ISSN: 2456-6616 (Online)

A Literature Survey of Energy-Efficient Medium Access Control Protocols for Wireless Sensor Networks

Sukaina Shukur Mahmood[1]
Computer Engineering Department, University of Mosul
Erbil, Iraq
[1]sukainashukur@uomosul.edu.iq

Salah Abdulghani Alabady[2]
Computer Engineering Department, University of Mosul
Mosul, Iraq
[2]eng.salah@uomosul.edu.iq

***Abstract*- In view of the importance of wireless sensor networks (WSNs) and used in wide areas such as target detection and tracking In, home security, medical monitoring, machine failure diagnosis, building monitoring, chemical/biological detection, surveillance and reconnaissance, animal/plant monitoring, military, environmental monitoring, etc. Several protocols have been proposed to medium access control (MAC) have different targets for WSNs like decreasing energy consumption, prolong the network lifetime, increasing throughput, reducing delay and latency, etc. Because the existing nodes in the WSNs usually operate without observation with a limited power source, energy consumption became a major constraint in WSNs and an active area of interest for researchers. Despite it can be performed energy saving in communications in the TCP/IP protocol suite within the various layers, saving energy is more efficient in the MAC layer Because of its capability to manage the radio immediately. Therefore, to guarantee a long-lived network of wireless sensors, researchers offer many MAC protocols capable of improving energy efficiency via maximizing sleeping interval, reduce idle listening and overhearing, and elimination of collision of packets or hidden terminal problems. This paper show a literature survey on several energy-efficient MAC protocols WSNs and it also provides a summarized analysis of these protocols that may be useful in the futurity work in this trend.**

Keywords-Wireless Sensor Networks (WSNs), Medium Access Control (MAC), Energy Efficient.

I. INTRODUCTION

Wireless Sensor Networks (WSN) consists of a large number of sensor nodes which are spatially dispersed and dedicated sensors for recording and monitoring the physical phenomenon of the environment and organizing the gathered data at a central location as shown in the Fig. 1. WSNs measure environmental conditions such as temperature, humidity, sound, pollution levels, wind speed, and direction, pressure, etc. In other words, it is a group of nodes "sensors" regular into a cooperative network.

The nodes connect wirelessly and often self-organize after being diffuse [1].

The sensor nodes which are a basic unit of the sensor network consist of multiple functional units including sensing unit which contains one or more kinds of sensors depending on the application such as pressure sensors,

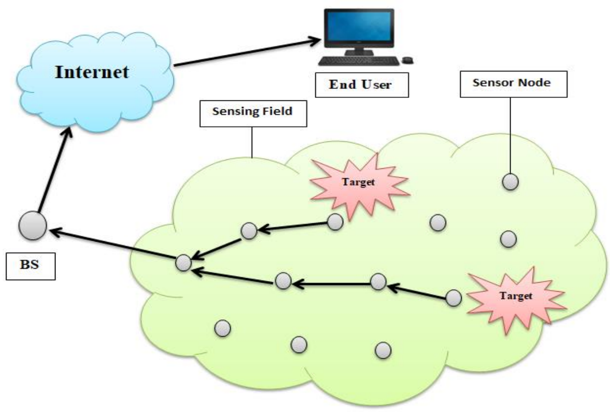

Fig. 1: Wireless Sensor Network (WSN)

humidity sensors, temperature sensors, acoustical sensors, vibration sensors, etc. and Analog to Digital Converter (ADC) used to transform the analog signals generated by a sensor into a digital signal to process the measured information, transceiver which is wireless transmitter and receiver to provide communication between nodes, micro-controller to process sensed data, external memory to store information, route information. Power unit used to supply the sensor with energy because most sensor nodes are battery-powered [2]. Fig. 2 illustrates the architecture of a typical sensor node.

In general, the major three activities that consumed energy in a node are sensing, processing and wireless communication. Among these factors the wireless communication losses the highest percentage of battery power [1].

This paper shows an overview of MAC protocols in WSN, the issues, and challenges of wireless sensor networks have been presented, the central causes of energy wastage in the MAC layer and survey and brief analysis on several wireless sensor networks protocols.

A general overview of MAC protocols on WSN is presented in section II. Some of the issues and challenges of WSN is mentioned in section III. Section IV contains the causes of loss of power in the MAC layer. Section V offers several MAC protocols proposed by researchers and finally, section VI conclude.

ISSN: 2456-6616 (Online)

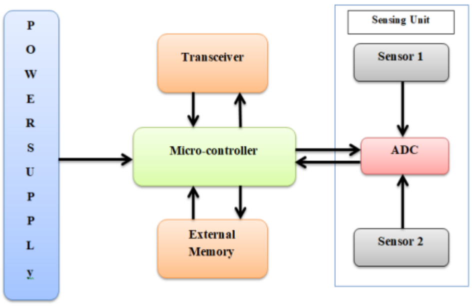

Fig. 2: Architecture of a typical sensor node

II. OVERVIEW OF MAC PROTOCOLS IN WSN

When there is more than one node or station trying to access the same link, this link called multipoint or broadcast link. Hence, Multiple-access protocols are needed to coordinate access to the shared link. A lot of protocols have been innovated to control access to a common link. These protocols belong to the medium access control (MAC) sub layer. Generally, the multiple-access protocols classified into three sets: random access, controlled access and channelization protocols [2] as shown in Fig. 3.

