy wastage.
3. Idle Listening is just to check that whether there is any data used to transfer over the network or not.

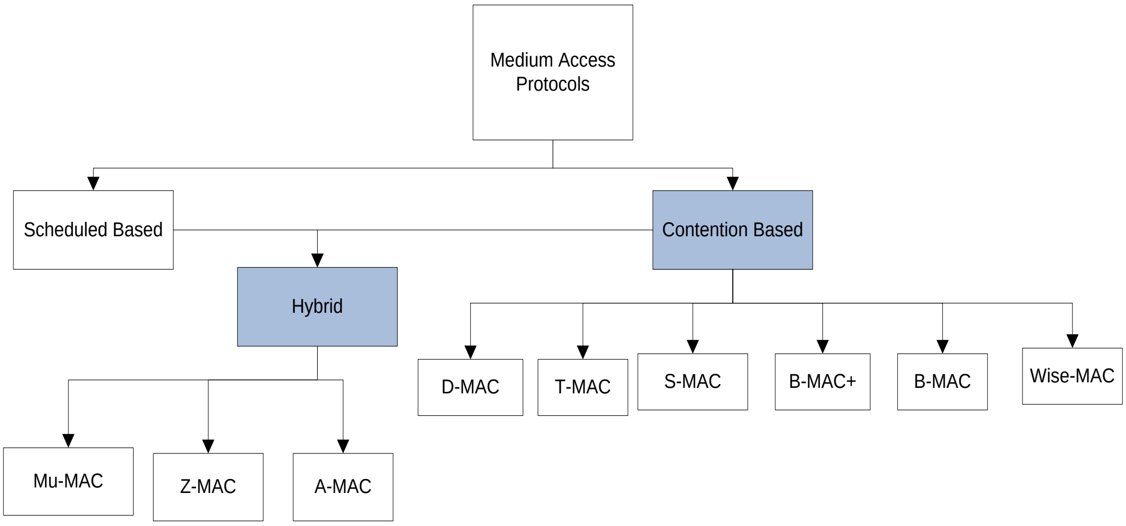

Figure 6. Classification of MAC protocols.

Table 1. Comparative analysis of MAC protocols for WSN.

Evaluation Parameters	D-MAC	B-MAC	B-MAC+	S-MAC	T-MAC	Wise-MAC	A-MAC	Z-MAC	Mu-MAC
Energy Reservation Method	Adaptive Duty Cycle	Overhearing Long Preamble LPL	Shortened Preamble	Periodic Sleep	Periodic Sleep	Preamble sampling	Periodic sleep	Low Power Listening (LPL)	Periodic Sleep
Idle Listening Avoiding Technique	Dynamic Sleep	Preamble sampling	Preamble sampling	Static Sleep	Dynamic Sleep	Preamble sampling	dynamic sleep	Preamble sampling	----
Fairness Achievement method	------	------	-----	-------	FRTS and Full Buffer Priority	Backoff Medium Reservation	------	-----	Multiple retransmission
Synchronization Mechanism	Unidirectional Synchronization (Root to Children's)	No Synchronization	No Synchronization	Virtual Synchronization	Virtual Synchronization	Local Synchronization	No synchronization	No synchronization	Global clock synchronization
Latency Minimization Mechanism	Adaptive Duty Cycle and staggered Wake up	------	------	Periodic sleep		------	alternative wakeup schedule	low latency	Periodic Sleep
Throughput Maximization Mechanism	------	------	------	Less due to periodic listen and sleep	Less due to Adaptive duty cycle	------	clusters to increase throughput	Broadcast for high throughput	Low radio duty-cycles to increase throughput

The transmission efficiency can be defined as transmission measure for the data packet from source node to the destination node in the effective and efficient way. The following three major factors are evaluated to measure transmission efficiency.

1. Latency is defined as time which is measured from sending a packet from source node till the destination node receives that packet. The main objective while designing the wireless sensor MAC is to decrease the latency.

2. Throughput can be defined as the size of the data packet which can be sent to the destination node over the network. In WSN, the throughput must be high enough so that complete data should be delivered in the certain amount of time period.

3. Fairness is measured in terms of giving same amount of time to all nodes in the network to transmit and receive the data. This is because, sometime the transmission medium is constantly busy for communication between some specific nodes and remaining nodes do not get chance to transmit the data packets to other nodes.

In this section, we will also focus on direct comparison between protocols. For this purpose we have picked up the main design features of a MAC protocol as discussed above and investigated the techniques available for that particular part.

The comparative analysis of nine MAC protocols for WSN is presented in Table 1. Six evaluation parameters are defined on column 1 which are energy reservation method, idle listening avoidance technique, latency, fairness, data synchronization, and throughput maximization technique. The nine MAC protocols selected for this study are defined at row 1 which are S-MAC, T-MAC, Wise-MAC, Mu-MAC, Z-MAC, A-MAC, D-MAC, B-MAC and B-MAC+. For some of the protocols, the information is minimal due to a lack of available information which is represented by ---. Information in each cell represents the technique used against each evaluation parameter for a MAC protocol.

4. Conclusion

In this paper, we have reviewed nine MAC protocols for Wireless Sensor Networks in terms of design features, so that readers will better understand basic concepts, challenges and processes. Our main focus in this paper is on contention based and hybrid protocols. Nine different protocols are discussed and their comparison is presented in section III. These nine protocols are S-MAC, T-MAC, Wise-MAC, Mu-MAC, Z-MAC, A-MAC, D-MAC, B-MAC, B-MAC+. A MAC protocol needs to give optimum results in terms of energy consumption, latency, fairness, data synchronization, and throughput. A comparative study is also carried out in terms of these parameters. It is analyzed that Contention based MAC protocols are less energy efficient as compared to hybrid MAC protocols. From the analysis of contention based MAC protocols in term of energy consumption, it is being observed that protocols based on preamble sampling consume lesser energy than protocols based on static or dynamic sleep schedule. In future we will work on the comparison based on simulation results.

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