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Overview of MAC Protocols in Wireless Sensor Networks

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Abstract: Wireless Sensor Networks (WSNs) have been an interesting research area for researchers worldwide. Wireless sensor nodes have problems such as low processor capacity, low memory, limited energy. However, sensor nodes have attractive features such as random placement, self-organization, collaboration and local computation; It is used in many fields such as military, environmental, health care and commercial applications. The biggest problem in WSN is energy efficiency. Many studies have been done in this area. In this paper, examined in detail IEEE 802.15.4 protocol used by wireless sensor nodes and the MAC protocols developed for energy efficiency in the datalink layer are presented in detail.

Index Terms **- Wireless sensor networks, Nodes, Energy efficiency, IEEE 802.15.4, MAC protocols.**

I. INTRODUCTION

Wireless Sensor Networks have emerged as a rapidly developing technology and its usage areas are constantly increasing. It can be said that they are very useful due to their small size and ability to organize themselves. It can be used in many areas such as patient monitoring, target tracking, monitoring military fields [1].

Sensor networks consist of many sensor nodes that have the ability to self-organize, detect desired parameters, transmit these data remote monitoring station, and make analysis of these values. The energy requirements of the sensor nodes are usually supplied by batteries. It is very difficult to charge the batteries of sensor nodes placed in unreachable areas of sensor networks. Therefore, more efficient way of usage of the batteries is required. Optimum utilization of these batteries emerge as the most important issue both for the life of the network and for the continuity of communication. For energy efficiency in sensor nodes, designs made in the MAC (Media Access Control) layer come first in importance [2].

Energy wastage in the MAC layer usually occurs due to excess control packets as overheads, unnecessary wakeup of the nodes, unintentional reception, packet collisions. The situation where the energy waste occurs mostly due to the unnecessary rest of the environment. The reason for this is that all nodes also receive and transmit messages that do not concern them. This creates a lot of energy consumption. In addition, in the case of transmitting received packets, it causes energy consuming situations such as packet conflicts. As a result, the lifetime of the node decreases rapidly and the lifetime of the network ends just like the lifetime of the nodes [3],[4].

II. ENERGY EFFICIENT MAC PROTOCOLS

In this section, the energy efficiency studies carried out in the MAC layer in WSN are explained. Figure 1 shows the classification of energy efficient MAC protocols according to the process parameter in the preamble.\

While some MAC protocols are trying to provide energy efficiency by processing the preamble, some protocols wanted to perform this process based on a planned or unplanned communication. In Figure 1, a classification is made based only on the preamble parameter. Details of these protocols will be given in the following sections. Here, in addition to the IEEE 802.15.4 protocol, which is suitable and used for sensor networks, it is explained how the protocols developed for energy efficiency in the MAC layer generally perform data communications, how they provide energy efficiency and how they contribute to sensor networks.

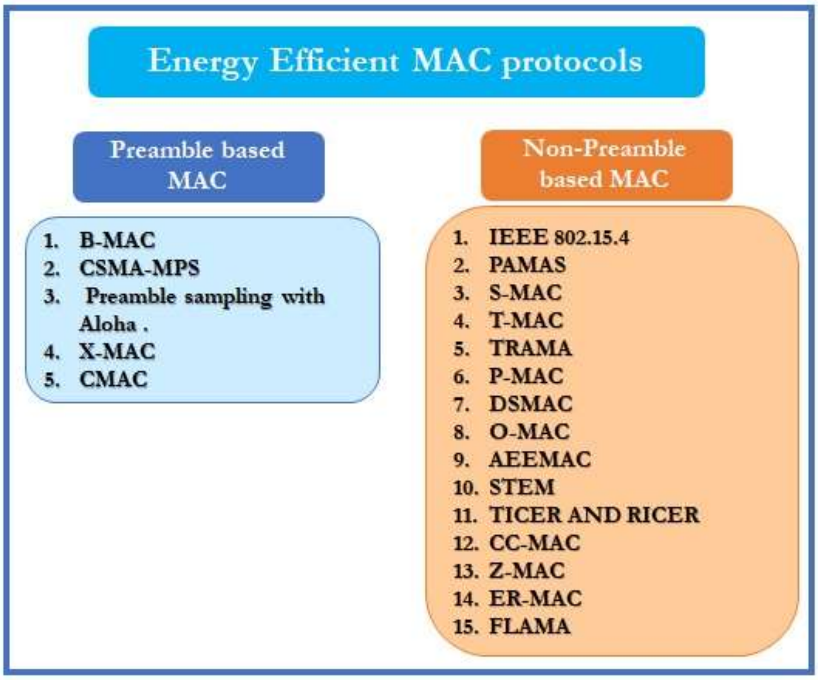

Figure 1. Preamble-based classification of MAC protocols.

2.1 IEEE 802.15.4

The IEEE 802.15.4 protocol was designed as a new standard for LR-WPANs (Low- Rate Wireless Personal Area Networks). The goal of this protocol is very little complexity, cost, and power. This standard also supports multi-hop packet transmission [5][6]. IEEE 802.15.4 supports the creation of a simple tabbed star mesh, as well as a multi-tabbed tree or mesh. For devices with limited power, network performance can be traded for power efficiency by utilizing the power conservation mechanism that comes with IEEE 802.15.4. The IEEE 802.15.4 standard defines beacon active mode and on-frame structure for power conservation purpose. Thus, operation can be performed either in beacon active mode or in beacon disabled mode.

In beacon active mode, a network coordinator broadcasts the beacon signal periodically in all directions, so that other nodes in the network synchronize the over-frame structure proposed by the coordinator by hearing these beacon signals.

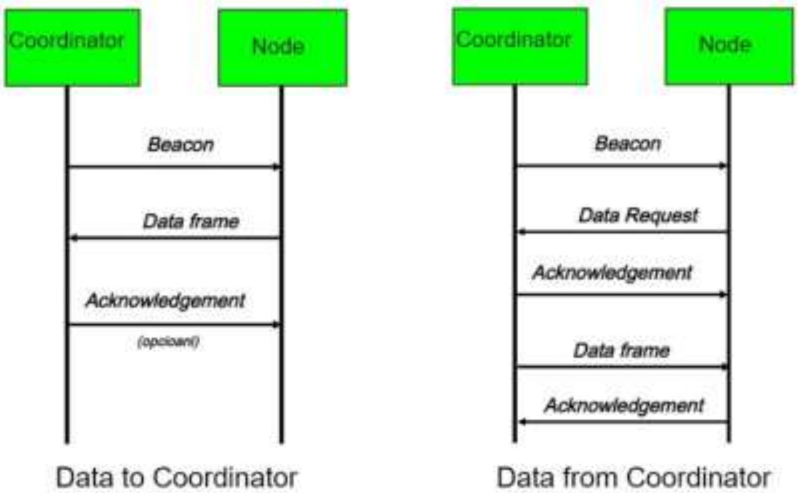

Figure 2. IEEE 802.15.4 Data Transfer.

In beacon disabled mode, a network coordinator does not send the beacon signal in all directions, only if other nodes request a beacon signal for scanning or association purposes. In the beacon signals broadcast in all directions, there is also structure information on the frame. When other nodes in the network receive a beacon signal, they acquire the super frame structure and start synchronizing with the super frame structure of the coordinator. The structure of a top of the frame is defined by network beacon signals. A network beacon signal marks the beginning of the top of the frame and at the same time marks the end of the previous top of the frame. A frame top consists of two parts. These are the active part and the inactive part. The length of the top of the frame and the duration of the active part, which is the range of the beacon signal, depends on the degree of beacon and the top of the frame, respectively.

