MAC PROTOCOLS FOR WSN

I. INTRODUCTION :

The inherent challenge in communicating sensors is energy consumption and autonomy. Indeed, these devices are often energy-autonomous for an extended period and must, therefore, consume very little. However, radio communication is highly energy-intensive. Link layer protocols have thus been proposed to reduce energy consumption.

II. MAC for IOTs APPLICATIONS :

Wireless Sensor Networks (WSNs) are expected to operate autonomously for extended periods of time without human intervention in a variety of applications. The energy limitations of sensor nodes present a problem, though. Nodes in a sensor network start to disconnect as their energy levels drop, which lowers the network's performance. Therefore, for the network to function at its best, increasing its lifespan is essential.

MAC (Medium Access Control) protocols exert a significant influence on sensor energy consumption. Important functions are performed by the MAC layer, which is located in the Data Link Layer, the second layer of the OSI model, just above the Physical layer. Since the radio is the most energy-intensive component and is governed by the MAC layer, MAC protocols play a significant role in the total energy consumption and ultimately determine the node's lifetime. Determining how nodes gain exclusive access to the shared medium and guaranteeing that only one node is on the channel at a time are the main purposes of MAC protocols. Furthermore, the channel sensing scheme is controlled by MAC protocols, which minimize collisions by designing their protocols effectively. Additionally, the duty cycle for sensors is defined by MAC protocols, which is essential for reducing idle listening to conserve energy.

Consequently, a MAC protocol that uses less energy can greatly increase the lifespan of sensor networks. Many MAC protocols for WSNs have been proposed in response to this demand, with the primary focus being on the significance of comprehending current MAC protocol features prior to designing new ones.

The mac protocols for WSN can be categorized into four main categories: asynchronous, synchronous, TDMA-based and FDMA-based protocols.

In the synchronous protocol, all nodes wake up at the same time[1], while in the asynchronous protocol nodes have different wake up times. Thus, the synchronous protocol is most suitable for real time data transmission as it does not require any extra negotiation for data exchange.
In FDMA,[2] the time slots are assigned to the users in a sequential fashion.In TDMA, the time slots are assigned to the users in a random fashion