The MAC protocol is playing a significant role to enable the successful operation of the network in WSN. In general, there are two basic groups of the MAC protocol: contention-based (Asynchronous) MAC protocol and scheduled-based (Synchronous) MAC protocol. In contention-based randomization is used to access communication media. There are no synchronization time slots nodes contending to gain the media. So, these protocols do not appropriate for applications that required real-time, where resulting in large access delay and loss packet. Asynchronous protocols are scalable and adjustable to changes in network topology or variations of traffic load, but they have several limitations regarding energy loss due to idle listening, overhearing and collision. The schedule

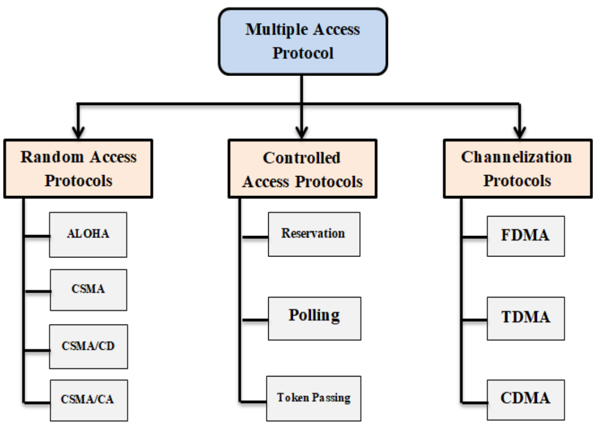

Fig. 3: Classification of the multiple-access protocols

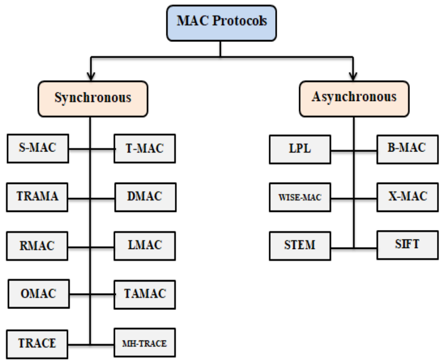

Fig. 4: Taxonomy of medium access control protocols

-base protocol needed to time synchronization and divided the time into slots, which is lead to needless power consumption through exchanging synchronization messages [3], [4]. Fig. 4 shows taxonomy of medium access control protocols.

III. ISSUES AND CHALLENGES OF WSN

The following are the main issues and challenges affecting the designing and achievement of the wireless sensor network [5], [6], [7], [8]:

- **Energy:** Sensors demand energy for their different procedures. It consumes power in the data sensing, processing, communication processes, collision, idle listening, control packet overhead and overhearing which are leading to batteries drain. Since it is difficult or complicated to replace or recharge sensor batteries, researchers should develop and design protocols for energy-efficient software and hardware protocols for wireless sensor networks that are one of the critical research challenges faced by researchers.

- **Ad-Hoc Deployment:** Most of the sensors are deployed in areas with no infrastructure at all. The sensors deployment can be either random (e.g. tossing sensors from a helicopter in a forest) or deterministic (e.g. Place sensors along the oil pipeline to monitor temperature and/or pressure and the boundary monitoring) and it relies mainly on the sort of application, the climate, and the sensors themselves. Generally, poor deployment of sensors nodes results in inactive network connectivity. A well choice of development strategy will extend network life and reduce cost; therefore, wireless sensor network deployment is a serious problem.

- **Secure Localization:** The sensor network utility often relies on its capability to automatically and carefully locate all sensors in the network. The sensor network designed to identify faults will require accurate location information to determine the fault location. Unfortunately, the attacker can easily tamper unsecured location information by reporting the strengths of the wrong signals, replaying signals, etc.

- **Network Topology:** Changes in the network topology during the running like adding new nodes to the system, failure of any node, changes in environmental conditions is another challenge that needs a solution.
- **Data Gathering:** Data collection is the main purpose of sensors. Sensors periodically sense data from the perimeter, process it and transport it to the sink node. Sometimes the sample data gathered is redundant and there is no necessity to transport these samples to the base station as they will only expend energy. Care must be taken in collecting and transmitting data.
- **Fault Tolerance:** The sensor network must stay functional even if one node fails, it will not affect the network. The network must be able to adapt by changing its connection in case of any error. In this case, adaptive protocols should develop to alteration the overall arrangement of the network.
- **Power Consumption:** Power management is a great issue in a sensor networks. Thus, it is critical to designing energy-aware protocols and algorithms for wireless sensor networks.
- **Production cost:** To make wireless sensor networks feasible, the price of the node must be less. As a result, the cost of the node will be a very difficult challenge.
- **Hardware design:** Wireless sensor network hardware must be energy-efficient. The power control, microcontroller, and communication in the sensor network must be designed to be less power consumption.
- **Computational power and memory size:** When every node sense data it stores the information separately and sometimes the same information save at several nodes cause power wastage and book capacity of nodes. So redundancy information should be reduced in wireless sensor networks by using effective schemes.

IV. CENTRAL REASONS OF ENERGY WASTAGE IN THE MAC LAYER

A. Sources of energy wastage

A large amount of energy is consumed and lost in MAC layer protocols for the following reasons [9]:

1- **Sensing, data gathering, processing and communicating**.

2- **Collision:** A collision occurs when two or more sensors simultaneously transmit the data packet to the same receiver. The collision result in discards the packet and transmit it again, which lead to increased energy consumption.

3- **Idle Listening**: Transceiver spends extra energy when being active waiting to receive a packet that is not sent.

4- **Overhearing:** happens while a node picks up a data packet which intended to another node that also consumed unnecessary energy.

5- Long distance transmission: long distance transmission should be avoided because it needs high energy.

B. Patterns of communication in WSNs

Three communication patterns have found in the wireless sensor network channel [10]:

1. **Broadcast:** message broadcast uses by base station to transmit the same message to all nodes that existence in the network. A broadcasted packet might contain of updates of specific programs for other nodes, control packets for the whole system, etc.
2. **Converge-cast:** A set of sensor nodes communicate with a particular sensor node. This intended sensor node may be a data fusion center, sink node, and cluster head, and so on.
3. **Local gossip:** Sensor nodes communicate locally, the sensor node sends a message to nearby nodes within the vicinity of it.
4. **Multicast:** In this pattern, the sensor node connects to a specified subset of nodes.

