# Energy Efficient with Collision Free MAC Protocol for Wireless Sensor Network

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***Abstract*—In modern networks, a Wireless Sensor Network (WSN) is distributed far and wide to monitor physical or environmental situations. In WSNs, the Medium Access Control (MAC) protocol is greatly affected in energy consumption of sensor nodes by controlling the node radio functionalities. Many MAC protocols have been successfully designed towards the prime objective of energy efficiency. However, the classical layered protocols are mostly based on the existing solutions, which lead to significant overhead. This paper mainly contributes towards developing MAC protocol that considers energy consumption, packet delay, packet delivery, traffic adaptability, and many others for nodes in wireless networks. The simulation results and analysis illustrate that the proposed MAC protocol outperforms the contention-based and scheduling-based MAC protocols in terms of packet delivery ratio, network lifetime, delivery delay to the BS and energy consumption for various traffic loads in the network.**

***Index Terms*—Wireless Sensor Network (WSN); MAC Protocol.**

## I. INTRODUCTION

Controlling the functionalities of radio for WSNs greatly influences the energy consumption of sensor nodes as they consume power for each node of sensor done by Medium Access Control (MAC) protocols [1]. In general, for WSNs there are three radio modes for each node of sensor (active mode, idle mode or sleep mode). The nodes consume energy in active mode when there are activities for receiving and transmission data packets. In idle mode, the sensor node consumes the same amount of energy as it is consumed in active mode. However in sleep mode, the sensor nodes turn off the radio to save energy. The main energy waste for nodes is due to collision, idle listening, control packet, overhead and overhearing [2]. The first reason is a collision that occurs when different nodes transmit at the same time, causing the failure of data and the need for retransmission. Moreover, an idle listening is the second major reason for energy wastage, i.e., the sensor nodes listen to receive a possible traffic packet, which is not sent. This problem is especially happening in many applications for sensor networks. For most of the time, the nodes are in idle mode when there is no data sensed by the sensor nodes. The control packet overhead is the third reason where the control packets are sending and receiving, causing the nodes to consume energy too although minimal useful data packets were transmitted. The fourth reason is overhearing, which means that the sensor node picks up the packets that are intended to other sensor nodes. A common mechanism to reduce energy consumption is to turn the mode of sensor nodes into a low power sleep mode when it is not used. This paper proposed MAC schedule protocol, which considers many performance criteria that enhance power consumption.

The rest of paper is organized as follows. The related work presented by section II. This is followed by section III, which shows the details of the proposed MAC protocol. Section IV presents the experimental results followed by Section V, which provides the conclusion of this paper.

## II. RELATED WORK

A number of MAC protocols have been successfully proposed to meet the stringent design requirements of WSNs. These protocols depend on how the protocol allows nodes to access the channel.

As proposed in [3], numerous designs for wireless MAC protocols based on time division multiplexing have been suggested, while some of them need global topology information that may not be scalable for large-size networks [4]. However, many distributed slot assignment schemes, such as DRAND [5], PACT [6], and TRAMA [7] have been proposed to overcome the difficulty of obtaining global topology information in the large networks. Specifically, [8] proposed to show the joint the maximum throughput for inter-connect and the allocation for fair rate in a WSN by taking into consideration the TDMA based on slot reuse.

## III. PROPOSED MAC PROTOCOL

This section describes the design of an efficient schedule algorithm. The proposed MAC method focuses on increasing sleep periods; thus, reducing overhead, and overhearing, avoiding collisions and hidden as well as exposed terminal problems, as shown in Figure 1.

