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Survey on Energy Efficiency of WSN MAC Protocols Comparisons

Maulidin[*,1], *M. Mahmuddin*[1], *and L. M. Kamarudin*[2]

[1]InterNetwork Research Laboratory, School of Computing, UUM College of Arts and Sciences, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia.
[2]School of Computer and Communication Engineering, Universiti Malaysia Perlis, Malaysia.
[*]*maulidin84@gmail.com*

Abstract – *Energy efficiency is the main issue in the Wireless Sensor Networks (WSNs). On the other hand, the concept of cooperative communication is one of the fastest growing areas of research in WSN. The growth of these open nature networks the multiple sensors participate in the network and has plenty number of nodes or sensors. Individual sensors communicate through a wireless channel comprise processing, transmission, reception, and the sensing channel which is needed the power for long elastic in the network. The nodes are constrained by battery power for their operation because of the open nature network each sensor is needed to use its own battery power. On the other hand, battery powered sensors operating in unattended environments, energy conservation becomes the key technique for improving WSN lifetimes. Based on these issues various techniques have been proposed in minimizing the energy consumption in WSN. This paper is twofold, first we classify the Connection-based and Schedule-based energy efficiency MAC (Medium Access Control) Protocols. Second, present the comparisons of Connection-based and Schedule-based energy efficiency MAC protocols in WSN. Furthermore, based on literature review, it gives the open area, which can help the future research directions by their limitations to develop the tools and techniques to mitigate the current limitations in energy efficiency MAC protocols in WSN.*

Keywords: WSN, MAC Protocol, CSMA, TDMA

1.0 INTRODUCTION

WSN offers the open nature environment of real-time monitoring systems that can be used in verity of plenty applications. Such as intrusion detection, administration of the network, health care, organization process administration, strategic systems etc. [12,14,27]. It is a wireless network and often composed of many nodes or sensors to monitor vast kinds of conditions. WSN contained a vast quantity of sensors which are cheaply enough to use in low cost. Then, there would be many limitations on the nodes, such as cheap power sources, and cheap circuit. On the other hand, the sensor nodes play critical role in the collection of information, and the power source is quite important. Nodes in such WSN applications generally used the battery which is power source with limited battery capacity for an extensive period [17]. Due to the partial capability of batteries and the strain of repeated battery refreshing with power, energy is a limited and costly resource in sensor networks.

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Extensive research has been done in various fields of the sensor networks. In WSN transmission messages among nodes is considered the maximum energy using in process. To efficiently communicate between sensor nodes, MAC protocol is the one of the key components that able to improve the energy efficiency. In WSN, the MAC protocols design suffers from several limitations, such as communicating, computing, sensing devices and memory capacities [3].

The major sources of energy wasted in WSN are fundamentally can be categorized in Table 1, which described the Idle listening, Collisions, Protocol overhead and Overhearing with detailed description [23]. In this article, the energy efficiency of WSN MAC protocols are classified with detailed description of each protocol and their techniques which has been proposed by different authors. The overall arrangement of this article is systemized as in section two present the classification of connection based and schedule based energy efficiency MAC (Medium Access Control) Protocols in WSN with detail of each technique Section three present the comparisons of above mentioned protocols in WSN along with open area and finally, the conclusion of this work.

Table 1: Causes of Energy Wasted in WSN

Causes Energy Wasted	Description
Idle listening	An event when node listens to the channel for traffic possibilities, but there is no packet data received. If node senses nothing, they will go back to idle phase. Various quantities had shown that idle listening requires 50–100% of the energy [30].
Collisions	This problem might occur when a transmit packet is damaged because of the interference. It is important to be abandoned and continue on retransmissions lead to increase the collision, latency, and energy consumption.
Protocol overhead	Energy consumption increases through sending and receiving the control packets. It only transmits the useful data packets. This process is brings the overhead in the network.
Overhearing	It is the situation where a node gets a data packet that is intended for certain other node. In this situation, mostly observed the overhearing.

2.0 WSN MAC PROTOCOLS CLASSIFICATION

Several approaches of MAC protocol have been designed for WSN [11,15]. In general MAC protocols in present WSNs assume a duty-cycling method that enables the sensor nodes to consecutively adjustment among lively to sleep situations which have been established to enhance the energy efficiency.

WSN MAC protocols are a broad area of research in current era, it has been many approaches deployed to mitigated issues related to energy efficiency. It can be categorized connection based and schedule based techniques for WSN MAC protocls, the classification of WSN MAC protocols is shown in Fig. 1.

A. Contention-Based Protocols

In a contention-based protocol, a sensor transmit or receive data whenever the medium is idle. This scheme however, leads to collisions as more than one node may transmit at the

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same time. The collision problem in the MAC has been given much attention nowadays by introducing some techniques for immediate mitigation if not totally eliminated. Current contention-based protocols for WSN referred to synchronous and asynchronous.

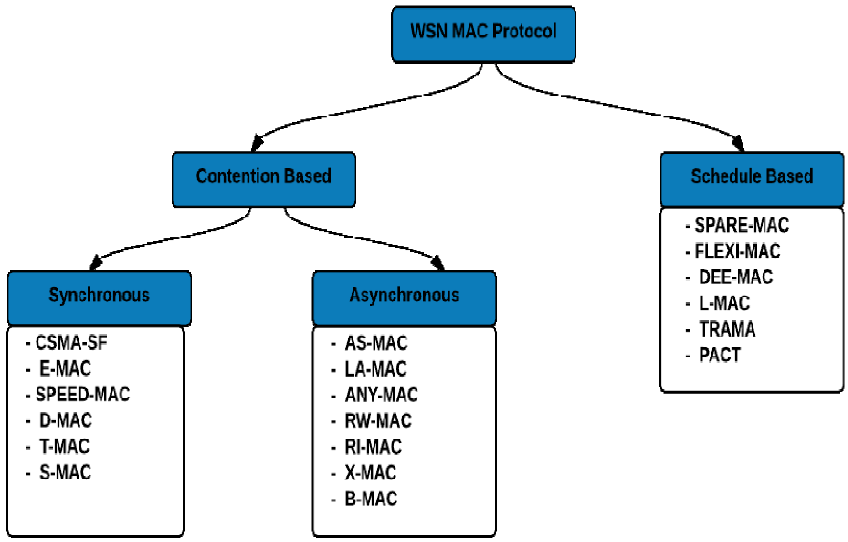

Figure 1: Classification of WSN_MAC_Protocols based on Connection based and Schedule based

In synchronous approach the sensor nodes to proficiently arrange active or sleeping phases. In this method observed to reduce idle listening time that is the greatest pointed cause of energy waste. However, the overhead and complication of employing synchronization are extensive.