V. PROPOSED MAC LAYER PROTOCOLS

This section, describe the main MAC layer protocols proposed for wireless sensor networks to increase sleeping time, hence increase energy efficient:

A. Synchronous MAC Protocols

1) Sleep MAC (S-MAC) protocol

S-MAC is a synchronous low power MAC protocol that relied on the CSMA/CA method. Periodical sleep and listening are submissions to minimize idle listening periods. The active period in S-MAC is fixed length; therefore if there is no real traffic flow happens the nodes remain unnecessarily awake which is causes energy consumption. In S-MAC, energy-saving relies on the duty cycle and employs three new techniques to decrease energy consumption and to obtain a low power duty cycle: periodic sleep, virtual clustering, and adaptive listening. The process of every node is preserved through frames. Every frame composed of two periods, listening and sleeping. The listening period is split to the SYNC and the DATA intervals as illustrated in Fig. 5. The central conception of the S-MAC is to build virtual sets of nodes sleeping and waking up simultaneously. This target is implemented through SYNC messages that are cyclic synchronization messages. The SYNC section of the listening period is booked for the swap of these messages. Thereafter, the nodes attempt to find the destined recipients through the data period. A collection of nodes in a network can regionally administer synchronizations and cyclic sleeping and listening schedules as clarify Fig. 6. Neighboring cells shape virtual clusters to set a mutual sleep schedule. Nevertheless, if two contiguous nodes settle in two various virtual clusters, they can wake up at a listening period for both clusters causing a delay. Collision avoidance is accomplished by carrier sense and exchanges request to send/clear to send (RTS/CTS) packet as in IEEE 802.11 standards [1], [11], [12], [13], [14].

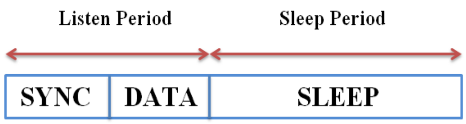

Fig. 5: Listen and sleep periods of Sleep-MAC

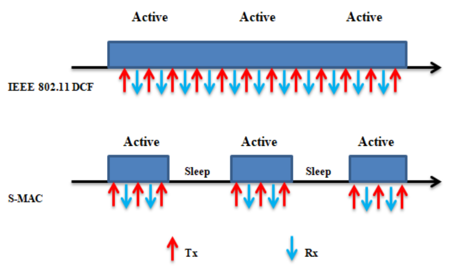

Fig. 6: IEEE 802.11 DCF and Sleep-MAC communication pattern

Characteristics of the S-MAC protocol:

- Reduce energy waste caused by idle listening through sleep schedules.
- The simplicity of implementation.

Drawbacks of the S-MAC protocol:

- The constant duty cycle principle for S-MAC makes nodes remain to wake up needlessly causing energy consumption when there is no actual traffic flow happens.
- Energy is still lost in idle listening when the message rate is low.
- Sleeping and listening intervals are predetermined and constant thereby decreasing the performance of the algorithm when there is a changing traffic load.
- ACK and RTS/CTS overhead during sending data.

- Time sync operation is overhead while the network is idle.

2) Timeout MAC (T-MAC) protocol

T-MAC is a synchronous MAC protocol based on CSMA. It is an enhancement on S-MAC protocol to reduce the problem of S-MAC that leads to low-efficiency and high latency as a result of staying nodes awake unnecessarily for constant intervals while there is no traffic. TMAC is purposed to enhance the poor consequences of S-MAC during the changeable traffic densities. The solution approached was to return the nodes to sleep prematurely when traffic did not occur for a specific period of time known as a timeout period (TA). This state is explained in Fig. 7. As long as a node in an active interval, it keeps listening and sending. T-MAC's active

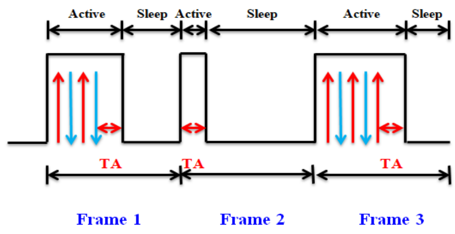

Fig. 7: Timeout-MAC protocol

time ends in an intuitive way. Nodes in T-MAC protocol communicate using an RTS, CTS, and ACK scheme [15], [16], [17], [18].

Characteristics of the T-MAC protocol:

- Less energy is spent in T-MAC comparing to S-MAC.
- Under the variable load, T-MAC gives a better result than S-MAC.

Drawbacks of the T-MAC protocol:

- T-MAC protocol causes more latency than S-MAC protocol.
- T-MAC protocol suffers from early sleep issue, and the node goes to sleep while the neighbor node still has own messages because of the asymmetric connection where virtual groups have diverse sleeping and listening intervals.

3) The traffic-adaptive medium access (TRAMA) protocol

TRAMA is a TDMA-based MAC protocol (reservation-based medium access) designed to obtain a collision-free energy-efficient MAC protocol. In this protocol, energy is saved by turning it off when the nodes are not sending or receiving. TRAMA is relied on a time-slotted framework and employs a distributed choice method depends on the traffic demands of any node. Accordingly to that, every node schedules the slots throughout which it will send or receive packets. Consequently, nodes can coordination when it should to sleep or stay active in the network [1], [16], [19]. TRAMA contains three prime components:

- **Neighbor Protocol (NP):** The NP collects information from neighboring nodes.
- **Schedule Exchange Protocol (SEP):** SEP permits nodes to interchange two-hop nearby information and schedules or programs.
- **Adaptive Election Algorithm (AEA):** AEA determines which nodes will be sent and receive during the existing time band by utilizing neighborhood and program information.

Characteristics of the TRAMA protocol:

- TRAMA reduces energy consumption by switching off nodes when there is no data for transmitting or receiving. Hence, TRAMA keeps energy more than S-MAC.
- TRAMA provides higher throughputs than S-MAC, IEEE 802.11and CSMA protocols.

Drawbacks of the TRAMA protocol:

- Compared to S-MAC, IEEE 802.11 and CSMA protocols, TRAMA protocol leads to more latency.

4) Data-Gathering MAC (D-MAC) protocol

D-MAC is low latency and energy-efficient synchronous based MAC protocol which is proposed for tree-based data aggregation in wireless sensor networks. In DMAC protocol, nodes used the multi-hop path to awake sequentially in a form similar to a chain. Time is split into receiving, transmitting and sleep intervals and perform carrier sense multiple access (CSMA) with an acknowledgment (ACK) during each period to transmit/receive a packet. In the receiving state, when a node is expecting to receive a packet it will transmit an acknowledgment (ACK) packet to the transmitter. In the transmitting state, a node will attempt to transmit a data packet to its next hop and receive an ACK packet. In the sleep state, nodes will switch off its radio to keep energy. Fig. 8 shows the data gathering tree and the times intervals for these states [3], [9], [20].