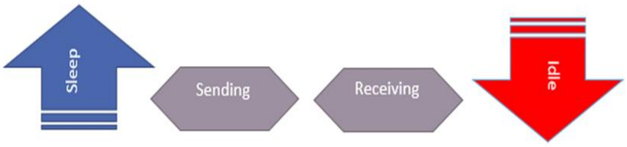


Figure 1: The main objectives of the proposed MAC method with respect to power consumption

The proposed MAC employs a distributed scheme by selecting a temporary admin node to schedule transmissions based on the nodes' high-level layer status. Then, this admin node distributes the shifts schedule (shifts table) to nodes in its cluster. This hierarchical algorithm has the advantages of improving network robustness and flexibility [9]. The proposed MAC algorithm consists of three sub-protocols: The Cluster Status Protocol (CSP), the Schedule Protocol (SP), and the Adaptive Protocol (AP). For both data and signaling, the proposed MAC protocol assumes a single time-slotted channel. Since this method specifies special ID for each node in the cluster, the node can directly communicate with other nodes by sending a dynamic wake-up packet that carries specific ID for the intended node (destination). The operation of the proposed MAC protocol is divided into rounds. The CSP sub-protocol is the beginning of each round when it is organized in clusters, followed by SP sub-protocol and ends up with AP sub-protocol, as illustrated in Figure 2. The following subsections provide the detailed description of the proposed MAC protocol.

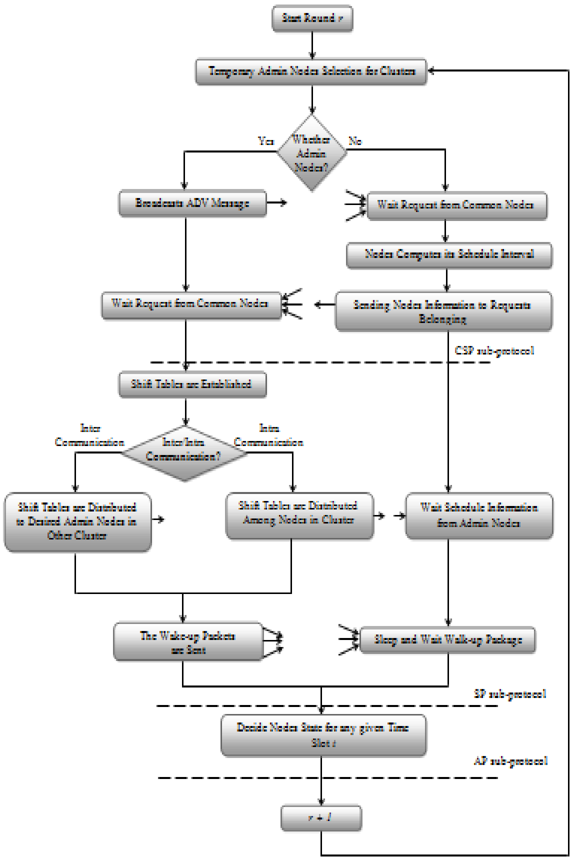
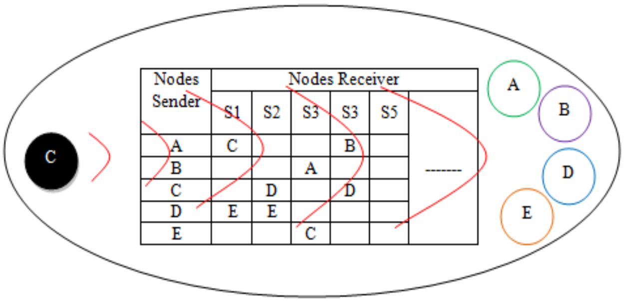


Figure 2: Flow Chart and Functional Architecture for MAC Protocol

### A. *Cluster Status Protocol (CSP)*

To form the clusters, CSP uses a distributed algorithm since the sensor nodes make independent decisions to elect a temporary admin node without any centralized control. This admin node produces shifts tables to organize data transmissions based on the nodes' loads and priorities during time slots. Figure 3 shows an example of one cluster for WSN, which consists of five nodes A, B, C, D and E. Node C is the temporary admin node for the current random access period.