The length of the inactive part is determined by subtracting the on-frame time from the beacon signal interval. The active segment is divided into 16 segments of equal length and has 2 periods. These periods are called CAP (Contention access period) and CFP (Optional contention free period). During CAP, IEEE802.15.4 uses CSMA/CA mechanism for channel access in slices. CFP, on the other hand, can be deployed in low-latency applications or applications that require certain data bandwidth. Only network beacon signals and ACKs are taken into account for energy consumption measurement. Efficient CSMA/CA is used for collision.

2.2 MAC Protocols Developed for Sensor Networks

In this study, energy efficient MAC protocols in sensor nodes are grouped under 2 general classes. These can be classified as protocols that use the sleep-wake and low-power listening techniques of the nodes for energy efficiency, and in addition to these, they try to prevent energy waste in the MAC layer by processing the prefix. In addition, the majority of these protocols have adopted the CSMA method. In addition, there are only protocols in which TDMA and TDMA/CSMA methods are used together. In this study, these protocols will be explained in detail.

2.3.1 PAMAS

PAMAS (The Power Aware Multiaccess With Signaling) was designed as a combination of the original MAC protocol and the idea of using a separate signaling channel [7][8]. It saves energy by utilizing two transceivers. Of these two transceivers, one is for data messages and the other is for control messages. For RTS and CTS message exchange, a signaling channel is used separately from the channel used for sending packets. This separate signaling channel allows nodes to decide when and for how long to power off. In this protocol, a node can have 6 states. These are idle, CTS standby, BEB (Binary Exponential Back-off), packet standby, it is called receiving and sending packets. If a node does not transmit and receive packets, if it does not have a packet to transmit, but cannot transmit due to the transmission of its neighbor, it is in idle mode. When the node receives a packet to transmit, RTS transmits and CTS goes into standby mode. If the expected CTS does not come, the node switches to BEB mode. If CTS arrives, it starts transmitting packets and switches to packet sending mode. The desired receiver switches to the packet standby mode depending on the CTS transmission. If the packet does not start arriving within a round trip time, the node goes into idle mode. If the packet starts to arrive, it transmits the busy tone on the signaling channel and enters the packet receiving mode. If none of its neighbors are in the state of sending packets and waiting for CTS, when the node in idle mode receives RTS, it responds with CTS [9][10]. PAMAS also uses the busy tone to communicate. PAMAS devices turn off the power in two situations. They either have no data to send or their neighbors have started sending data with another node. Figure 3 shows the data transfer of the PAMAS protocol.

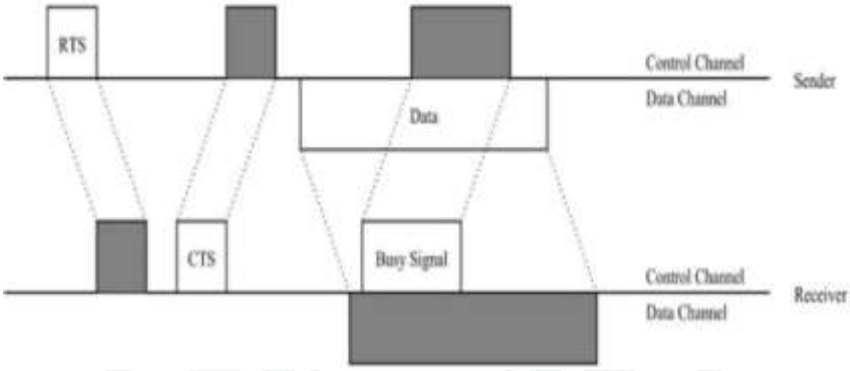

Figure 3. PAMAS data transfer

Packet delays do not increase as a result of node shutdowns, they do increase as a result of the node downtime period. This protocol also catches the hidden terminal problem.

2.3.2 S-MAC

The S-MAC (Sensor Medium Access Protocol) protocol is a CSMA-based protocol. S- MAC uses three new techniques to reduce energy consumption and support self- configuration phenomenon. Nodes are periodically put into sleep mode in order to reduce the energy consumed during the unnecessary rest of the environment.

Neighboring nodes are in virtual clustering and sleep schedules are automatically synchronized [11][12]. Inspired by the PAMAS protocol, in the S-MAC protocol, a node can turn off its own radio while communicating with other nodes. Another aspect of the PAMAS protocol is that it uses the in-channel signaling technique. In addition, the S-MAC protocol uses message transfer method to reduce the latency caused by collision for sensor network applications. Unified planning and competition planning were utilized for good scalability and conflict avoidance. The message transfer concept used in the S-MAC protocol provides the transmission of large data. In this way, the most basic information, which is the case of sending large packets into small pieces, arises. Latency is either important or not depending on which application is running on the node. If there is no flow in the network, very low data communication will occur. Therefore, most of the time the nodes are in the empty state. In this case, very little delays are not so important, even if there is some delay, this event can be used for energy conservation. Therefore, in the S-MAC protocol, the nodes periodically send the nodes to sleep mode when the environment is resting unnecessarily. Therefore, listening and sleeping times are fixed and periodic. In this way, the energy consumption that will arise from unnecessary rest of the environment is reduced thanks to the S-MAC protocol [13][14].

However, in this case, the delay increases. A very good synchronization is needed so that the nodes can cooperate and act together. The S-MAC architecture diagram is shown in Figure 4.

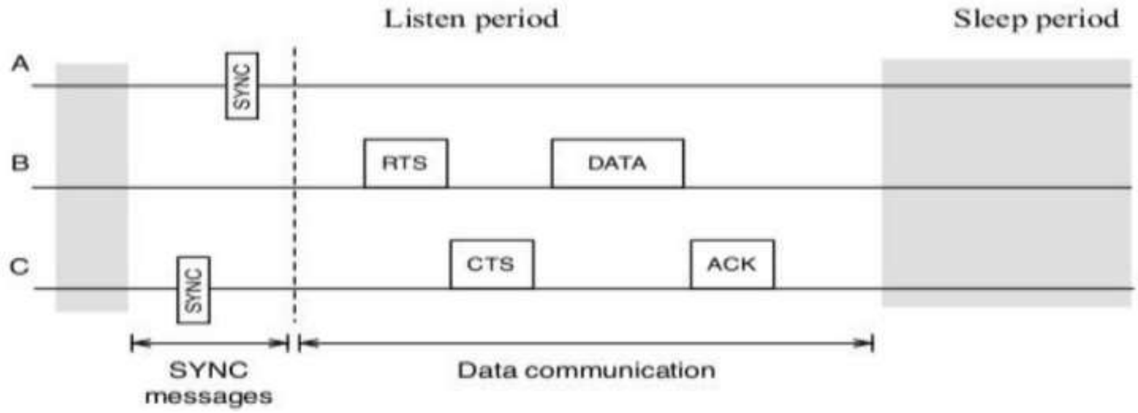

Figure 4. S-MAC architecture

A timer is used for periodic listening and sleeping in the S-MAC protocol. All nodes can set their own listening and sleeping times. They use RTS/CTS control packets like IEEE 802.11. Virtual clustering is used for synchronization. Before going into periodic listen/sleep mode, each node must choose a plan and report it to its neighbors. Each node has a plan table and the plans of all known neighbors are updated in this table.