Characteristics of the D-MAC protocol:

- DMAC Provides good latency when compared to other protocols which is work on sleeping/listening period.
- D-MAC protocol does not utilize RTS/CTS control packets as they will add additional overhead due to the comparatively small packet size in wireless sensor network applications.

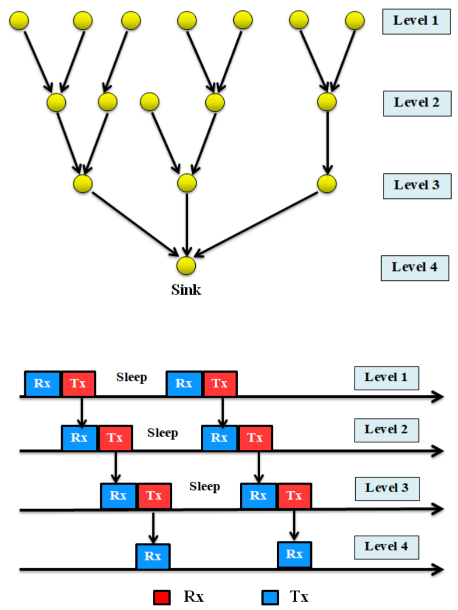

Fig. 8: Data gathering tree in DMAC protocol

Drawbacks of the D-MAC protocol:

- In D-MAC, collision avoidance is not considered, therefore when two nodes or more attempt to transmit data to the same node in the tree, it will cause collisions to occur.
- Data transfer tracks might not be predetermined, thus preventing the forming of a data collection tree in advance.

5) Routing-Enhanced MAC (R-MAC) protocol

R-MAC is a synchronous MAC protocol that exploits duty-cycles to decrease latency and hence save energy. The basic thought of RMAC is the alignment of sleeping/waking up intervals of the nodes over the data track so that the node can forward the packet to the destination during a single operational cycle. This is done by transmitting a frame control over the track to notify sensor nodes of the coming packet, letting them know when they wake up to receive/reroute the packet.

In R-MAC, the operational interval partitioned to the SYNC interval, the DATA interval, and the SLEEP interval as illustrated in Figure (9). Through the SYNC period synchronization of the sensor nodes for their clocks with the required accuracy, the DATA interval which relies on contention-based advertises the start of the sending process. The transmitter waits a randomly chosen time period in addition to a DIFS period. If no activity had been revealed, the transmitter sends a Pioneer Control Frame (PION), include the source address, destination address, and next-hop address; the number of hops the PION has traveled, and the time of the transmission. A PION is utilized instead of RTS/CTS frames to request communication and confirm a request. Actual data transfer occurs throughout the SLEEP interval, as shown in Fig. 9. Node A wakes up to receipt the packet from the transmitter and after the succeeded transfer, node A replies by the acknowledgment (ACK) packet. After receipting the ACK packet, the transmitter completes its portion and switch off its radio and go to SLEEP mode. Node A transfers the receipted packet to its expected next-hop, Node B. Likewise, node B will transmit the ACK packet to node A and forward the receipted packet to the next-hop then switches off its radio and go to SLEEP mode. This operation resumes until the destination receipt and acknowledgment of the packet [3], [21], [22].

Characteristics of the R-MAC protocol:

- R-MAC handles the large latency, which is often tested in the MAC protocols which employ duty-cycles to reduce energy exhaustion to a minimum.
- R-MAC is capable to forward the packet from the sender to the receiver during one operational interval.
- R-MAC mitigates competition via partitioning the medium and transferring data packet during two splits intervals.

Drawbacks of the R-MAC protocol:

- A collision can happen throughout sleep times because a sender permanently initiates sending at the start of SLEEP interval.

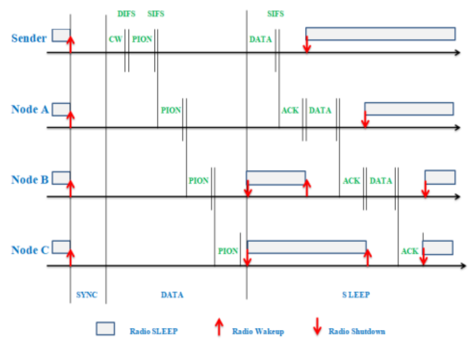

Fig. 9: Duty-cycle of routing enhanced MAC protocol

6) Lightweight MAC (L-MAC) protocol

L-MAC protocol is a scheduled-based MAC protocol where the contention period is split into frames and slots and each node reserves its own slot to send and receive data. L-MAC assigns slots to nodes using a distributed algorithm instead of a central manager. Each slot, in turn, is consisting of a control message and data unit.

The control message has fixed-size and carries information about the controller of time slot identity and distance from the node to the base station, the meant recipient address, and the data unit length. When the node receives a control message, it checks if it is the meant recipient and hence determines whether to remains in active mode or to switch off the radio and go to sleep mode till the following slot. The allocated slot represents by 1 in the control message and an unallocated slot represents by 0. The node will be capable to identify unallocated slots, through integrating control messages from entire neighbors. The procedure of requiring slots begins at the base station that defines its special slots. Subsequent one frame, the all base station's immediate neighbors realize the slots of the base station and elect their special slots. This operation resumes over the network. Every node should choose slots that are not used through two-hop vicinity. The process of select slots is random; consequently, it is potential for several nodes to choose the same slot. Hence, a collision will occur during a slot. The L-MAC protocol is capable to prolong the network lifetime by a factor 3.8 compared to S-MAC [3], [23], [24].

Characteristics of the L-MAC protocol:

- L-MAC is a TDMA energy-efficient collision-free protocol that extension network lifetime.
- L-MAC set up transmission schedules using a distributed algorithm.

Drawbacks of the L-MAC protocol:

- L-MAC leads to inefficient bandwidth because of the fixed slot size and slot allocations.

7) Organized Energy Aware MAC (O-MAC) protocol

O-MAC is a low latency MAC protocol proposed to reduce energy consumption. It is Design fundamentally depends on two main ideas: (1) it relies on a carrier sense multiple access protocol which prevents potential collisions between the competitor nodes. (2) it authorizes the nodes in the neighborhood of sending and which is not interested in the data being transmitted and give them the chance to sleep throughout the period of one sending and to notify the neighbors about the eventual entree to sleeping mode to avoid them from sending data carelessly throughout the sleep interval [3], [25].