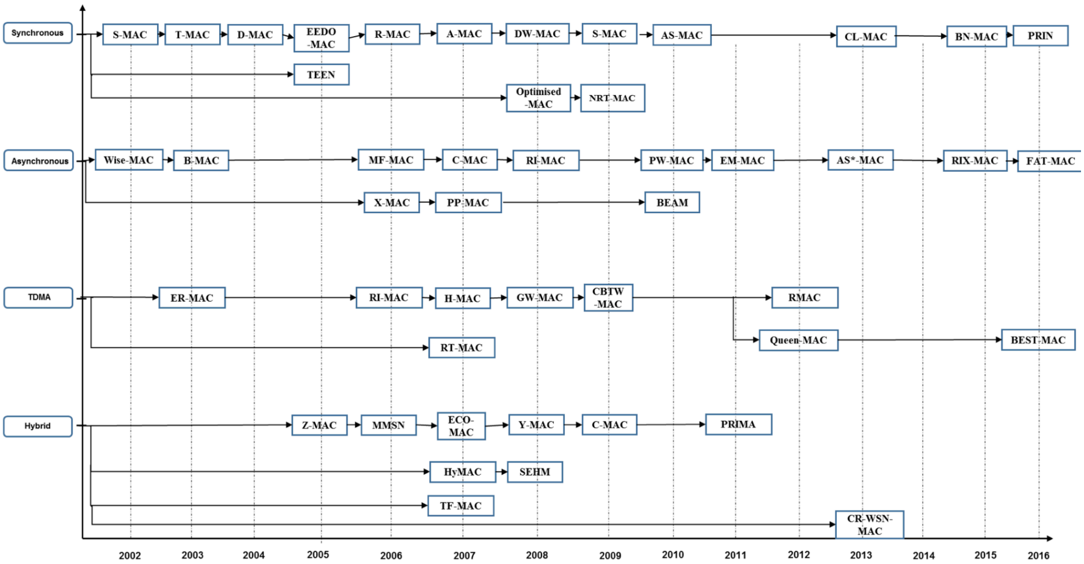

Figure 1 - Taxonomy of WSN MAC protocols

III. SYNCHRONOUS PROTOCOL :

1. SENSOR MAC

1.1. THE OPERATIONAL PRINCIPLE

The S-MAC (Sensor Medium Access Protocol) is an early communication protocol designed for wireless sensor networks, focusing on optimizing energy efficiency through the synchronization of wake-up and sleep periods for sensor nodes. In its operation, nodes initially listen to the channel for a set duration, awaiting a synchronization packet (SYNC). If no SYNC packet is received,[3] a node selects a scheduling scheme and transmits it to its immediate neighbors, encapsulating its wake time and the duration until the next wake-up.On the other hand, if a node receives a SYNC packet during the listening period, it adopts the sender's scheduling scheme and forwards it to others. Hence, Synchronization is done periodically to reduce clock drift among neighboring nodes.
To avoid collision, overhearing and hidden terminal problems, S-MAC uses RTS/CTS(Request-to-Send/Clear-to-Send) hand handshaking mechanisms for data transmission. It also uses a Network Allocation Vector (NAV) that records the transmission period for virtual carrier sense. When a node intends to transmit a packet, it sends an RTS to the destination node. As the RTS packet includes the destination address, neighboring nodes are informed that they can enter a sleep mode throughout the SLEEP period.

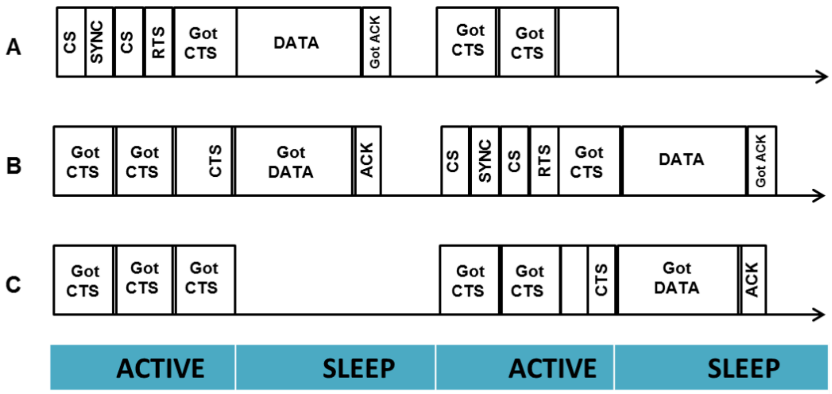

FIGURE 2. An example of duty-cycling in S-MAC, and data transmission from node A to node B followed by from node B to node C.

1.2. ADVANTAGES OF S-MAC:

S-MAC introduces significant advantages to Wireless Sensor Networks (WSNs). One key contribution is the concept of message passing, where long messages are efficiently divided into fragments and transmitted in a burst. This approach utilizes a single Request-to-Send (RTS) packet and one Clear-to-Send (CTS) packet to reserve the communication medium for transmitting all fragments, along with individual acknowledgments (ACKs) for each fragment. This methodology optimizes the utilization of network resources and ensures reliable data delivery. However, it's noted that this approach may not be ideal in terms of node fairness.

1.3 DISADVANTAGES OF S-MAC:

Despite its advantages, S-MAC presents several drawbacks. The periodic sleep characteristic of the protocol can lead to high end-to-end latency, particularly in multi-hop networks. This latency arises from the necessity of a node to wait until the next-hop node is awake before transmitting, a phenomenon known as sleep delay. Nodes at the boundary of two schedules face the challenge of adopting both schedules, resulting in increased energy consumption for these boundary nodes.