On the other hand, with synchronous method, every node in asynchronous individually wakeup, due to its specific duty cycling schedule. This approach improves energy without synchronization and no overhead. The detail of each technique based on Contention-based MAC (synchronous and asynchronous) protocols that are explicitly targeted towards wireless sensor networks is following;

Synchronous Protocol

CSMA/SF is contention-based that use shortest first approach to reduce energy consumption [28]. This protocol modifies the carrier sense by using scheduling algorithm and adding priority to each transmission. Fig. 2 shown the CSMA/SF channel access approach. CSMA/SF confirms the nodes continuing shorter packet has greater significance in conflict by executing a circulated scheduling method and integrating length detection structure.

Further, CSMA/SF switched an Anti-Starvation mechanism which is responsible to resolve the starvation issue of shortest-first protocol. This approach can reduce energy cost and improve channel utilization. Even though CSMA/SF can reduce the number of contention nodes in any specific time slot, it cannot improve channel utilization with large number of nodes. It is because the increasing amount of collisions.

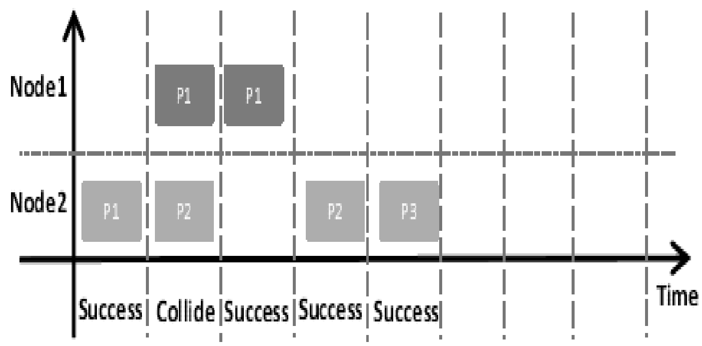

Figure 2: CSMA/SF_Channel access

Liu [19] proposed a MAC protocol for EDDA (event-driven data aggregation), with efficient mechanisms of scheduling multiple data packets (referred to as E-MAC). E-MAC protocol categorizes the nodes in EDDA and divisions the transportation of packets into some phases, Fig. 3 shown the example of this technique. This protocol schedule wakeup staggers for episode nodes to forward wakeup sequentially and setup receive pioneer packet (PION) that employed to ensure multi-hop reservations besides broadcasting track. In the sleeping period, this protocol uses the route info to set path and produce multi-hop reservation for data transportations. E-MAC protocol has a better performance than R-MAC, which provide small latency and great energy efficiency. However, since this protocol ignore the intra-flow interference, will causes collision with another packet in the same flow.

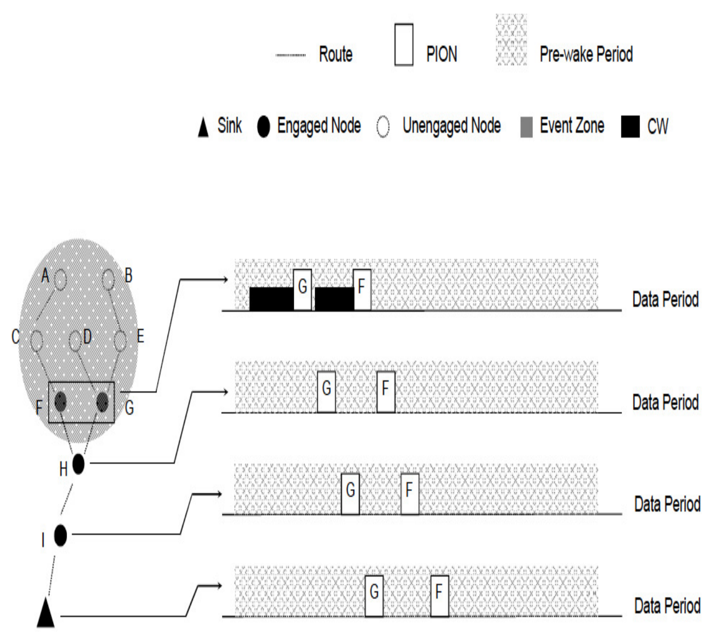

Figure 3: E-MAC_Schedulling process

SPEED-MAC have been proposed as a synchronous skewed wakeup signaling of each node in a pipelined data delivery [8]. In this protocol each cycle time is divided into event announcement (signaling wakeup) and data transmission delivery which is shown in Fig. 4

describes the overview of this technique. In the event announcement, a node announce the event by sending a SIGNAL packet (consist of receiver address and collision bit).

During data transmission delivery period node transfer message bay sending DATA Packets (DATA and more flag). For transmission in single-source event, the period use DATA/ACK, and for multi-source event, the period use CSMA/CA with RTS/CTS/DATA/ACK to avoid collision and to allow multiple transmissions dynamically. Though, this protocol can still work properly in single-source event. However, more contention and collision incurred by multi-source event will affect transmission delay.