Characteristics of the O-MAC protocol:

- O-MAC produces OTS and NTS control frames to aid nodes to emphasize the channel booking to whole nodes that might go to the sleeping because of RTS or CTS conflicts.
- The O-MAC protocol authorizes isolated nodes in the neighborhood of single transmission to go to the sleep period and switch off its radios.

Drawbacks of the O-MAC protocol:

- The performance of O-MAC protocol is decreasing with increased node intensity, because of the overheads produced through novel O-MAC overhead packets.
- With increasing the number of neighbors, the packet size of NTS and OTS increases, conducting to large overheads.

8) Task Aware (TA-MAC) protocol

TA-MAC is consisting of two steps: (1) task monitoring. (2) Collaborative adjusting. At first, the node observes the activity of the task participates by the node and assessment of the sending try rate. The sending try rate is the frequency at which the node attempts to reach the channel through a unit of time. As optimal channel access relies on the traffic load of the network, the node regulates the probability of channel access during collaborating with nearby nodes. An interpretive example of task monitoring displays in Fig. 10 [3], [26],[27].

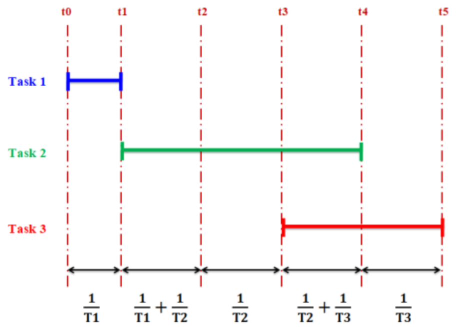

Fig. 10: Task monitoring in task aware MAC protocol

Characteristics of the TA-MAC protocol:

- The TA-MAC protocol defines the possibility of channel access based on node's and its neighbor traffic loads by interacting with the data propagation protocol, as a type of cross-layer approach.
- TA-MAC protocol can eliminate unnecessary collisions thus decrease energy consumption and enhance the throughput.
- The TA-MAC protocol can be combined with energy-efficient MAC protocols such as S-MAC because of its concentrate on determining the possibility of channels access which are perpendicular to former MAC protocols for WSN networks.

Drawbacks of the TA-MAC protocol:

- The node gathers neighboring node's task activities and defines the possibility of it accessing the channel using the information gathered, and may lead to disruption of node's activity whether the nearby traffic is high adequate to generate computational overhead.

9) Time Reservation using Adaptive Control for Energy Efficiency (TRACE) protocol

TRACE is an energy-efficient time-division multiple-access (TDMA) protocol designed for real-time data broadcasting. In TRACE, data is transferred according to a dynamically updated transfer schedule. At first, nodes need to contention to access data slots and reserves it, but once the slot reserved, a slot for this node is assigned in the subsequent frames automatically as long the sensor node remains to broadcast packet in every frame. The network controller is responsible for creating the schedule of TDMA and depends on the nodes that have continued to reserve from prior frames and that have succeeded compete for data slots in the present frame. At the beginning of the sub-frame data, the controller sends a TDMA schedule to the residue nodes in the network. When the energy of the controller is dropped less than the energy level of the other nodes by more than a specified amount, it allocates other radio with more energy than itself as the following controller.

Finally, when the number of transmissions within a frame overtakes a predestined threshold, every node hears to data from specific nodes only. Every node decides which transmitters to hear depend on information collected from all nodes throughout the information summarization (IS) slot [16], [28].

Characteristics of the TRACE protocol:

- TRACE protocol provides a bounded delay, stability, and high throughput under a vast scope of data traffic.
- TRACE protocol achieves energy-efficient by utilizing dynamic scheduling for data transmissions.
- Energy dissipation in the TRACE protocol is distributed between the nodes via changing network controllers during the energy of the immediate controller is less than other sensor nodes.

Drawbacks of the TRACE protocol:

- TRACE protocol is used for single-hop radio networks.

10) Multi-Hop Time Reservation using Adaptive Control for Energy Efficiency (MH-TRACE) protocol

MH-TRACE is an energy-efficient MAC protocol designed for a broadcasting real-time packet in a multi-hop radio network. MH-TRACE uses two mechanisms to conserve energy. The first mechanism is to decrease energy waste at the medium access control sub-layer. The first mechanism is to decrease energy waste at the medium access control sub-layer. The nodes should go to sleep mode whenever possible to prevent:

1. Energy waste in idle state.
2. Overhearing transmissions starting from nodes that exceed the succeeded transmission range.
3. Receiving damaged packets consequent to collisions.

The second mechanism is to decrease energy waste by averting pick up packet which will be dropped at the upper layers of the protocol stack if it is not dropped at the MAC layer. The MAC layer uses the information transmitted in the information summarization (IS) slots in order to decide to receive the data packets or not [16], [29].

Characteristics of the MH-TRACE protocol:

- MH-TRACE protocol provides energy-efficiency throughout the use of TDMA and IS slots that enable nodes to go to sleep mode oftentimes.
- MH-TRACE coordinates channel access which is leads to high throughput.
- MH-TRACE provides quality of service to real-time data due to periodic timeframe operation.

Drawbacks of the MH-TRACE protocol:

- The long inter-frame space and high overhead in the packets affect on the performance of MH-TRACE.
- The performance of the MH-TRACE Protocol is also degrading by the effects of burst noise and white noise.
- The density of nodes in the network impacts the achievement of the MH-TRACE protocol which is designed to work correctly in constant node density.

B. Asynchronous MAC Protocols

1) Low Power Listening (LPL) protocol

The basic idea of LPL protocol comes from the nodes in a network that does not require to waking up and sleeping simultaneously which is the main drawback of S-MAC protocol and its derivatives. In LPL every node can schedule its own sleeping and waking up time without any synchronization together with other nodes. In LPL protocol, the sender transmits a preamble before every packet to warn the intended recipient to wake up. Consequently, every node regularly wakes up, switch on its radio, and checking for activity on the channel. If the node detects activity it will remain in the receipt mode, else it will go to sleeping mode. Preamble sampling of the LPL protocol is shown in Fig. 11 [1], [3], [11].