1.4. POWER CONSUMPTION :

During a simulation according to a study[4], the energy consumption of S-MAC at a node is approximately 0.034 J for a rate of incoming data of 0.24.

2. TEEM : Traffic Aware Energy Efficient Multiple Access Control.

2.1. THE OPERATIONAL PRINCIPLE:

TEEM utilizes a modified approach compared to protocols like S-MAC. It introduces the concept of dividing the active period into two parts: SYNCDATA and SYNCNODATA. During SYNCDATA, a node with data to transmit contends for the channel, transmitting a combined SYNCRTS packet. The SYNCRTS packet includes both synchronization information and a Request-to-Send (RTS) signal. Destination node, after receiving a SYNCRTS, immediately sends a CTS packet to the sender and data transmission will commence during the SLEEP period. Other nodes receiving SYNCRTS knows that the incoming data is not destined for them, putting itself to sleep immediately to avoid overhearing during SYNCNODATA period. When there is no data to transmit, the node transmits a SYNC packet only during SYNCNODATA period for synchronization purpose.This approach minimizes channel contention, as the node only needs to contend once.

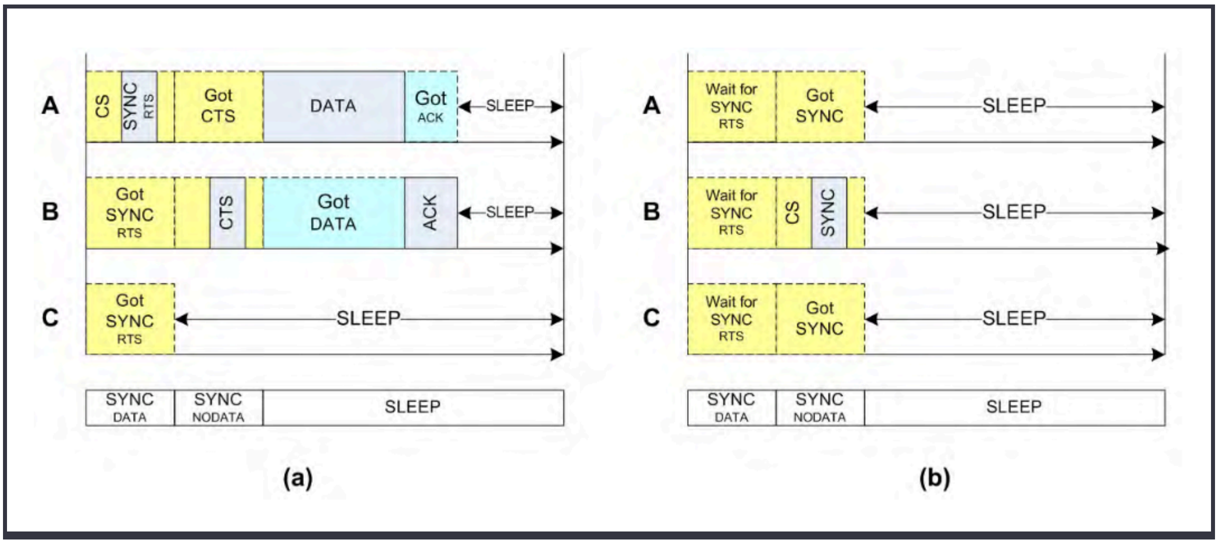

FIGURE 3. TEEM reduces the use of control packets, overhearing, and idle listening

2.2. ADVANTAGES OF TEEM:

Energy efficiency is increased as compared to S-Mac and TEEM as a result of reduced listening period. The number of control packet transmission is reduced.[3]

2.3. DISADVANTAGES OF TEEM:

Although energy consumption is lower due to a reduction in usage of control packets and overhearing, it still suffers from high end-to-end delay latency because of its fixed periodic duty cycle.[3]

IV. ASYNCHRONOUS PROTOCOL :

1. WISE MAC

1.1. THE OPERATIONAL PRINCIPLE:

WiseMAC optimizes energy consumption in wireless sensor networks by employing the preamble sampling technique. Nodes regularly sample the radio channel independently of actual traffic, using a constant period, TW.[3]

The preamble length (TP) is adjusted dynamically based on $\boldsymbol{T_p = \min(4\theta L, T_w)}$

Here, θ is the frequency tolerance of the time-base quartz and L is the interval between the communications. This resulting WiseMAC has less overhearing in high traffic conditions.