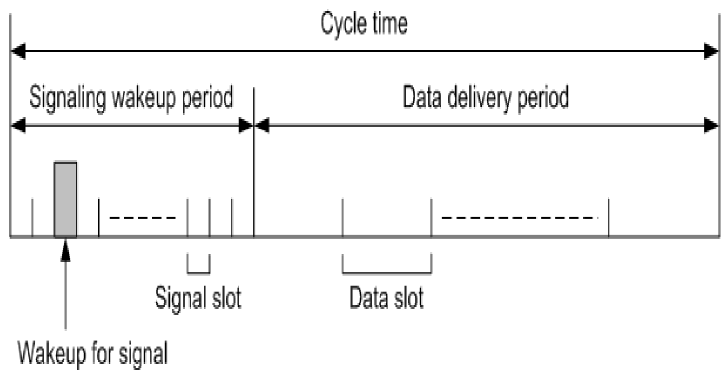

Figure 4: SPEED-MAC_Cycle time breakdown

Data-Gathering-MAC (D-MAC) protocol proposed to evade the data forwarding issue [18]. It is energy efficient and small latency protocol which is established on data gathering trees where the flow of packets is directed in one predetermined far by initiator nodes to one coordinator which is the only destination in the network.

The tree architecture is distributed into levels, which are shown in Fig. 5. Each level consists of a set of nodes that get data from the nodes of lower level and forward them to the nodes in the higher level. The frame is distributed into three main modes: transmitting, receiving and sleeping, and the schedule proposed is designed in a way so when a node at a given level is sending data, the neighbor node in the upper level will be in the receiving mode. The advantage of this protocol latency is reduced because the nodes involved in the communication wakeup in a sequence manner from bottom up to the destination. However, local-gossip communication pattern cannot be used in D-MAC protocol.

Timeout-MAC (T-MAC) adopts contention-based scheme that lays on improvement of S-MAC protocol by allowing active nodes to have adaptive duty-cycles for the operation [10]. In this protocol every node from time to time wakeup to broadcast with its nearby nodes and then go to sleep over until the next frame, overcomes this scheme is shown in Fig. 6.

T-MAC protocol can simply handle variable load due to active sleeping schedule and better energy performance for low data rate applications. Although, it is familiar against great delay compared to S-MAC protocol. The problem in this protocol is the early sleeping problem occurs in case of asymmetric communication.

Sensor-MAC (S-MAC) protocol is a contention-based approach that employs periodic listen and sleep to minimize idle listening time [30]. In this protocol, it divides time into frame. In Fig. 7 depicts that every frame is classified into two periods that are active and sleep. During

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active period, node of each transmitter-receiver is switched on and during sleep period is switched off.

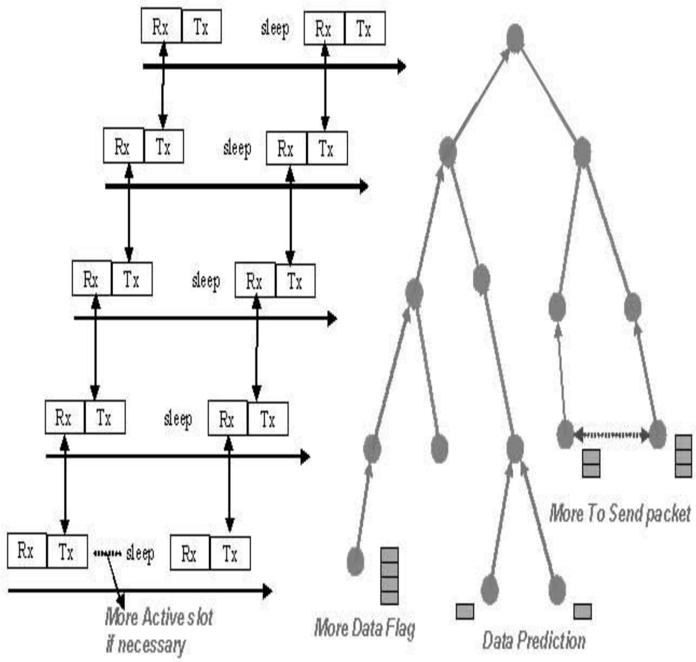

Figure 5: D-MAC_Data Gathering Tree

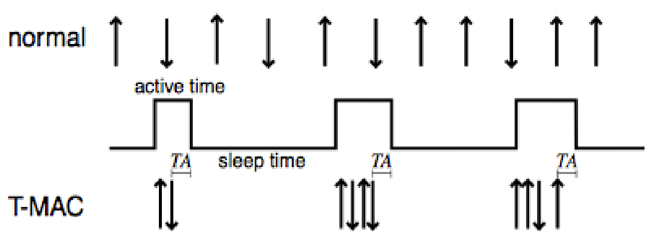

Figure 6: T-MAC_Adaptive Active Time

All nodes periodically listen, sleep and wakeup, with all nodes synchronizing the start of their active and sleep periods. Nodes listen and send data (using Request-to-Send (RTS) and Clear-to-Send (CTS) handshaking) during the active period and switch off their radios while sleep period.

The goal is to control the duty cycle to trade off higher delay for lower energy consumption. S-MAC protocol is able to provide better latency and minimize throughput. The disadvantage of this protocol is increases collision probability on broadcast data packets and sleep latency.

Asynchronous Protocol

Asynchronous Scheduled MAC (AS-MAC) formerly evaded overhearing, compact contention, delay, power consumption and packet loss by asynchronously coordinates the wakeup_time of neighboring nodes [13]. This technique is divided into two parts. First, initialization phase, in this part each node listens for a fixed amount of time for "hello" packet, which contains neighbor's scheduling information (Iwakeup, Ihello, and Ow). At start-up, node received the hello_packet completely from its nearby nodes and stores a table from the received information. After new node sets its unique Ow, it starts periodic listening and sleep phase (second phase).