2.3.3 T-MAC

T-MAC (Timeout Medium Access Control- Timeout Media Access Protocol) protocol is a CSMA based protocol. Inspired by the S-MAC protocol. T-MAC minimizes idle listening for CAA. It decides whether to terminate the active period by replacing the fixed-length duty cycle with a timer [15][16]. Its length is dynamically decided to maintain the optimal active time at different loads. Active time is terminated intuitively, that is, when nothing is heard. Each node wakes up periodically to communicate with its neighbors and then goes back to sleep until the next frame. New messages are queued at this time. Nodes communicate with each other using RTS, CTS, ACK packets. A node will continue to listen and transmit potential as long as it is in the active period. The active period will end if an activation event does not occur within a certain time. If the node is not in the active period, it will sleep. Frame synchronization is inspired by virtual clustering described in the S-MAC protocol. Whenever a node wakes up, it starts to wait and listen. If it doesn't hear anything for a certain period of time, it selects the frame schedule and sends a SYNC packet containing the start of the next frame. If a node hears a SYNC from another node during startup, it will follow the schedule in that SYNC packet and send its own SYNC packet similarly. Nodes resend their SYNCs once in a while. The T-MAC architecture is shown in Figure 5. will expire if no activation event occurs within a certain time. If the node is not in the active period, it will sleep. Frame synchronization is inspired by virtual clustering described in the S-MAC protocol. Whenever a node wakes up, it starts to wait and listen. If it doesn't hear anything for a certain period of time, it selects the frame schedule and sends a SYNC packet containing the start of the next frame. If a node hears a SYNC from another node during startup, it will follow the schedule in the SYNC packet and send its own SYNC packet similarly. Nodes resend their SYNC once in a while. The T-MAC architecture is shown in Figure 5. will expire if no activation event occurs within a certain time. If the node is not in the active period, it will sleep. Frame synchronization is inspired by virtual clustering described in the S- MAC protocol. Whenever a node wakes up, it starts to wait and listen. If it doesn't hear anything for a certain period of time, it selects the frame schedule and sends a SYNC packet containing the start of the next frame. If a node hears a SYNC from another node during startup, it will follow the schedule in that SYNC packet and send its own SYNC packet similarly.

Nodes resend their SYNC once in a while. The T-MAC architecture is shown in Figure 5. Whenever a node wakes up, it starts to wait and listen. If it doesn't hear anything for a certain period of time, it selects the frame schedule and sends a SYNC packet containing the start of the next frame. If a node hears a SYNC from another node during startup, it will follow the schedule in the SYNC packet and send its own SYNC packet similarly. Nodes resend their SYNC once in a while. The T-MAC architecture is shown in Figure 5. Whenever a node wakes up, it starts to wait and listen. If it doesn't hear anything for a certain period of time, it selects the frame schedule and sends a SYNC packet containing the start of the next frame. If a node hears a SYNC from another node during startup, it will follow the schedule in that SYNC packet and send its own SYNC packet similarly. Nodes resend their SYNCs once in a while. The T-MAC architecture is shown in Figure 5. Nodes resend their SYNC once in a while.

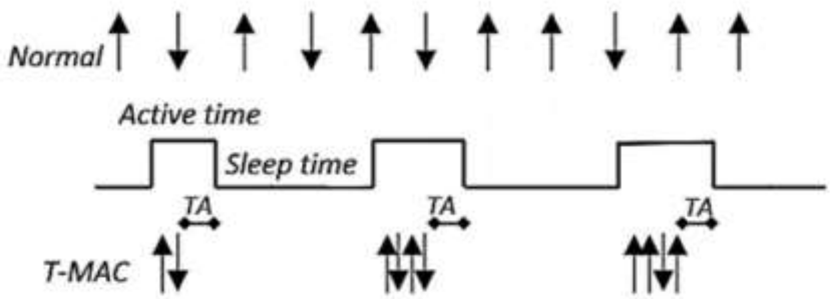

Figure 5. T-MAC architecture

The virtual clustering technique is easy to implement. However, listening periods in virtual clustering disrupt its synchronization. Due to this problem, the problem of sleeping early in the T-MAC protocol arises.

2.3.4 TRAMA

TRAMA (Traffic-Adaptive Medium Access) is a protocol developed for energy efficient conflict-free channel access for WSNs. It is a TDMA-based protocol [17][18]. TRAMA reduces energy consumption in unicast, multicast, and omni-cast transmission by allowing collision-free and allowing nodes to switch to low-power mode when not receiving or transmitting.

TRAMA uses time slots and uses the distributed selection scheme on information about traffic at each node to decide which node will transmit in a given time slot. Using the planned time frame. It support random access to time slots for small and periodic control messages, avoiding contention for large data messages. Nodes use the TRAMA exchange to identify their two-hop neighborhood information and transmission schedules in chronological order to identify desired receiving nodes in their traffic and then select nodes to transmit and receive during each slot. Figure 6 shows the frame structure of the TRAMA protocol.\

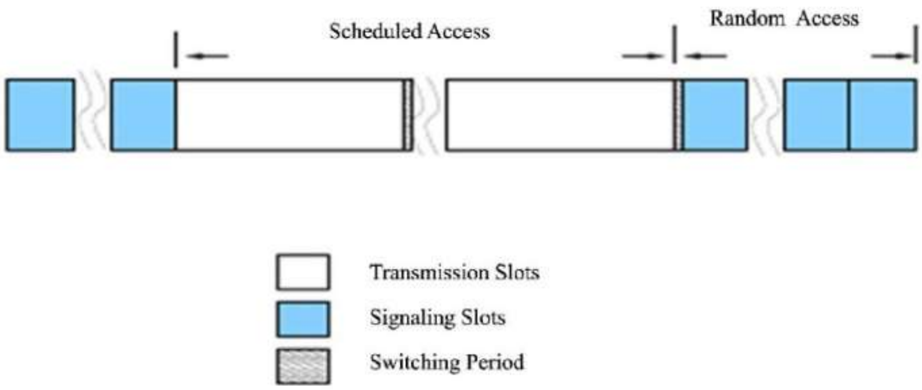

Figure 6.TRAMA frame structure

TRAMA uses Neighbor Protocol (NP) to share topology information and plan-exchange protocol, which shares information about how much traffic nodes have in their queues and also allows nodes to exchange two-hop neighborhood information and plans, and neighborhood and plan information. It uses adaptive selection algorithm (ASA) to select senders and receivers that will use the time slot and to leave all other nodes in low power mode. The NP spreads one-hop neighborhood information among neighboring nodes during the random access period, using signal slices to obtain consistent two-hop topology information across all nodes. During the random access period, nodes perform contentious channel acquisition. Nodes use PETP to exchange traffic-based information or plans with their neighbors [19][20]. Before a node can start actual transmission, it must announce its plan using PETP. PETP keeps consistent plan information of neighbors and performs the process of updating plans periodically. The ASA protocol uses the information obtained from NP and PETP to select suitable forwarders and receivers to be successful in communication without conflicts. ASA uses traffic information to increase the efficient use of the channel. Time synchronization can be done during the period. The NP collects neighborhood information by exchanging small signal packets during the random access period. The latency of the TRAMA protocol is higher when compared to other similar protocols.