In the presence of busy channels, the receiver continues listening until a data packet is received or until the medium becomes idle. A wake-up preamble precedes each transmission to ensure the receiver is awake for data reception, introducing a power overhead. To minimize this, sensor nodes learn offset schedules of direct neighbors, sending messages with minimized wake-up preambles. This approach naturally mitigates overhearing, enhancing efficiency. WiseMAC adapts to varying traffic loads, adjusting wake-up overhead accordingly. It employs non-persistent carrier sensing and randomized medium reservation preambles to mitigate collisions, and extends carrier sense range to address the hidden node effect. The receive threshold is set strategically to balance power consumption against potential transmission range extension. WiseMAC goes beyond efficient data transmission and power management by incorporating an up-to-date table mechanism. Each node maintains a table containing the sampling schedule offset of its direct neighbors. This information is continually updated through ACK packets, including the remaining duration until the next scheduled preamble sampling.

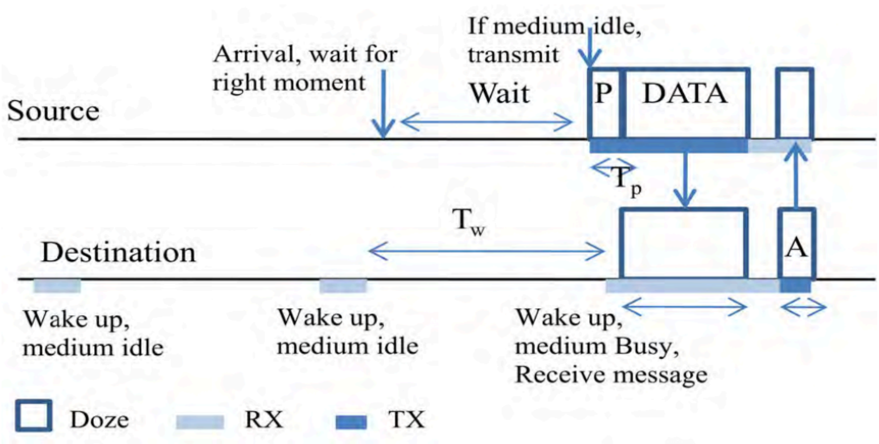

FIGURE 4. WISE MAC operational principle

By keeping this table current, WiseMAC ensures that nodes have accurate and synchronized data regarding the sampling schedules of neighboring nodes. This feature enhances the adaptability of the protocol to the dynamic nature of wireless sensor networks, allowing nodes to intelligently time their transmissions and minimize unnecessary wake-up periods. The up-to-date table plays a crucial role in optimizing the overall efficiency of WiseMAC by facilitating coordinated communication among nodes and contributing to effective power management strategies.
The protocol efficiently transports data bursts using the 'more' bit, contributing to its overall effectiveness in optimizing energy consumption in wireless sensor networks.

1.2. ADVANTAGE OF WISE MAC:

WiseMAC can achieve better performance with its dynamic preamble length adjustment scheme for variable traffic load compared to S-MAC. Overhearing is reduced significantly when traffic is high.[3]

1.3. DISADVANTAGES OF WISE MAC:

For frequently changing topology, WiseMAC can cause high preamble overhead and high latency because some nodes have to use long preambles after failing to communicate with the destination.[3]

1.4. POWER CONSUMPTION :

During a simulation of the WISE MAC protocol on the GloMoSim platform[5], statistics collected on a central forwarding node revealed that with the WiseNET transceiver, the average power consumption was 25 µW when forwarding a message approximately every 100 seconds. With a single alkaline battery of capacity C=2.6 Ah and constant power leakage of 27 µW, this translated to a battery life of more than 5 years.n higher traffic conditions (inter-arrivals between 100 and 5 seconds), the average power consumption of WiseMAC grows up to 200µW, but the energy efficiency reaches over75%.