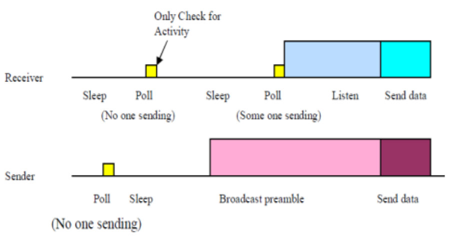

Fig. 11: Preamble sampling of the low power listening protocol

Characteristics of the LPL protocol:

- In low traffic network, LPL protocol consumes low power.
- Due to synchronization LPL protocol does not incur overhead.

Drawbacks of the LPL protocol:

- LPL suffers from increasing latency at each hop because the receiver should wait for the whole preamble before receiving the data.
- More of energy may be lost on sending the preamble bits that do not carry worthy information, therefore the length of the preamble must be selected conservatively.
- The neighbor nodes of the intended receiver must also be kept in the wake-up mode till the end of data packet transmission which is lead to unnecessary preamble overhearing, hence results in additional wasteful energy.

2) Berkeley MAC (B-MAC) protocol

B-MAC is a contention-based MAC protocol that combines carrier sense multiple access (CSMA) and low power listening LPL mechanisms. B-MAC reduces the listening time and duty cycle by using an adaptive preamble sampling to wake up receivers. The length of the preamble is longer than the sleep time of the receivers to guarantee linkage as shown in Fig. 12. Moreover, B-MAC employs clear channel assessment (CCA) and packet back-off for channel arbitration. In B-MAC, a CCA technique is utilized to locate whether there is an upcoming packet when the node wakes up or not during the LPL period. If no packet came, the node goes back to the sleep mode. Furthermore, B-MAC does

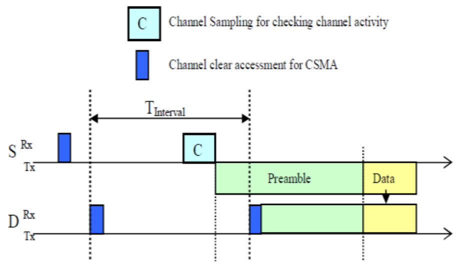

Fig. 12: Preamble sampling in Berkeley MAC protocol

not demand a large memory size due to its lightweight and simplicity. As a result, a lot of functionalities of the MAC layer can be supplied without spending rare memory resources. Additionally, B-MAC has no synchronization, RTS, CTS [11], [24], [30], [31].

Characteristics of the B-MAC protocol:

- B-MAC protocol reduces the idle listening period to a minimum hence the overall performance of B-MAC is best than S-MAC protocol.
- B-MAC is simple to implement and Low overhead when the network is idle.
- B-MAC does not demand a large memory space.

Drawbacks of the B-MAC protocol:

- The overhearing issue is not solved.
- Long preamble increases the energy dissipation of all nodes in the transmitter's transmission range.
- The lower duty cycle of the B-MAC leading to higher overhear cost, higher transmissions cost,

and more average latency, which leads to more contention.

- The hidden terminal issue is not handled due to use a simple CSMA MAC protocol.

3) Wireless Sensor MAC (Wise-MAC) protocol

Wise-MAC is a contention-based MAC protocol that bases on a preamble sampling mechanism. A source starting a preamble before the recipient is expecting to wake up Instead of choosing a random time to check the activity of the channel. The preamble comes before every packet to warn a recipient node. All of the sensor nodes sample the medium with the same regular period in the network, but the relative schedule offsets of nodes are independent. If the medium is detected busy, a node persists to listen till a packet is received or until detecting the idle medium again. Initially, the preamble size is set to be equal to the size of the sampling period. The minimization of the preamble in the wise-MAC protocol is shown in Fig. 13. Throughout each data exchange, the nodes inform and refresh the sleep schedule of their neighbor as part of the ACK message. Each node decides its own sleep schedule according to the saved sleep schedules of its neighbors. In order to reduce the probability of occurrence of collisions resulting from the specified start time of the wake-up preamble, a random wake-up preamble could be used. The clock drifts among source and destination effect on the length of the wake-up preamble [3], [9], [11], [32].

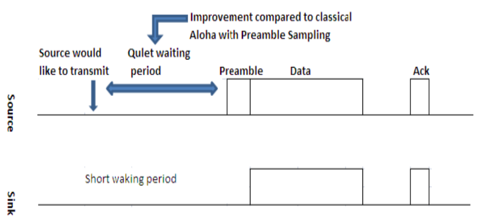

Fig. 13: preamble minimization of wise-MAC protocol

Characteristics of the Wise-MAC protocol:

- Under variable traffic loads, wise-MAC protocol performs better performance than S-MAC protocol.
- Wise-MAC alleviates the external time synchronization request, where clock drifts are addressed in the protocol definition.

Drawbacks of the Wise-MAC protocol:

- In the wise-MAC protocol, the decentralized sleeping-listening schedule leads to various sleeping and waking up periods for every node's neighbors resulting in dissipation power for synchronization.
- A collision happens at the starting of the node transition because of the hidden terminal problem.
- Due to the broadcast communication, data packets are delivered numerous times while every neighbor wakens causing more energy consumption and higher latency.

4) Short preamble MAC (X-MAC) protocol

X-MAC is a contention-based low power duty-cycled MAC protocol. X-MAC proposed to reduce the latency by handling some vulnerable of B-MAC protocol. Furthermore, it designed to recover the issues of overhearing, low power listening, and excessive preamble by using strobe preamble that enables interruption and allows the node to wake up quicker. The strobe preamble consists of short preambles with sufficient information to recognize the recipient. Time lapses used to split these short preambles allow the receiver to transmit an Early ACK signal. This signal notifies the sender to the start of transmitting the information. X-MAC employs randomized back-off time, further to the utilization of short preambles. Both techniques permit the existence of multiple transmitters, minimizing collisions. The behavior of X-MAC is shown in Fig. 14, where node A wants to transmit its information to node B. Node A transmits a repeated short preamble and waits for an E-ACK signal from node B. Once the E-ACK signal is received, node A transmits the data, and then goes to the sleep mode. After node B receives the data it stays in low power listening mode to guarantee assured there is no further data to be transmitted [3], [11], [30], [33].