2.3.5 P-MAC

The P-MAC (Pattern Medium Access Control) protocol is a CSMA-based protocol. In the P-MAC protocol, instead of waking up to a fixed sleep, it is decided adaptively whether the sensor nodes wake up or go to sleep. Plans are decided by looking at the traffic of the nodes themselves and the traffic of their neighbors. P-MAC is a time slot protocol like the S-MAC protocol. In the P-MAC protocol, a node can be asleep or awake for a period of time [21][22]. Figure 7 shows the length of the idle listening period of the S-MAC T-MAC and P-MAC protocols in the absence of traffic on the sensor network. In the P-MAC protocol, a sensor node receives information about the activity in its neighbors before obtaining its patterns.

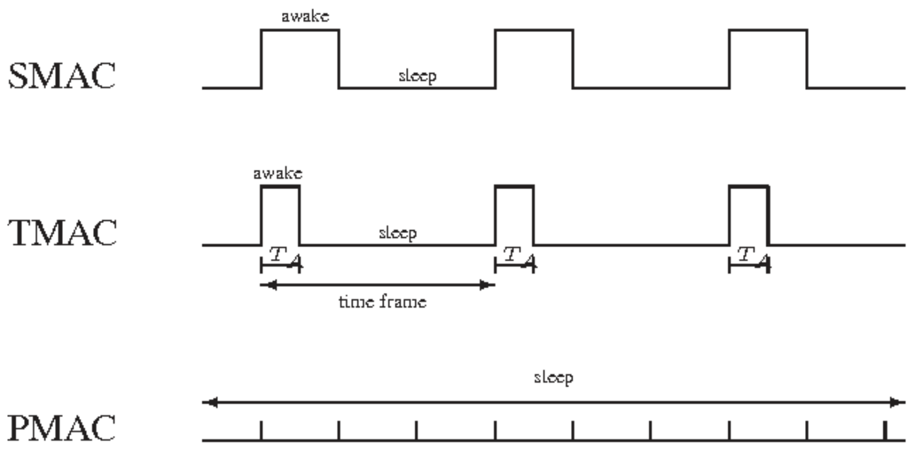

Figure 7. S-MAC, T-MAC, P-MAC comparison

Due to these patterns, when there is no traffic on the network, a sensor node puts itself into a long sleep for several time slots. When there is an activity in its neighbor, it knows it through these patterns and wakes up when necessary. The sleep-wake pattern is a string of bits and shows the temporary sleep-wake schedule for the sensor node in many time slots. The value of 1 in the String indicates that the node will be awake for a period of time, while 0 indicates that the node will be in the sleep state [23][24]. For example, 001 pattern for a node indicates that it will be asleep in 2 consecutive time slots in its temporal plan and awake in the 3rd slot. Time is divided into Super Time Frames (STF) to enable pattern exchange. Each STC contains the node's temporary sleep-wake schedule. Each STC has 2 subframes. The first is called the Pattern Repetition Timeframe (PRTF) and is used when each node is repeating its current plan. The second sub-frame of the STC is called the Pattern Exchange Time Frame (PETF). This is used when exchanging new patterns between neighboring nodes. PRTF is divided into many time zones. The pattern created last during a particular PETF becomes the pattern of the next PETF and is broadcast to these neighbors during the PETF. If a node does not receive new patterns from any of its neighbors during the PRTF period, it repeats their old scheme.

2.3.6 DSMAC

The DSMAC (Medium Access Control With A Dynamic Duty Cycle For Sensor Networks) protocol is inspired by the S-MAC protocol. DSMAC provides a good trade-off between the two performance metrics without incurring much overhead [25]. In addition, DSMAC can adjust duty cycles in changing traffic conditions without the need for prior knowledge of application requirements. More specifically, depending on the application, a sensor first performs a scanning phase, the sensor listens for a certain period channel, tries to adopt the existing sleep-wake schedule, if any, encapsulated by a SYNC packet. However, if a SYNC packet is not received by the end of the period, The sensor node assumes itself to be the first active sensor in the neighborhood and freely chooses the plan. The node then notifies the available nodes of its schedule by periodically broadcasting SYNC packets in all directions. Each node maintains a synchronization table for its neighboring nodes. When the sleep-wake schedule is decided, each node begins to propagate SYNC packets containing clock synchronization information in all directions. Whenever a node hears a SYNC packet, it updates its sync table and sets its own timer according to the SYNC packet generator. Average delay of the receiving node each node begins to propagate SYNC packets containing clock synchronization information in all directions. Whenever a node hears a SYNC packet, it updates its sync table and sets its own timer according to the SYNC packet generator. Average delay of the receiving node each node begins to propagate SYNC packets containing clock synchronization information in all directions. Whenever a node hears a SYNC packet, it updates its sync table and sets its own timer according to the SYNC packet generator.

It is the average value of all hop delay values collected during the current SYNC period. This average delay value allows the receiving nodes to make an approximate estimation of the current traffic conditions and serve to display the parameters. The DSMAC protocol uses a dual-phase tuning module. Apart from that, each receiving node also keeps track of its own energy consumption efficiency and average latency. Figure 8 shows the DSMAC architecture.

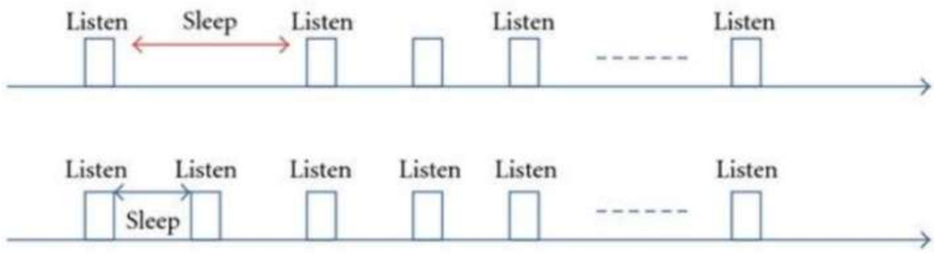

Figure 8. DSMAC architecture

Also in the SYNC package is a new field that displays the SYNC duty cycle initiator. The node broadcasts the current duty cycle in all directions in addition to the synchronization information via the SYNC packet. Those who hear the SYNC packet from neighboring sensor nodes control their own queue and double their duty cycle if they have a packet to send and the specified duty cycle in the SYNC packet is greater than the existing plan. Otherwise, if it's a new plan, the receiver updates its plan table. The overhead of the DSMAC protocol is the extra duty cycle space available in SYNC packets and the delay space for data packets that can be neglected.

2.3.7 O-MAC

The O-MAC (Organized Medium Access Control Protocol) protocol is inspired by the SMAC protocol. The purpose of the O-MAC protocol is to extend the life of the network by avoiding collision, unintentional reception and unnecessary listening, which are the main energy consumption causes. O-MAC is a conflict-based protocol. The design of this protocol consists of two main ideas [26]. First of all, a locally time-determined algorithm is adopted on the CSMA protocol in order to prevent possible conflicts between competing neighboring nodes. Secondly, nodes that are in the environment of the transmission and are not related to the sent data can go to sleep during this transmission and can prevent them from sending waste packets to themselves by informing all the other nodes in the environment without going into sleep state. Two new control packages are introduced in the O-MAC protocol and this verifies the channel reservation for all nodes. In this way, this operation of the nodes that go into sleep mode due to the conflict of RTS and CTS packets is prevented. In the O-MAC protocol, energy conservation is realized by putting the nodes that do not need this communication in the sleep mode around a transmission. This can be achieved while installing the sensor network. At this stage, each node can obtain an identifier (id) of its neighbors and sort them by the identifier. Any node in the environment must follow a node identifier-based plan algorithm to access the channel in transmit and receive situations. This identifier can be a sample or any other identifier for the MAC address of the sensor node. Two new control packages have been defined to replace the classic RTS/CTS control packages. The first control packet is called OTS (Order To Sleep) and is sent by the node that will transmit the data packet or by the receiver that will receive this data packet. An OTS is sent by the transmitter to access a channel. The packet contains the list of neighbors and the times of subsequent data. In this way, the sender indicates the number of neighbors and the order in which the OTS will announce its receivers' requests to go to sleep. This broadcasting process is done by sending the NTS (Node To Sleep) packet containing the duration of the sleep mode period.