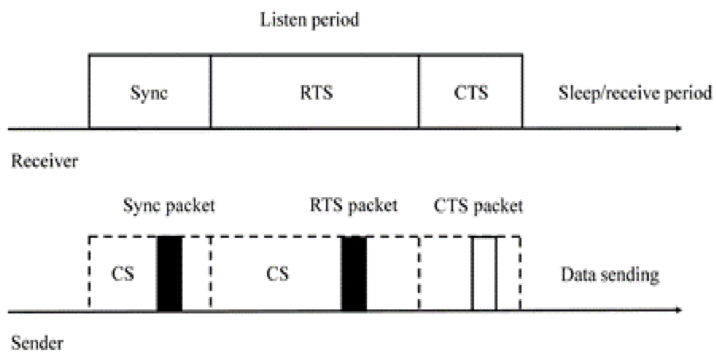

Figure 7: S-MAC_Periodic Active and Sleep

Node in periodic listening and sleep phase periodically wakes up in its given interval also called hello interval, and performs a Low power Listening (LPL) mode to detect of potential incoming message. If node detects the communication channel is busy, it then start listening for an incoming message. Furthermore, the receiving nodes transmit the hello_packet before receiving a message. However a node has data that send to the senders must be aware of the time while the receiver is transmitting a hello_packet.

The scenario is depicted in Fig. 8 which shown this technique. The sender also performs collision avoidance back off. The major disadvantage of this protocol is the memory overhead for maintaining a neighbors' table, especially in a dense network. Another one is help packets transmission. Although this approach permits new nodes entering the network dynamically, however the non-application related hello_packets claims extra amount of resources such as energy and bandwidth.

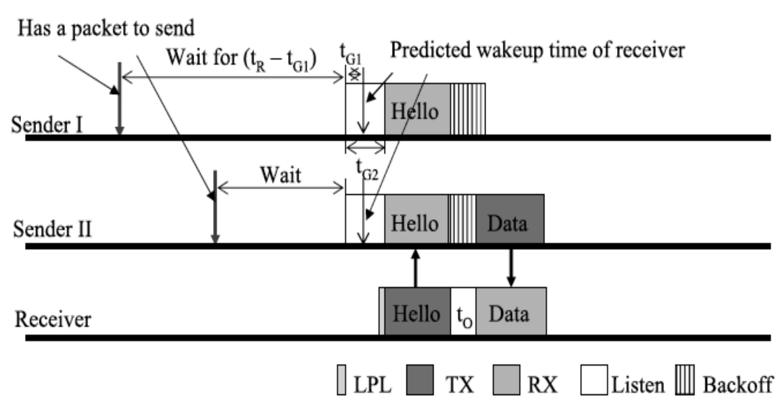

Figure 8: AS-MAC_Communication at Hello Time

Low-Latency Asynchronous MAC (LA-MAC) introduced from the fact that no presence MAC access approach can efficiently modify its performance to the variation of some network parameters such as traffic fluctuations [9]. This protocol suitable for handle heterogeneous traffic, support for multiple applications, and creating MAC to control due to

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the network configuration and potential various routes developed at the network layer (tree, DAG, partial mesh).

There are two bursts of frames the process of LA-MAC for observing which is shown in Fig. 9. LA-MAC contained some sequential steps: wakeup and sense the channel, preamble sampling, broadcast of the schedule frame, burst transmission, data forwarding, and next wakeup period. The advantages of LA-MAC protocol can achieve excellent performance on latency, packet delivery ratio, reduce packet overhead and energy cost. Additionally, this protocol need an enhancement for ability to handle mobile nodes.

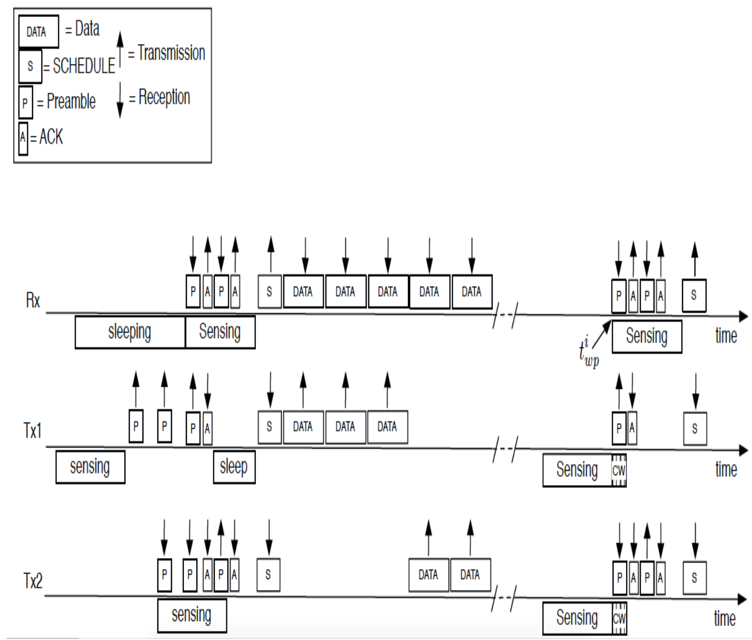

Figure 9: LA-MAC_Transmission of Two Bursts of Frames

Ashraf et al. [2] proposed a generic low overhead extension which possibly be practical to any present asynchronous MAC protocol to enable MAC-layer anycast (Any-MAC protocol) to improve delay in WSN. Any-MAC only assumed nodes that are the same in lowest routing cost to the destination as candidate forwarders.

Any-MAC proposed two different techniques to generic any cast. In receiver-driven protocols use a beacon-based extension for all receiver-driven MAC protocols. And a probe-based extension technique for all sender driven MAC, this technique is shown in Figure-10. Any-MAC protocol can achieve 30% improvement in delay and compact energy waste, approximately by 30% reserves for X-MAC and approximately by 12% reserves for NPM.

RW-MAC is an asynchronous receiver-initiated MAC which vitally reduces energy waste by exactly guessing the receiver's wakeup_time while still achieves high synchronized enactment [29]. These protocols combine the basic operations of RI-MAC protocol and WiseMAC protocol to reduce the idle-listening and energy consumption.

This protocol use the beacon to evaluation the receiver's wakeup_time to decrease sender's idle listening and dynamic stagger wakeup_time of individual nodes to mitigate the collision, Fig. 11 shown RW-MAC design. The major drawback of RW-MAC is decreases the senders

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energy consumption by exactly guessing the receivers wakeup_time and reduces collision by dynamically incredible nodes wakeup_time.