Characteristics of the X-MAC protocol:

- X-MAC is an energy-efficient and low latency for data due to diminished preamble length MAC protocol.
- X-MAC does not request synchronization. Consequently, has low overhead and it characterized by simplicity.
- X-MAC has high throughput for data.

Drawbacks of the X-MAC protocol:

- The "avoiding hearing" process by inserting the target receiver node ID letting multicasting/broadcasting difficult.
- X-MAC is not able to schedule small listening periods sufficiently.

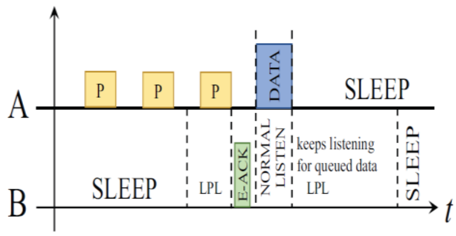

Fig. 14: The Early ACK and short preamble introduced in X-MAC protocol

5) Sparse Topology and Energy Management (STEM) protocol

The STEM protocol is a contention-based event-triggered MAC protocol adopted for nodes that expend a large amount of time waiting for an event. When an event happens, it redirects the data packets to the required nodes. During sensing the event and redirecting it into the correct destinations, a huge part of the energy is spent. STEM protocol decreased the power consumes in a surveillance status and diminished the latency among transferring and monitoring statuses. All nodes should be synchronized in order to track an event and redirect it to the base station.

When the event is detected by a node far away from the BS and not detected by the one near to the BS. The information cannot be forwarded to the BS due to the subsequent node is in a sleeping mode. To address this type of state, STEM allows the nodes to switch on its radio regularly and listening whether any node needs to connect with them [3], [34].

Characteristics of the STEM protocol:

- In STEM, the node transmits a beacon signal before the packet is sent. The radios operate on a low duty round and when there is data that needs to be processed using data radio, it wakes up the data radio.
- This protocol is suitable for event-triggered applications in which the average of an event happening is not high.

Drawbacks of the STEM protocol:

- Quality of service (QoS) is not concentrated in STEM protocol because it attempts to optimize energy dissipation for a node via employing two radios where radios are the main reason for energy dissipation.
- The STEM mechanism can raise the delay if there is dense connecting between the nodes.

6) SIFT-MAC protocol

SIFT is a randomized CSMA-based MAC protocol presented for event-driven wireless sensor networks. Sift employs a constant contention window of length CW instead of a changeable contention window utilized through CSMA/CA. The stimulus behind proposes SIFT is to reduce the time taken to transmit packets in the network [1], [3], [35], [36].

Characteristics of the SIFT-MAC protocol:

- When there are a lot of nodes that are trying to transmit data, [31] showed that SIFT greatly reduces latency comparing to the 802.11 MAC protocol.

Drawbacks of the SIFT-MAC protocol:

- Hearing to all nodes before transmitting caused to an increase idle listening period.
- Increase the overhearing that occur when there is a continuous sending and the nodes should listen until the termination of the sending to compete for the subsequent sending chance.

VI. CONCLUSION

One of the crucial issues that face wireless sensor networks in the current era is the scarcity of energy sources. So, the efficient utilization of energy and prolong the network lifetime is an important matter. One of the factors that contribute to reducing energy consumption is the MAC protocols. Recently, numerous MAC protocols have been submitted for wireless sensor networks by researchers. This paper offered a literature survey of energy-efficient MAC protocols and presents an abstracted analysis of these protocols that may be helpful in the future. In addition to, the characteristics and drawbacks of each protocol have been mentioned.

REFERENCES

[1] I. F. Akyildiz, and M. C. Vuran, “Wireless Sensor Networks,” John Wiley & Sons Ltd, 2010.
[2] N. R Patel, and Sh. Kumar, "Wireless Sensor Networks’ Challenges and Future Prospects," In IEEE International Conference on System Modeling & Advancement in Research Trends (SMART), 2018, pp. 1-6.
[3] M. N. Riaz , M. N. Qureshi , and A. Mahboob, " Energy Efficient MAC Protocols For Wireless Sensor Networks: A Survey," International Journal of Scientific & Engineering Research, vol. 4, Issue 5, 2013, pp. 1859-1879.
[4] T. Kaur, and K. Dilip, "TDMA-based MAC protocols for wireless sensor networks: A survey and comparative analysis." In IEEE 5th International Conference on Wireless Networks and Embedded Systems (WECON), 2016, pp. 1-6.
[5] M. K. Singh, S. I. Amin, S. A. Imam, V. K. Sachan, and A. Choudhary, "A Survey of Wireless Sensor Network and its types," In IEEE International Conference on Advances in Computing, Communication Control and Networking (ICACCCN), 2018, pp. 326-330.
[6] S. Sharma, R. K. Bansal, and S. Bansal, "Issues and challenges in wireless sensor networks," In IEEE International Conference on Machine Intelligence and Research Advancement, 2013, pp. 58-62.
[7] V. Devi, and M. Naik, “A Review of Lifetime Analysis of a Slotted Aloha Based Wireless Sensor Network Using a Cross-Layer Frame Rate Adaptation Scheme,” In IEEE International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 4, Issue 2, 2015, pp. 534-540.
[8] S. Abdollahzadeh, and N. J. Navimipour, "Deployment strategies in the wireless sensor network: A comprehensive review," Computer Communications, 2016, pp. 1-16.
[9] B. Narain, A. Sharma, S. Kumar, and V. Patle, "Energy Efficient MAC Protocols for Wireless Sensor Networks: A Survey," International Journal of Computer Science & Engineering Survey (IJCSES), Vol. 2, No. 3, 2011, pp. 121-131.
[10] A. Verma, M. P. Singh, J. P. Singh, and P. Kumar, "Survey of MAC protocol for wireless sensor networks," In IEEE Second International Conference on Advances in Computing and Communication Engineering, 2015, pp. 92-97.
[11] A. Roy, and N. Sarma, "Energy saving in MAC layer of wireless sensor networks: a survey," In National Workshop in Design and Analysis of Algorithm (NWDAA), Tezpur University, India, 2010, pp. 1-16.
[12] A. Roy, and N. Sarma, "Performance Evaluation of Synchronous Energy Efficient MAC Protocols for Wireless Sensor Networks," Procedia Technology 6, 2012, pp. 806-813.
[13] W. Ye. J. Heidemann, and D. Estrin, "An energy-efficient MAC protocol for wireless sensor networks," in Proceedings of the IEEE Infocom, 2002, pp. 1567–1576.
[14] X. Zheng, "Improvement strategy of S-MAC protocol for wireless sensors in IoT based on data and energy priorities," Systems Science & Control Engineering, Vol. 7, No. 2, 2019, pp. 1-7.