2.3.8 AEEMAC

The AEEMAC protocol is inspired by the S-MAC protocol [27]. The idle listening event, which is one of the areas with the highest energy consumption in the WMA, is used in the AEEMAC protocol to avoid idle listening in the AEEMAC protocol. In addition, this protocol uses three additional improvements to achieve greater energy efficiency at the MAC layer. These improvements can be defined as adaptive sleep and channel reuse, the use of the combined SYNC-RTS control package, and the use of the combined ACK-RTS control package in two-way data transport.

2.3.9 STEM

STEM (Sparse Topology and Energy Management) is an encounter-based protocol. STEM does not work for capacity conservation so it saves great energy and orientation is not affected by it. STEM has a low-duty-cycle radio instead of a low- power radio [28]. The most important event in this protocol is that the sensor nodes can go into sleep mode independently. In the STEM protocol, energy conservation is achieved by waking up a neighboring node that is in sleep mode with a short message and using low power. A node can wake up its neighbor in two ways, either by sending a beacon message (STEM-B) or by a wake-up tone (STEM-B).

The initiating node that wants to communicate sends a signal with the id of that node to try to wake up the so-called target node. As soon as the destination node receives the signal, it responds to the origin node and both keep their radios on at this point. When both nodes establish a connection to turn on their radio, the connection is active and can be used for subsequent packets. In order not to interfere with the current data transmission with the wake-up protocol, STEM sends them in different frequency bands, using a different radio in each band. One approach with respect to STEM is to use a separate paging channel to wake up nodes that have turned on their main radio. Nevertheless, the paging channel radio cannot be put to sleep for some reason. In this approach, the paging channel is of lower power than those used for regular data communication. It revives the STEM paging channel by having a radio with a low- duty cycle radio instead of a low-power radio.

2.3.10 TICER AND RICER

The TICER (Transmitter Initiated Cycled Receiver) protocol works similar to the STEM-B case [29]. If a sensor node does not have the data packet for transmission, it wakes up with T period to watch the channel and returns to sleep mode after the wake-up time tone. If a node receives a sender packet created at the top layer of the protocol stack or forwarded by another node, it wakes up and monitors the channel for the duration of the tone.

If it does not hear a transmission in progress on the channel, it starts sending an RTS signal to the target node and watches the channel for a certain period of time for a response after each RTS transmission. The destination node that wakes up according to its wake-up schedule immediately receives RTS and responds to the source node with CTS. When the CTS signal is received, the source node starts transmitting the data packet. After receiving the data packet correctly, the destination node notifies the source node by sending an ACK signal that the session is over. Figure 9 shows the TICER architecture.

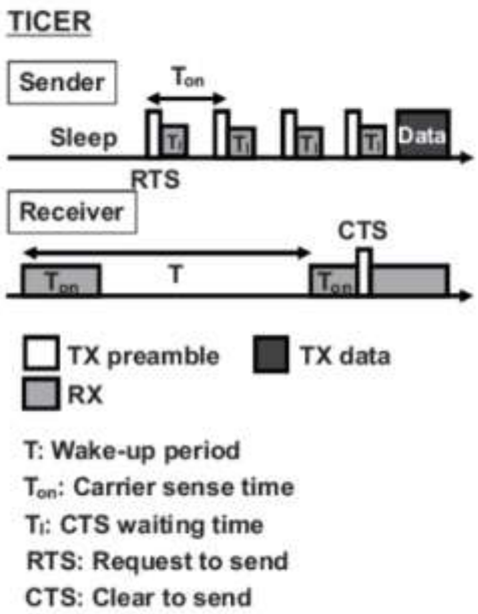

Figure 9. TICER architecture.

RICER (Receiver Initiated Cycled Receiver) Similar to the TICER scheme, a sensor node wakes up in the T period if there is no packet to transmit. It then sends a short wake-up beacon of definite length to let you know it is awake and watches the channel for a response for a certain period of time. If there is no response, the node goes to sleep again. The source node that has the data to transmit stays awake and watches the channel, waiting for a wake-up signal from the destination node. When it receives the reply, it starts transmitting the data packet. After correctly receiving the data packet, the session ends with the destination node sending an ACK to the source node. Figure 10 shows the TICER architecture.

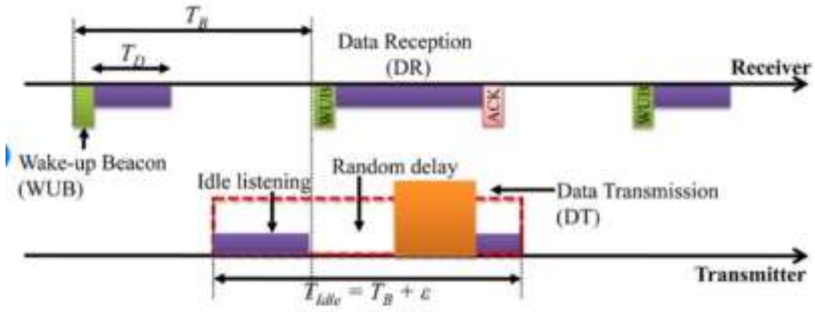

Figure 10. RICER architecture.

2.3.11 B-MAC

B-MAC (Berkeley Medium Access Control Protocol) is a CSMA-based protocol. B- MAC uses an adaptive prefix sampling scheme to provide low power functionality [30]. This reduces the duty cycle and idle listening. B-MAC supports on-the-fly reconfiguration and provides a bidirectional interface to optimize performance. The B-MAC protocol uses a very long prefix for message transfer. With the large prefix and transfer, there is an optimum trade-off in terms of energy conservation and delay. B-MAC CCA (Clear Channel Assessment), packet withdrawal for channel resolution, link layer acknowledgment for security, uses a low power listening scheme for low power communication. B-MAC has a set of interfaces. These interfaces provide the possibility to set operations in addition to the standard message interface. These interfaces are CCA, ACK, retreat and allows tuning to network services for situations included in the B-MAC mechanism such as LPL. B-MAC implements software automatic gain control for the noise environment that changes depending on the environment. If 5 samples are taken and no outliers are found, the channel is busy [36][37]. If CCA is enabled, B-MAC uses the initial channel delay when sending packets. The B-MAC does not set the pullback time, instead an event is signaled to the sending service via the Mac Back-off interface. The service returns an initial pullback time or ignores the signaled event. If it ignores, a small random pullback is used. After the initial pullback, the CCA outlier algorithm works. If the channel is not clear, an event signals the service for the congestion retracement time. If withdrawal time is not given, small random pullback is used. The technique used in B-MAC is similar to the prefix sampling in Aloha but adapted to different radio characteristics. In the B-MAC protocol, a threshold value is set for the use of signal strength to reduce energy use. To receive data securely, the initial prefix length is mapped to the range of detecting activity on the channel. The hidden terminal problem found in traditional wireless networks is one of the problems in this protocol. Figure 11 shows the transmission mode of the B-MAC protocol. In the B-MAC protocol, a threshold value is set for the use of signal strength to reduce energy use. To receive data securely, the initial prefix length is mapped to the detection range for activity on the channel. The hidden terminal problem found in traditional wireless networks is one of the problems in this protocol.