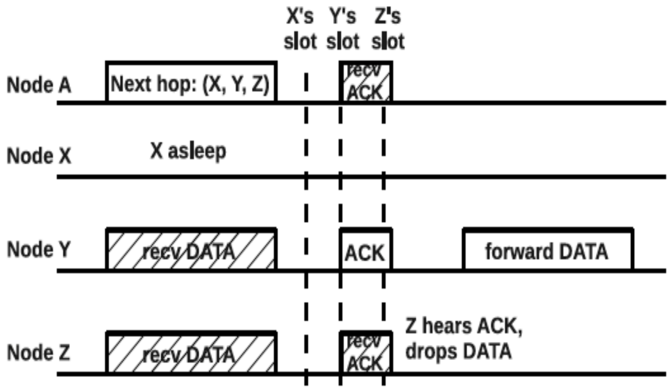

Figure 10: Any-MAC_Slotted ACK Mechanism for Probing-based Extension

Receiver Initiated MAC (RI-MAC) familiarized by [24] is a receiver-initiated asynchronous duty-cycle MAC protocol and thus eliminates the preamble. In this protocol every node has its individual working schedule to wakeup periodically. If the wireless medium is idle when a node wakeup, it sends a beacon message to indicate that it is ready for receiving data, in Fig. 12 which depicts the scenario of this technique. When a sender gets the beacon, it start transmitting packet to the intentional receiver. When transmission complete, the target receiver will send out another beacon.

Another scheme by X-MAC protocol [5] proposed an adaptive algorithm that dynamically amends the asynchronous duty-cycles to enhance energy consumption per packet, Quality of Service (QoS) parameters. This protocol improves low power listening, overhearing, and reducing preamble length.

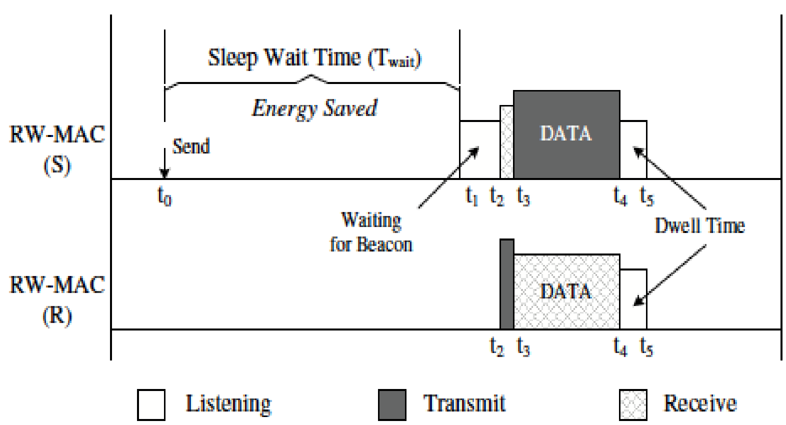

Figure 11: RW-MAC_Reduce Sender Idle Listening Design

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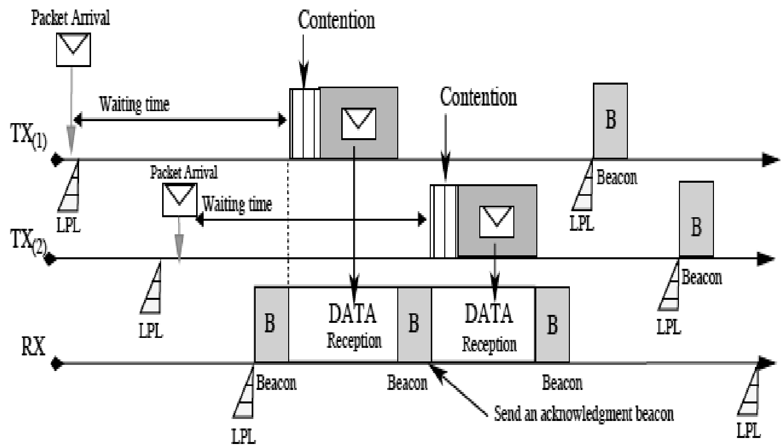

Figure 12: RI-MAC_Receiver-initiated Technique

Firstly, X-MAC use short preamble along embeds address information of the target. Secondly, this protocol is also use strobe preamble approach that allows the receiver to interrupt and wakeup faster to achieve a better performance than ordinary Low Power Listening is shown in Fig. 13 the scenario of this approach.

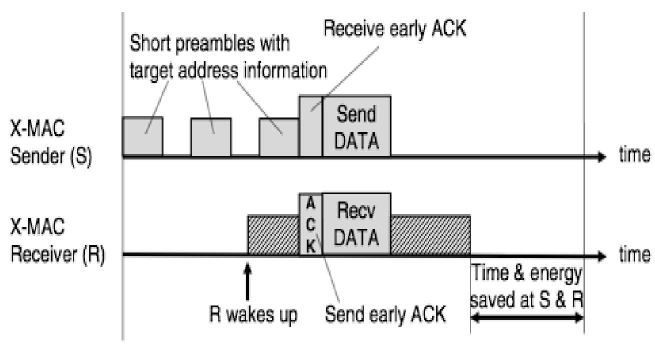

Figure 13: X-MAC_Short Preamble

The advantages of X-MAC protocol over LPL are energy-efficient, low latency, increase throughput, and low overhead. The disadvantages of X-MAC protocol are process of avoiding overhearing and unable to schedule sufficiently small listening periods.

Berkeley-MAC (B-MAC) protocol employs static wakeup preamble sampling structure to decrease the duty-cycle and reduce idle listening [21]. In order to gain low power consumption, B-MAC combines both techniques of CSMA and Low Power Listening (LPL) as it is show in Fig. 14, both Clear Channel Assessment (CCA) and packet back-offs are useful to protocol design for channel arbitration.

The reliability is insured through the use of link layer acknowledgments and LPL for low power communications. This protocol has a better performance than S-MAC, idle listening is reduced to minimum and can be scaled to a large network. Furthermore the drawback of this protocol is that the long preamble transmission creates large overhead and overhearing cost.