V. TDMA BASED PROTOCOL

1. ER MAC

1.1. THE OPERATIONAL PRINCIPLE:

A TDMA-based MAC protocol called ER-MAC (Energy-and-Rate based MAC) makes use of the periodic listen and sleep mechanism that S-MAC proposed. With the use of this protocol, each node's "energy criticality" , a concept of its remaining lifespan—is defined. A node's energy criticality is determined by taking into account the maximum energy (Ej) and flow rate (Fj) values among its neighbors in the TDMA-group, as well as its remaining energy level (Ei) and packet flow rate (Fi). By distributing energy usage among nodes, ER-MAC aims to increase network lifetime.

$$Ci= Ei/\max\{Ej \} + F /\max\{Fj \}$$

The energy criticality of the node determines how transmission slots are allotted, with more active nodes with greater criticality levels being given preference.
The Normal phase and the Voting phase are the two primary stages as defined by the protocol. A new leader is chosen in the voting phase, which is started by a node when its energy criticality drops below a certain level and is triggered if its criticality is lower than that of its neighbor. While the other nodes in the group are only given one transmission slot, the leader is given multiple slots.

A node that owns the current slot during the Normal phase either transmits the available data or sleeps when there is nothing to be transmitted. A node remains awake in order to receive data from its neighbors if it does not possess the slot. The node falls to sleep and the slot stays idle if it is the current leader's second slot.

By guaranteeing effective data transmission and reception within the TDMA schedule, this technique seeks to optimize energy usage and contributes to the overall objective of prolonging the network lifetime.[3]

1.2. ADVANTAGES OF ER MAC:

Because ER-MAC uses a TDMA protocol—that is, no two nodes transmit during the same time slot—it does not have packet loss. To conserve bandwidth and costs, the voting phase is also incorporated into the regular TDMA phase. This protocol demonstrates that, in terms of realized energy savings, it is more effective in higher load traffic.

1.3. DISADVANTAGES OF ER MAC:

A node can communicate with other nodes only if the bandwidth available in its assigned slot is low during data transmission.[3]

VI. FDMA BASED PROTOCOL :

1. HyMAC HYBRID

1.1. THE OPERATIONAL PRINCIPLE:

The Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) techniques are combined in HyMAC, a hybrid MAC layer protocol. A super-frame in HyMAC is separated into scheduled-slots and contention-slots, two separate time periods. The time it takes to send a packet of the maximum size determines how long these slots will last. Every network node has its time slots and frequencies assigned by the base station. HyMAC performs better on platforms like FireFly that have out-of-band hardware synchronization, but it is not dependent on the underlying synchronization protocols.

Broadcast communications are made possible by all nodes switching to the same frequency during the contention period. During the contention period, all nodes—scheduled and unscheduled—engage in Low Power Listening (LPL). Unscheduled nodes send HELLO packets to the base station at random times. Any node that receives a HELLO packet from another node within its one-hop radius updates its neighbor list in preparation for the subsequent HELLO packet transmission. These packets are gathered by the base station, which then creates a schedule and transmits it to every node via a SCHEDULE packet.