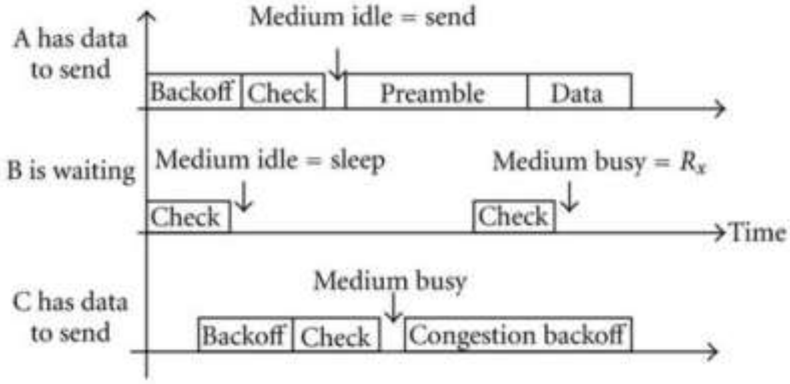

Figure 2.11. B-MAC Data transfer

2.3.12 CSMA-MPS

In the CSMA-MPS (CSMA With Minimal Preamble Sampling- CSMA) protocol, the issue of latency and energy in the B-MAC protocol has been developed [31]. The CSMA-MPS protocol uses a very efficient wake-up mechanism and thus appears as a MAC protocol that optimizes low energy consumption. CSMA-MPS was developed to increase the efficiency of wake-up mechanisms of STEM type protocols and this process was tried to be achieved by combining the best features of both protocols. The CSMA-MPS protocol uses the alternative transmission and reception of the STEM protocol and combines them with more efficient wake-up capability. Using alternate transmission and reception allows for near-instant synchronization without the need to send a prefix with worst-case length. Figure 12 shows how CSMA-MPS data transfer is done.

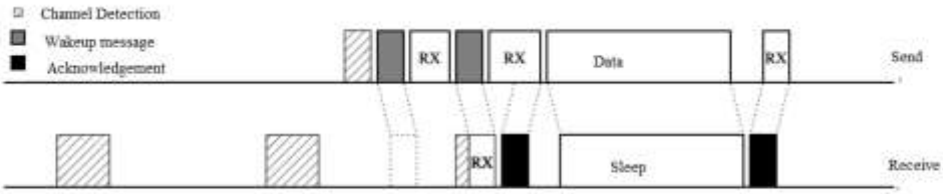

Figure 12. CSMA-MPS Data transfer.

Similar to STEM-B and TICER protocols, instead of sending long prefixes, source nodes send small control messages and line the line to see if there is a response from the receiver. A node that wants to communicate with one of its neighbors may or may not have a sampling plan of its neighbors. If it doesn't, the CSMA algorithm is started immediately, otherwise if there is a clock estimate, it is sent back a few times for the carrier to start detecting at the right time just before the receiver starts its periodic listening interval. When the sampling schedule and the time of the last synchronization are known, the source waits for the sampling schedule and sends the wake-up data message sequence at the same time as the minimum-size wake-up sequence. This protocol does not require network-wide synchronization and periodic local synchronization messages. Only when messages are exchanged, the wake-up plan exists in both the data frame and the ACK frame. In the CSMA-MPS protocol, the source node is given the opportunity to determine the sampling of its neighbor and there is no need for an additional field in the ACK. In addition, small control messages perform the function of RTS and CTS control messages.

2.3.13 PREFIX SAMPLING WITH ALOHA

The prefix sampling protocol with Aloha is a protocol that combines the ALOHA protocol and the prefix sampling technique [32]. The purpose of the prefix sampling technique is to allow the receiver to sleep mostly while the channel is empty. This includes a prefix transmission of a certain length in front of each packet. A receiver wakes up periodically at certain times and checks for activity on the channel. If it finds the channel empty, the receiver goes back to sleep. If a prefix is detected, the receiver stays awake and continues listening until the packet is received. By combining the features of Aloha and prefix sampling, the time spent on unnecessary listening to the environment can be reduced. Due to the long transmission, the reception length increases. It will also increase the probability of collision. Each message is prioritized by a prefix. In other words, the sending node waits for a response from the receiving node to understand whether the intended communication was successful. After the RX to TX conversion time, on successful receipt of a message, the destination node will send a readmission message. If a conflict occurs in the sent packet, it will be sent again after a certain period of time. The biggest disadvantage of the ALOHA protocol is the unnecessary listening of the environment. Here, low power listening technique is used to prevent energy loss. In order to sample incoming messages, the header in the message uses a prefix that identifies the recipient of subsequent messages. If the sent prefix is not heard by the receiving party, the radio is turned off until the next sample arrives. The prefix sampling technique is the only way to implement Genie, which notifies when the channel is busy. the other way, it could be having a second awake receiver that is constantly listening. This second receiver should be very simple and therefore consume very little power to allow its stationary use. When the traffic in the environment is detected, the main receiver is awake. On the transducer side, message transmission must be prioritized so that the main receiver can be awake at the start of the message. The sampling architecture of this protocol is shown in Figure 13. This protocol appears to be more suitable for applications under low traffic conditions. Message transmission should be prioritized so that the main receiver can be awake at the start of the message. This protocol appears to be more suitable for applications under low traffic conditions.

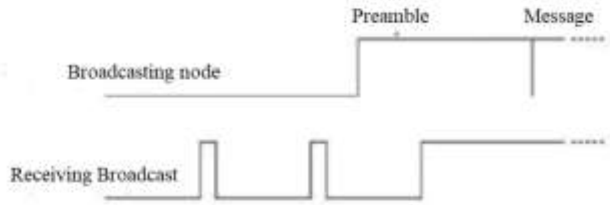

Figure 13. Prefix sampling architecture with Aloha

2.3.14 X-MAC

X-MAC is inspired by the B-MAC protocol. X-MAC applies a short prefix to reduce energy consumption and latency and allows low power listening operation. By having the address information of the target in the prefix, it is aimed to quickly put the non-target receiver nodes to sleep. It also allows the target recipient node to cut the long prefix and allows the node to use the triggered prefix as soon as it wakes up (Kredo and Mohapatra, 2007; Buettner et al., 2006). The short triggered prefix approach reduces the energy and time it takes to complete the entire prefix. X-MAC uses a short prefix and each of these prefixes contains destination address information. Thus, it avoids low power listening problem and provides energy conservation in non-target receivers. It also reduces the latency as the short prefix is used. It gives better results in latency, efficiency and power consumption than B-MAC during unidirectional broadcast. Energy losses due to involuntary listening are reduced. Same as B-MAC in anycast. The design objectives of the X-MAC protocol in the duty cycles of WSNs can be explained as energy efficiency, simple, low overhead, distributed application, low latency, high throughput. X-MAC tries to provide energy efficiency by using the advantages of low power listening technique together with the short prefix approach in the method he calls low power communication [33].

2.3.15 CMAC

CMAC (Convergent Medium Access Control) is a low duty cycle convergent MAC protocol. The traditional wake-up plan approach causes high packet delivery delay for either periodic synchronization message or any synchronization [34]. CMAC supports low latency while avoiding synchronization overhead.