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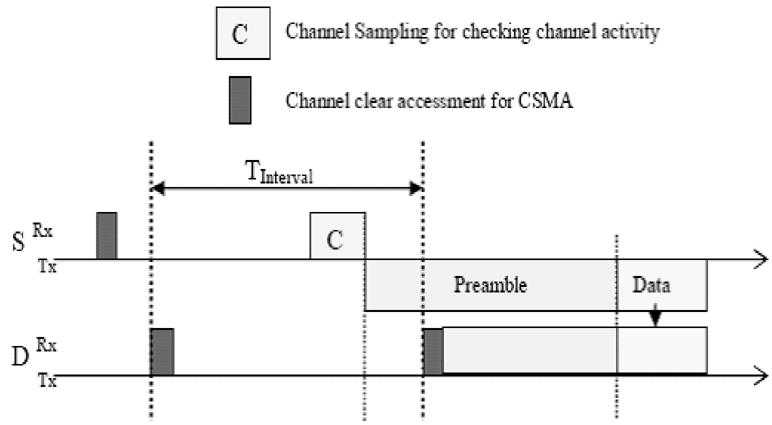

Figure 14: B-MAC_Preamble Sampling

B. Scheduled-Based Protocols

Schedule-based protocols require synchronization between nodes. Most of these protocols utilize Time Division Multiple Access (TDMA) [25]. In this technique, time distributed into periodic frames, each obtaining a certain number of slots. All nodes is given more than one slots per frame, during that it is free to send or receive packets from other nodes, according to a certain scheduling algorithm [1].

Slot Periodic Assignment of Reception-MAC (SPARE-MAC) is dynamic TDMA-based access control for data diffusion [6]. It limits the energy wastage on idle listening, over-emitting, and traffic overhearing. SPARE-MAC protocol involve time arrangement in frames in which each of the frame is divided by Signaling Sub Frame (SSU), Wakeup Slot (WS), and DATA Sub Frame (DSU) as depict in Figure-15, which describe the overview of this scenario.

Furthermore, to solve the hidden terminal problem SPARE-MAC uses Wakeup Reliable Reservation ALOHA (WRR-ALOHA) protocol, and to avoid long delay it proposed a dynamic technique to reserve reception. SPARE-MAC can significantly improves throughput, energy efficiency, and faster delivery compared to S-MAC protocol. SPARE-MAC does not avoid collisions entirely. It is appear that transmission process of multiple sensor nodes come to collisions on the same Reception Schedule.

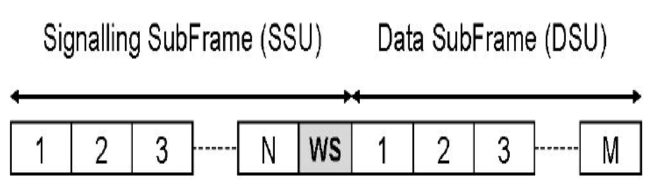

Figure 15: SPARE-MAC_Frame Structure

In order to deal with both fault tolerant and energy efficient Lee et al [16] come with Flexible TDMA-based MAC Protocol (Flexi-MAC) which refer to a novel TDMA-based protocol using a loose slot structure. In this protocol, transmission involve each node by their own time slot(s) then shift into sleep mode after they are not schedule to send or receive.

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Flexi-MAC contention period is defined nodes in the network to construct a data-gathering tree rooted at the sink node. Slot assignment is done according to the tree with aim to interference reduction and improvement of spatial reuse, nodes schedule shown in Figure-16 which gives overall view of this approach. In Flexi-MAC, the Fault Tolerant-Listening Slot (FTS) is simply a short CSMA period where all nodes in the network are in the listen mode. Each node uses three lists for slot assignment and maintenance: Receive Slot List (RSL), Transmit Slot List (TSL), and Conflict Slot List (CSL).

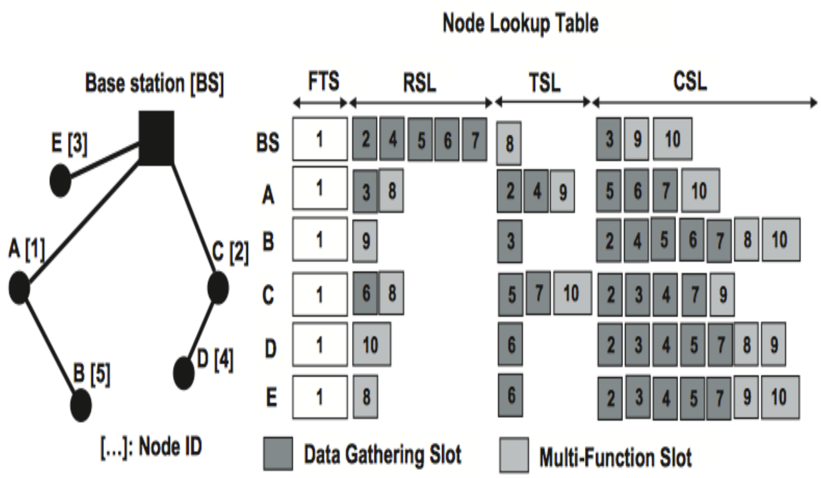

Figure 16: FlexiMAC_Nodes Schedule in the Data Gathering

Dynamic Energy Efficient MAC (DEE-MAC) protocol presents a method of synchronization that is done at the cluster head in which by forcing the idle listening modes to sleep mode [7]. In this protocol node-radios can be switched off during idle times to preserve energy Fig. 17 shown that operation of DEE-MAC protocol is divided into round, which consist of phases of both cluster formation and transmission. It appears that a cluster head comes from a node in the cluster formation phase. The transmission phase composes some sessions, which consists of both periods of contention and data transmission. A reasonable solution in this protocol brings idle listening which is more efficient in large-scale WSNs. The disadvantage of this protocol may occur with depleted power of cluster head and not appropriate in frequently changing network.