[15] W. Lee, Y. Lee, S. Lee, and D. Kim, "Analysis of S-MAC/T-MAC Protocols for Wireless Sensor Networks," In WSEAS International Conference on COMMUNICATIONS, 2006**,** pp. 260-265.

[16] M. Dener, and Ö. F. Bay, "Medium Access Control Protocols For Wireless Sensor Networks: Literature Survey," Gazi University Journal of Science, Vol. 25, No. 2, 2012, pp. 455-464.

[17] T. V. Dam, and K. Langendoen, "An adaptive energy-efficient MAC protocol for wireless sensor networks," in Proceedings of the 1st international conference on Embedded networked sensor systems, 2003, pp. 171-180.

[18] M. Ram, S. Kumar, V. Kumar, A. Sikandar, and R. Kharel, "Enabling Green Wireless Sensor Networks: Energy Efficient T-MAC Using Markov Chain Based Optimization," Electronics, Vol. 8, No. 5, 2019, pp. 1-14.

[19] V. Rajendran, K. Obraczka and J.J. Garcia-Luna-Aceves, "Energy-efficient, collision-free medium access control for wireless sensor networks," Wireless networks, Vol. 12, No. 1, 2006, pp. 63-78.

[20] G. Lu, B. Krishnamachari, and C. S. Raghavendra, "An adaptive energy-efficient and low-latency MAC for data gathering in wireless sensor networks." In IEEE 18th International Parallel and Distributed Processing Symposium, 2004, pp. 1-8.

[21] S. Du, A. K. Saha, and D. B. Johnson, "RMAC: A routing-enhanced duty-cycle MAC protocol for wireless sensor networks." In IEEE INFOCOM 2007-26th IEEE International Conference on Computer Communications, 2007, pp. 1478-1486.

[22] K. Shim and H. Park, "Priority-Based Pipelined-Forwarding MAC Protocol for EH-WSNs," Wireless Communications and Mobile Computing, 2019.

[23] L. F. W. van Hoesel, and P. J. M. Havinga, "A lightweight medium access protocol (LMAC) for wireless sensor networks." In 1st Int. Workshop on Networked Sensing Systems (INSS 2004), 2004, pp. 1-4.

[24] F. Al-Obaidy, Sh. Momtahen, and F. Mohammadi, "Wireless Sensor Networks Analysis based on MAC Protocols," in the IEEE Canadian Conference of Electrical and Computer Engineering (CCECE), 2019, pp. 1-4.

[25] F. N. Abdesselam, B.Bensaou, Th. Soete, and K. L. Hung, "O-MAC: An Organized Energy-aware MAC Protocol for wireless sensor networks." In 2007 IEEE International Conference on Communications, 2007, pp. 3648-3653.

[26] S. Pack. J. Choi, T. Kwon, and Y. Choi, "TA-MAC: Task Aware MAC Protocol for Wireless Sensor Networks," In IEEE 63rd Vehicular Technology Conference, Vol. 1, 2006, pp. 294-298.

[27] W. Torfs, "Implementation and evaluation of timeliness in wireless networks: to be or not to be on time," Ph.D. Thesis, University of Antwerp, 2019.

[28] B. Tavli, and W. B. Heinzelman, "TRACE: Time reservation using adaptive control for energy efficiency," IEEE Journal on Selected Areas in Communications, Vol. 21, No.10, 2003, pp. 1506-1515.

[29] B. Tavli, and W. B. Heinzelman, "MH-TRACE: multihop time reservation using adaptive control for energy efficiency," IEEE Journal on Selected Areas in Communications, Vol. 22, No. 5, 2004, pp. 942-953.

[30] V. Quintero, C. Estevez, M. Orchard, and A. Pérez, "Improvements of Energy-Efficient Techniques in WSNs: A MAC-Protocol Approach," IEEE Communications Surveys & Tutorials, Vol. 21, No. 2, 2018, pp. 1188-1208.

[31] J. Polastre, J. Hill, and D. Culler, "Versatile low power media access for wireless sensor networks," in Proceedings of the 2nd international conference on embedded networked sensor systems, ACM, 2004, pp. 95-107.

[32] A. El-Hoiydi, and J. Decotignie, "Low power downlink MAC protocols for infrastructure wireless sensor networks," Mobile Networks and Applications, Vol. 10, No. 5, 2005, pp. 675-690.

[33] M. Buettner, G. V. Yee, E. Anderson, and R. Han, "X-MAC: A short preamble MAC protocol for duty-cycled wireless sensor networks," in Proc. Sensys'06, 2006, pp. 307-320.

[34] C. Schurgers, V. Tsiatsis, S. Ganeriwal, and M. Srivastava, "Optimizing sensor networks in the energy-latency-density design space," IEEE transactions on mobile computing, Vol. 1, No.1, 2002, pp. 70-80.

[35] K. Jamieson, H. Balakrishnan, and Y. C. Tay, "Sift: A MAC protocol for event-driven wireless sensor networks," In European workshop on wireless sensor networks, Springer, Berlin, Heidelberg, 2003, pp. 260-275.

[36] Sh. Sh. Anjum, R. M. Noor, I. Ahmedy, and M. H. Anisi, "Energy optimization of sustainable Internet of Things (IoT) systems using an energy harvesting medium access protocol," in IOP Conference Series: Earth and Environmental Science, IOP Publishing, Vol. 268, No. 1, 2019, pp. 1-7.