Because it uses zero communication when there is no traffic, CMAC allows operations at a very low duty cycle. If traffic occurs, CMAC first uses omnidirectional broadcast to wake up the nodes and converges from the unsynchronized omnidirectional insufficient path duty cycle to a one-way optimal path duty cycle, i.e. a synchronous plan. When there is no packet to be transmitted, CMAC uses asynchronous sleep schedule similar to BMAC protocol. If the sender is able to transmit packets to a node with acceptable routing metrics, CMAC converges from anycast to unicast to avoid the overhead of anycast. In the CMAC protocol, long prefixes are fragmented and converted into many RTS packets by using offensive RTS instead of long prefixes. RTS packets do not use long prefixes and split these long prefixes into fixed short ones, allowing receivers to send CTS packets back. The CMAC protocol includes three components such as offensive RTS using dual channel control for channel determination, anycast to find the forwarder quickly, and convergence of packet transmission to reduce the overhead of anycast.

2.3.16 CC-MAC

Integrity-based MAC protocol design has been made in CC-MAC (Spatial Correlation- Based Collaborative Medium Access Protocol-Spatial Correlation Based Collaborative Media Access Protocol). This protocol protects media access from redundant transmission generated by nearby sensor nodes. The spatial CC-MAC protocol regulates the cooperative sensor node transmission and the disturbance restriction is about an event, it can be achieved even if the number of nodes sending information decreases [35]. By cleverly choosing the locations of the nodes, distortion can be reduced. To achieve this purpose, the INS algorithm decides the association diameter for the distortion restriction located in the base station. Then, this information is sent to each sensor node by broadcasting in all directions during the network setup. The CC-MAC protocol implemented in each sensor node uses a distributed MAC structure [36]. CC-MAC uses the relationship radius to stop the unnecessary flow of information in the WSN. When a particular source node transmits its event log to the base station, all its associated neighbors have redundant information due to the corruption constraint. This useless information if sent, it increases the overall latency and contention in the relationship region, in addition to wasting WSN resources. The spatial CC-MAC protocol tries to transmit the filtered data to the base station with priority and thus avoid unnecessary transmission of information. The sensor nodes in the WSN have dual functionality: data generation and routing. Therefore, media access occurs for two reasons. CC-MAC protocol includes two components depending on source and routing functionality. E- MAC (Event MAC) filters associated records and N-MAC (Network MAC) ensures the prioritization of forwarded packets. More specifically, when a node uses the E-MAC when it wants to transmit its detection read to the base station,

2.3.17 Z-MAC

Z-MAC (Zebra Medium Access Control Protocol) is a hybrid MAC protocol. Z-MAC protocol assigns time slots to sensor nodes. It behaves like CSMA at low traffic density and like TDMA at high traffic density [38]. Unlike TDMA, it is resistant to dynamic topology changes and time synchronization instability seen in sensor networks. It also handles hidden terminals with very low overhead, unlike CSMA. DRAND uses the old scalable channel planning algorithm. DRAND is the first distributed implementation of RAND. DRAND is a scheduling algorithm for central channel reuse. In the applied plan, it is necessary to ensure that two hop neighbors are not assigned to the same slice number. After the slice assignment, each node periodically reuses its assigned slice at a predetermined period. They can have more than one slice per slice. Because DRAND allows two nodes separated by more than two hops to have the same slice. As in CSMA, before a node transmits in a slice, it always checks the line and sends packets if the channel is clear. However, the owner of the slice has priority over the others on the channel. This priority is implemented by setting the initial withdrawal period. The higher priority node is the one with the shorter withdrawal period. In Z-MAC, a node can obviously switch between two modes of operation depending on the current state of the network contention [37]. Under low contention, non-owners are allowed to compete for the low priority tranche. This mode is called low contention. Under high contention on two hops, the hidden terminal problem may arise. If more data contention occurs, the node sets its mode to high contention. In this mode, it does not act as a stealth terminal against those who do not have a slice. Z-MAC only needs local time synchronization between two hop neighbor senders. Z-MAC protocol has similar advantages and disadvantages to B- MAC protocol. The disadvantage of the Z-MAC protocol is that its performance lags behind CSMA. with other protocols If more data contention occurs, the node sets its mode to high contention. This mode does not act as a stealth terminal against those who do not have a slice. Z-MAC only needs local time synchronization between two hop neighbor senders. Z-MAC protocol has similar advantages and disadvantages to B-MAC protocol. The disadvantage of the Z-MAC protocol is that its performance lags behind CSMA. with other protocols If more data contention occurs, the node sets its mode to high contention. In this mode, it does not act as a stealth terminal against those who do not have a slice. Z-MAC only needs local time synchronization between two hop neighbor senders. Z-MAC protocol has similar advantages and disadvantages to B-MAC protocol. The disadvantage of the Z-MAC protocol is that its performance lags behind CSMA. with other protocols The disadvantage of the Z-MAC protocol is that its performance lags behind CSMA. with other protocols The disadvantage of the Z-MAC protocol is that its performance lags behind CSMA. By comparison, the Z-MAC protocol requires few processing and memory resources.

2.3.18 ER-MAC

ER-MAC [39] is a hybrid MAC protocol for WSN. The ERMAC design is a mix of TDMA and CSMA protocols. In this way, it can offer a flexible adaptation for traffic and topology changes. In the TDMA approach, it adopts the non-conflict time zone plan. Nodes wake up for their scheduled slices, but otherwise go to sleep for power conservation. Nodes participating in the emergency control can change their MAC behavior. They do this by allowing overlap in TDMA slots for high transport rate and low latency.

The ER-MAC protocol provides a synchronized and sparse slice structure for nodes to enter and exit the network. The ER-MAC protocol initially communicates with CSMA/CA using the random access mechanism.

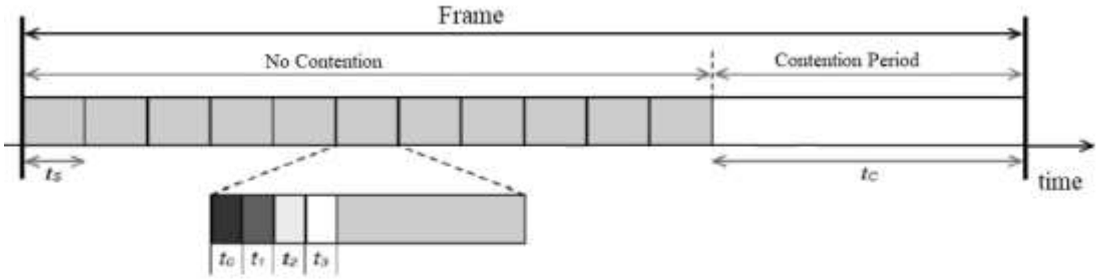

Figure 14. ER-MAC frame structure

During the initial phase, the data collection tree and TDMA plans are created. In topology discovery, the base station initiates the tree structure using the simple flow mechanism. The purpose of topology discovery of this protocol is not just to establish a routing tree, but to monitor neighbors and changes in the tree. Each node maintains the hop count to the base station, the parent member id, the child member list, and a hop neighbor list. In the TDMA slice assignment phase, nodes assign slices and exchange plans, so that two nodes in a 2-hop neighborhood do not use the same slice.