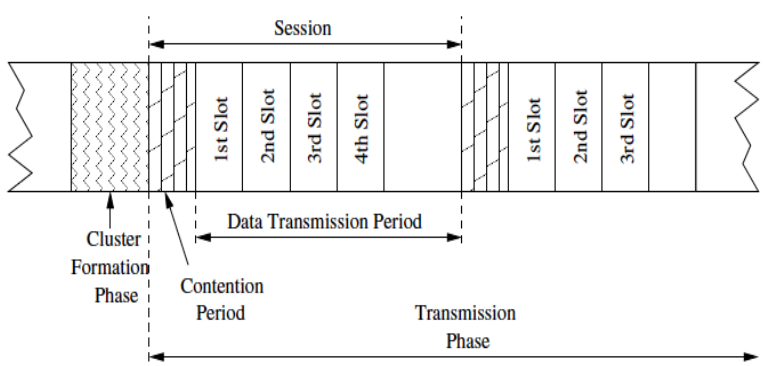

Figure 17: DEE-MAC_Transmission Phase

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Hoesel & Havinga [26] presented Lightweight MAC (L-MAC) protocol, is a TDMA based MAC protocol uses a distributed algorithm for slot selection mechanism based on two-hop neighborhoods information. Each slot consists two parts: control message and data Message period. Upon receiving message receiver will decide to stay awake or not. By combining message from all neighboring node is able to determine unoccupied slots. Process starts from base station, during each frame it continuous throughout network. This network is composed of gateways and sensing devices; each sensor synchronizes its clock with respect to the closest gateway, this method is shown in Fig. 18 which describes this method.

Node cannot select a slot that is in two-hop neighbor. Problem with this protocol is, if collision occurs in control message during selection of slots, process needs to be restarted. The major drawback of this protocol is the frame that needs to be split into many slots. This implies increasing latency and decreasing throughput. Furthermore, the L-MAC bitmap broadcasts are an unnecessary overhead in a clustered network, and the fact that slot allocation process lacks interference awareness results in low system spectral efficiency.

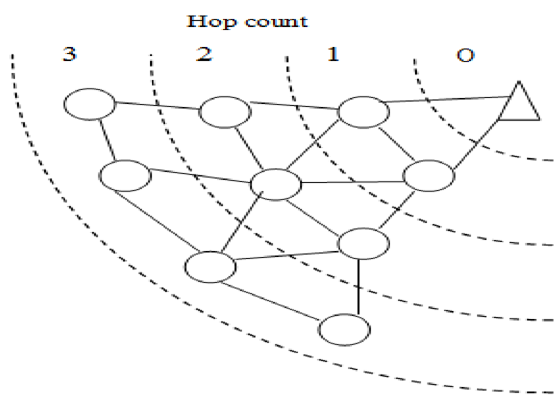

Figure 18: L-MAC_Communication Range of the Gateway Nodes

Traffic-Adaptive MAC (TRAMA) tries to reduce energy consumption and network throughput [22]. TRAMA consists of three main parts, which are responsible for different areas of the medium access control: Neighbor Protocol (NP) and the Schedule Exchange Protocol (SEP) which in charge of organizing the exchange of two-hop neighbor and schedules information.

The Election Algorithm (AEA) allows node to utilize this information to schedule transmissions for the next time slot, making it possible for idle nodes to enter their low-power mode. TRAMA use a single time-slotted channel access. The time slotted is distributed into random and reserved access phases which is shown in Fig. 19.

Power Aware Cluster TDMA (PACT) protocol is a TDMA-based MAC protocol which is employed for large multi-hop WSNs [20]. PACT protocol utilize adaptive duty-cycles to the traffic load obtains the duty cycle of the user traffic by turning off the radio if the network is inactive. It employed passive clustering to take benefit of the redundant dense topology and extend the lifetime of the network, this method is shown in Fig. 20.

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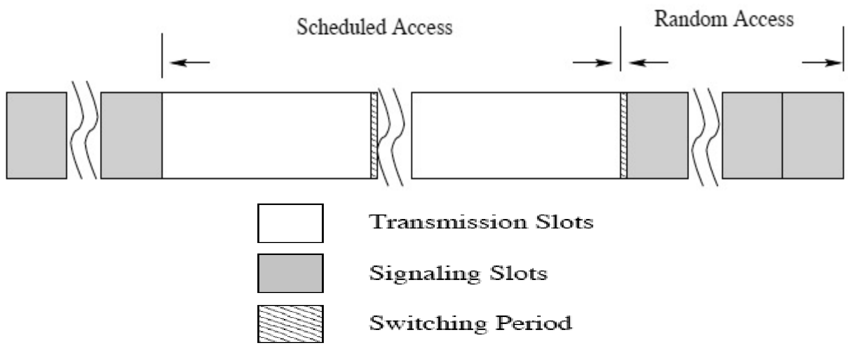

Figure 19: TRAMA_Time Slot Organization

At any given time, only a subset of network nodes and CHs participate in the communication. The TDMA MAC frame begins with mini-slots and transmission slots of sensor nodes. Time adjusting brings more efficiency in energy consumption through activating times of the nodes to the data traffic present in the network at a certain time. Both expense of additional control traffic overhead and idle listening in large scale networks become disadvantages of PACT protocol. Static networks provide good performance through complex data slot scheduling algorithm instead of support for dynamic network.

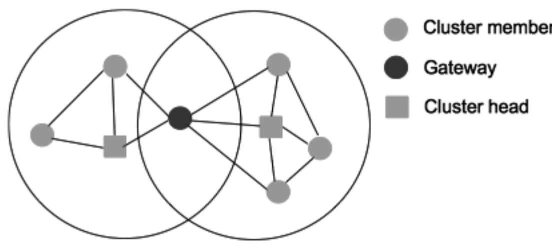

Figure 20: PACT _Passive clustering

3.0 OPEN AREA

This era process improvement has been given a lot of attention to prolong WSN lifetime by choosing energy efficient operations. A lot of work has been done, there are some opportunities for researchers to improve MAC protocol for WSN such as revision on time division, manage synchronization to reduce delay as low as possible and more efficient channel utilization.