The base station is the root of a tree that is formed by the HyMAC scheduling algorithm. Every node in the network can send DATA packets to its parent. Nodes are given distinct time slots when they have disputing neighbors, particularly when they are siblings. Nodes that are not siblings involved in a conflict are given different frequencies.[3]

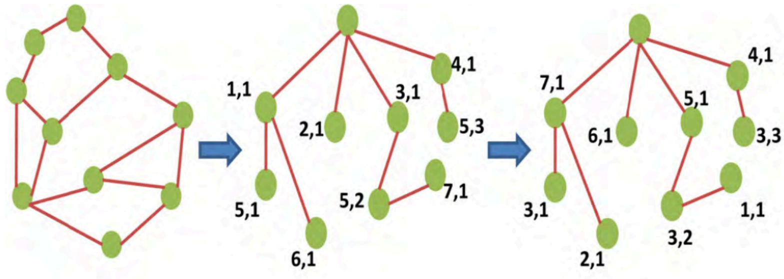

FIGURE 5. The operation of HyMAC scheduling algorithm.

The primary objective of HyMAC's performance evaluation is to evaluate the scheduling algorithm's possible conflicts. Comparison with two algorithms—even-selection and eavesdropping—presented in MMSN (Multi-Frequency Media Access Control for Wireless Sensor Networks) shows that HyMAC consistently generates zero potential conflicts, regardless of node density, even when there are only two available frequencies. In contrast, as node density increases in MMSN, so do potential conflicts. This demonstrates how effective HyMAC is in conflict mitigation and network performance.

1.2. ADVANTAGES OF ER MAC:

HyMAC is best suited for sensor network applications like real-time voice streaming because of its high throughput and low end-to-end delay.

1.3. DISADVANTAGES OF ER MAC:

Control packet overhead is high because of HELLO packet exchange when a new node joins.

VII. COMPARISON

A detailed comparison of MAC protocols for WSNs is given in Table 1[3] :

mac	year	contention	basic concept	collision (receiver)	idle listening (receiver)	overhearing(receiver)	over-emitting(transmitter)	control packets overheads
SMAC	2002	sync	active/sleep duty cycle with fixed period	broadcast of sync and control packets in virtual cluster	DATA period during low traffic	DATA period	None	SYNC for synchronization RTS, CTS ACK : collision avoidance
TEEM	2005	sync	similar to s-mac, different control packets to indicate if there is or no data to transmit allowing neighboring nodes to sleep earlier	broadcast of SYNcrts or SYNc packets	SYNCdata period when no SYNC	none	none	SYNCrts, SYNC required for synchronization and collision avoidance
WISE-MAC	2003	async	uses dynamic-length preamble based on traffic load and synchronized with receiver wake-up schedule	for 2 transmitter wanting to transmit to same receiver node	during wakeup period	transmission of redundant data packet during low traffic	transmission of redundant data packet during low traffic	wakeup preamble ACK
ER-MAC	2003	tdma	more time slots are assigned to more energy-and-rate-critical node	none	when it's not in its time slot	when its not in its time slot	none	vote packet, radio-mode packet
HYMAC	2007	fdma/ tdma	hybrid fdma/tdma with zero potential frequency conflict scheduling algorithm	in contention slots, for broadcast, scheduling purpose	when there is no transmission in its timeslot	none	none	for scheduling purpose

TABLE 1 - Comparison of MAC protocols for WSN

VIII. CONCLUSION :

In summary, addressing the energy consumption and autonomy challenges in wireless sensor networks (WSNs) is crucial for prolonged operation. Medium Access Control (MAC) protocols play a pivotal role in this context. S-MAC, a synchronous protocol, optimizes energy by synchronizing wake-up and sleep periods, but it may introduce latency. WiseMAC, an asynchronous protocol, minimizes idle listening through preamble sampling and introduces adaptability with an up-to-date table mechanism. ER-MAC, a TDMA-based protocol, balances energy consumption among nodes, showing effectiveness in higher load traffic. HyMAC, a hybrid protocol, combines TDMA and FDMA, demonstrating zero potential conflicts and suitability for real-time applications. Choosing the right MAC protocol depends on specific WSN application requirements, considering factors such as energy consumption, latency, and adaptability.

IX. REFERENCES:

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