TDMA slice assignment follows a bottom-up approach where leaf nodes initiate slice assignment. Initiating slice assignment from leaf nodes must have a transmission schedule that delivers the message stream to the base station. Except for the base station, non-leaf nodes wait for the plans of all sub-members before assigning one-way slice to send their own data, multiple slots to transmit data of sub-members, and anycast slot to synchronize their sub-members. This slice assignment phase ends after the base station receives a plan notification message from all its sub-members. The base station switches to TDMA by sending the first synchronization message. When the child receives the message, it switches to TDMA and synchronizes its children using the anycast slot. The base station switches to TDMA by sending the first synchronization message. When the child receives the message, it switches to TDMA and synchronizes its children using the anycast slot. The base station switches to TDMA by sending the first synchronization message. When the child receives the message, it switches to TDMA and synchronizes its children using the anycast slot.

2.3.19 STREAMER

FLAMA (Flow-Aware Medium Access Protocol) achieves energy efficiency by preventing unnecessary listening, data conflict and transmission of the node that is not ready to receive packets [40]. This protocol adapts the media access plans to the traffic flow exhibited by the application. FLAMA is a plan-based MAC protocol used to provide strong traffic prediction in sensor network applications. FLAMA uses the flow concept to characterize the traffic patterns of applications. FLAMA uses flow-based traffic information to determine its forwarding schedule, as well as to determine when nodes will be in receiver mode or go into a low-power sleep state. The main feature of FLAMA is its use of simple adaptive traffic and distributed selection scheme for energy efficient channel access. To realize this selection, two hops need neighborhood and neighborhood flow information. Using two-hop neighborhood information makes the FLAMA protocol scalable. A single channel assumption is made for data and signaling. However, FLAMA can easily adapt to the use of many channels. Access to the channel is conflict-based during random access and timed during the scheduled access period. Neighbor discovery during random access, time synchronization and full exchange of traffic information are carried out. Data communication takes place during scheduled access. Figure 15 shows the FLAMA time organization.

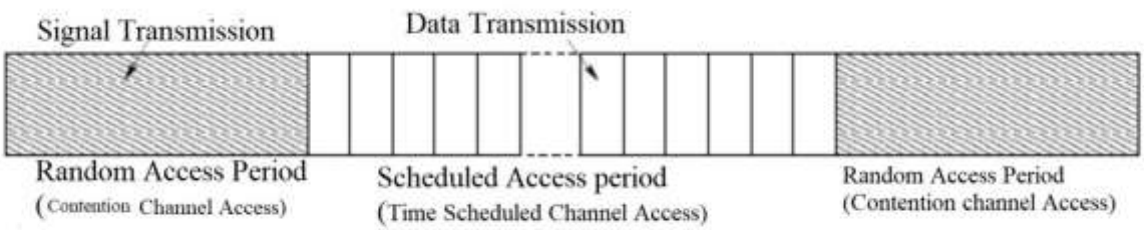

Figure 15. FLAMA time organization

The use of random access periods allows the FLAMA protocol to adapt to traffic changes and topology in the network. FLAMA has no requirement to announce the full plan during scheduled access periods. FLAMA achieves traffic adaptability by giving a time slot to the node depending on the amount of traffic generated by the node. More time slots are used for nodes that route or generate more data.

III. COMPARISON

Energy efficiency is a very important and necessary element for WSNs. When the MAC protocols described in detail are examined, the importance of energy efficiency can be understood more easily. All of the protocols described in detail provide energy efficiency in some way. Related protocols have used many different mechanisms for this energy efficiency. Some of the protocols described in detail in Table 1. Comparisons were made on the basis of parameters. It is seen in Table 1 that the majority of the protocols implemented in the MAC layer in WSNs have adopted the CSMA method as the media access protocol. Some protocols have provided energy efficiency by providing their own plans or synchronization with the plans they have obtained in the network. In the comparison, a parameter is used to understand the plans that the protocols use for energy efficiency and whether these plans are exchanged and the results of the analysis are shown. Most of these protocols have simulations but no implementations. Although simulation and application results are generally parallel, they are not the same. Even if the implementations of the protocols have been done, the applicability of the proposed protocol will have been tested in the real environment. This will provide a more precise information and estimation opportunity for institutions and researchers interested in this subject. In this study, the protocols are divided into two parts. These can be explained as protocols that try to achieve energy efficiency using the preamble and protocols that try to achieve it without using it. A comparison parameter related to this issue, which is considered important for sensor networks, is used. In this way, it is understood which protocol follows which method in the MAC layer. In addition, only RTS and CTS are accepted as control packages and protocols that use and do not use these control packages are shown.

IV. CONCLUSION

The use of wireless sensor nodes is increasing day by day. This situation brings together the problem of energy efficiency, which is one of the most important problems for WSN. Therefore, a lot of work is being done on energy efficiency. In general, in this study, we have contributed significantly to the subject of WSN are examined in detail here and grouped and compared in terms of various parameters. Studies on this subject are constantly increasing and new methods are being developed. The issue of ensuring energy efficiency in the WSN, which is rapidly developing in both academic and industrial fields and whose importance is increasing day by day, which is very important for researchers. A detailed examination of the study in this field and presenting the differences between them will be a source for future study in this field.

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Table 1. Analysis made for some parameters of the protocols and results.

Protocol	Control Packet (RTS/CTS)	Channel Access Protocol	Comparison	Preamble	Planned/ Unplanned	Application specific	Similarity
IEEE 802.15.4	Not used	CSMA	Own version	NO	UNPLANNED	YES	YES
PAMAS	RTS/CTS	CSMA	mathematical	NO	UNPLANNED	NO	YES
S-MAC	RTS/CTS	CSMA	IEEE 802.11	NO	PLANNED	YES	YES
T-MAC	RTS/CTS	CSMA	S-MAC, CSMA	NO	PLANNED	NO	YES
TRAMA	Not used	TDMA	NAMA, S-MAC, IEEE802.11, CSMA	NO	PLANNED	NO	YES
P-MAC	RTS/CTS	CSMA	S-MAC	NO	PLANNED	NO	YES
DSMAC	RTS/CTS	CSMA	S-MAC	NO	PLANNED	NO	YES
O-MAC	RTS/CTS, OTS,NTS	CSMA	IEEE802.11, S-MAC	NO	PLANNED	NO	YES
AEEMAC	RTS/CTS, SYNC-RTS, ACK-RTS	CSMA	S-MAC	NO	PLANNED	NO	YES
STEM	Not used	CSMA	SYMULATION	NO	UNPLANNED	NO	YES
TICER-RUCER	RTS/CTS	IDENTIFICATION	MATHEMATICAL	NO	UNPLANNED	NO	NO
B-MAC	Not used	CSMA	S-MAC,	YES	UNPLANNED	YES	YES
CSMA-MPS	Not used	CSMA	TDMA, WISEMAC	YES	UNPLANNED	YES	YES
ALOHA PREAMBLE SAMPLING	Not used	ALOHA	WITH OWN VERSION	YES	UNPLANNED / PLANNED	NO	YES
X-MAC	Not used	CSMA	LPL	YES	PLANNED	YES	YES

CMAC	RTS/CTS	CSMA	CSMA,S-MAC, GERAF, CMAC, B-MAC	YES	PLANNED	YES	YES
CC-MAC	RTS/CTS	CSMA	TRAMA, S-MAC, CSMA	NO	UNPLANNED	NO	YES
Z-MAC	Not used	CSMA/TDMA	B-MAC	NO	PLANNED	YES	YES
ER-MAC	Not used	CSMA/TDMA	Z-MAC	NO	PLANNED	NO	YES
STREANER	Not used	TDMA	TRAMA, S-MAC	NO	PLANNED	YES	YES