In this paper, we have surveyed the several techniques employ in the design MAC protocol for WSN. We categorized WSN protocols based on their common scheme that are CSMA (Synchronous and Asynchronous), TDMA, The objective of this categorization is to identify the energy efficiency and data delivery achievement which is present in Table 2 with their limitation by comparing with Quality of Service (QoS) parameters is implied to researchers in this area to design and implement in energy efficiency mechanism in WSN to provide better deployment and regulate advanced usage of WSN for betterment in their applications and communication.

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4.0 CONCLUSIONS

The Synchronous protocols approach goal is to make synchronizing nodes on a common active/sleep scheduling program. In this protocol establishment of communication do not face any problem, therefore most of protocols on this approach concern on delay and throughput enhancement. The synchronous approach, each node in asynchronous sleep scheduling each node wakes up and goes to sleep independently according to its own duty cycling schedule. This technique can reduce the cost of synchronizing and might be capable to attain low duty-cycle, however, delay has become the main issue in this protocol.

TDMA based MAC protocols are also utilize in synchronous protocols, but if active periods of two clusters are overlapping then there is a collision. Hence TDMA follows global time synchronization rather than local time synchronization. The main obstacle in this technique suffers from low channel utilization.

However, the design of a multichannel MAC protocol for different application classes, concerning energy efficiency, throughput and delay, because no specific medium access scheme offers the best performances in varying traffic condition and density of the network. From all of these techniques we can say that all the method with their protocols achieve energy efficiency, solve data delivery ratio that depend on application-oriented design.

Table 2: Comparison of Connection-based and Schedule-based Energy Efficiency of WSN MAC Protocols

Protocol	Scheme Used	Energy Saving Mechanism	Delay Decrease	Latency	Throughput	Overhearing	Collision	Delivery Ratio	Overhead
CSMA-SF (Wang et al, 2014) [28]	CSMA-Synchronous	Implement shortest-first scheduling during transmission	End to end delay decrease	×	High	Low	✓	✓	Low (Modify length of data and periodical transmission)
E-MAC (Liu & Yao, 2012) [19]	CSMA-Synchronous	Scheduling Multiple Data Packets from the event zone across multiple hops in the same cycle	End to end delay decrease	Low	High	Low	✓	✓	Low (Scheduling Process in Pre-wake Period)
SPEED-MAC (Choi et al, 2010) [8]	CSMA-Synchronous	Divide the cycle time into an event announcement and data transmission	End to end delay decrease	Low	High	Low	✓	✓	Increased control packet overhead for multi-source events
D-MAC (Gang Lu et al., 2004) [18]	CSMA-Synchronous	Utilization of data gathering tree structure	End to end delay decrease	Low	High	Low	✓	✓	Low (Use ACK)
T-MAC (van Dam and Langendoen, K., 2003) [10]	CSMA-Synchronous	Reduced by decrease the idle listening time and manage to has low throughput	Node to Node decrease (Two Hop)	Low	Low	Low	✓	✓	High (RTS/CTS)

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S-MAC (Ye et al, 2002) [30]	CSMA-Synchronous	Fixed duty cycle, Virtual Cluster	Node to Node decrease (One Hop)	High	High	Low	✓	✓	Sleep schedule message
AS-MAC (Jang et al, 2013) [13]	CSMA-Asynchronous	Minimize the periodic wakeup_time by usig LPL	Probabilistic End-to-End decrease	Low	Low	Low	✓	✓	Overhead for broadcast
LA-MAC (Corbellini et al, 2012) [9]	CSMA-Asynchronous	Forwarding based on proper scheduling of children nodes that want to transmit, transmissions of frame bursts, and traffic differentiation	End to end delay decrease	Low	High	Low	✓	✓	Low (Decrease node coordination per frame)
PACT (Pei & Chien,. 2001) [20]	TDMA	Use passive clustering and adaptive duty cycle	End to end delay decrease	Low	High	×	✓	✓	Neighbor protocol and schedule transmission
Any-MAC (Ashraf et al, 2011) [2]	CSMA-Asynchronous	Forward data packets to the next hop node by using shortest path routing	Node To Node decrease (One Hop)	Low	High	Low	✓	✓	Low (control redundant ACK transmission)
RW-MAC (Yang et al, 2010) [29]	CSMA-Asynchronous	Use beacon frame format and short preamble	Node To Node decrease (One Hop)	Low	High	×	✓	✓	Overhead when listening two cycles
RI-MAC (Sun et al, 2008) [24]	CSMA-Asynchronous	Uses the beacon message for the reliable data transmission (receiver initiated)	Node To Node decrease (One Hop)	Low	High	Low	✓	✓	Not require any synchronization, thus saving the overhead and complexity of clock synchronization
X-MAC (Buettner et al., 2006) [5]	CSMA-Asynchronous	Use strobe preamble and LPL	Node To Node decrease (One Hop)	Low	High	Low	✓	✓	Low (Use short preamble and early ACK)
B-MAC (Polastre et al., 2004) [21]	CSMA-Asynchronous	Employ static wakeup preamble and LPL	×	High	High	High	✓	✓	Low (RTS, CTS, ACK)
SPARE-MAC (Campelli et al., 2007) [6]	TDMA	Assign time-slot to each node for data reception.	End to end delay decrease	Low	High	Low	✓	✓	Network setup and schedule transmission
Flexi-MAC (Lee et al., 2006) [16]	TDMA	Use a loose slot structure and data gathering	End to end delay decrease	Low	Low	Low	✓	✓	Network setup and schedule transmission
DEE-MAC (Cho Sung-Rae et al., 2005) [7]	TDMA	Use synchronization which is done at the cluster head	End to end delay decrease	Low	Low	Low	✓	✓	Neighbor protocol and schedule transmission
L-MAC (Van Hoesel & Havinga, 2004) [26]	TDMA	Self-organization of timeslot assignment and snychronization	×	High	Low	High	✓	×	Network setup and control message

TRAMA (Rajendran et al, 2003) [22]	TDMA	Utilization of classical TDMA	×	High	High	Low	√	√	Neighbor protocol and schedule transmission

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