| Nodes Sender | Nodes Receiver | | | | | |
|---|---|---|---|---|---|---|
| | S1 | S2 | S3 | S3 | S5 | |
| A | C | | | B | | ------- |
| B | | | A | | | |
| C | | D | | D | | |
| D | E | E | | | | |
| E | | | C | | | |

Figure 3: The temporary admin node "C" distributes the shifts schedule for nods in its cluster

In this clustered network, admin nodes in each cluster are more intensive than non-admin nodes. Given round r, and at the beginning of round r + 1, each sensor node i elects itself to be admin node that starts at time t with probability $P_i(t)$. Equation 1shows the chosen $P_i(t)$ since k is the cluster admin nodes expected number for the round r is in a network with N nodes.

$$E[\#Admn] = \sum_{i=1}^{N} P_i(t) = k \tag{1}$$

where, E[#Admn] is the admin nodes expected number for round r and N is a network nodes number.

In general, ensuring that all nodes are the admin nodes that will take the same time, which subsequently requires the admin to be an admin node once in N/k rounds on average. As shown by Equation 2, $C_i(t)$ is initialized to 1, at the time t if the node is eligible to be an admin node otherwise, $C_i(t)$ is valued as 0.

$$P_i(t) = \begin{cases} \dfrac{k}{N - k * \left(r \bmod \dfrac{N}{k}\right)} & : \ C_i(t) = 1 \\ 0 & : C_i(t) = 0 \end{cases} \tag{2}$$

The probability of selecting an admin node is based on all nodes that have data packet to be sent, as well as all the assumptions that all sensor nodes start with equal initial energy. On the other hand, selecting an admin node between the nodes with different energy is successfully designed by selecting the highest energy nodes to ensure that all nodes die approximately at the same time. Equation 3 is the probability of the node being an admin node as the node's energy level function. $E_i(t)$ is illustrated as the node *i* current energy, and $E_{total}(t)$ is represented by Equation 4.

$$P_i(t) = \min\left\{\frac{E_i(t)}{E_{total}(t)} k, 1\right\} \tag{3}$$

$$E_{total}(t) = \sum_{i=1}^{N} E_i(t) \tag{4}$$

By using a non-persistent carrier-sense multiple access (CSMA) MAC protocol [10], each admin node broadcasts an advertisement message (ADV) during the random access period. In fact, this ADV message is a small message that contains the node's ID and the header, which make this message as an announcement message.

Each node must inform the cluster admin node that it will be a member of the cluster after it has determined its cluster by exchanging small signalling packets during the random access period. These packets are short packets, as shown by Fig.4. In CSP sub-protocol, each node computes the interval of schedule based on the rate that packets are produced by the higher layer application.

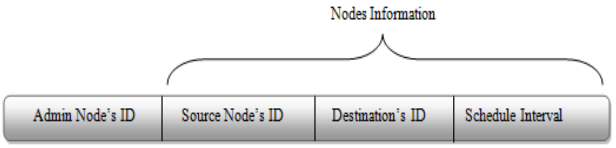


Figure 4: Signalling packet format

Clustering scheme for the proposed MAC protocol organizes the sensor nodes of the network into two virtual domains. The first domain is the intra-cluster, and the second is the inter-cluster domains. In the intra-cluster domain, communication between the nodes is scheduled by the admin nodes within the cluster (single hop) or through other nodes (multi hop). The other characteristic for the proposed MAC protocol is utilized to achieve high energy efficiency in the intra-cluster domain, where the radio channel has high contention. In the inter-cluster domain, the communication is between separated clusters, in which each cluster has to choose its admin node, and the admin nodes exchange their shifts tables before distributing them to the clusters.

### *B. Schedule Protocol (SP)*

In SP, the traffic-based schedule information is established and maintained by an admin node, which is required for the transmitter and receiver selection. In the proposed protocol, this schedule is defined as the shifts table.

The proposed method supposes that all nodes should be sleep by default, while the nodes are not active for sending or receiving data. This method improves energy efficiency while the node calls its destination (or receiving) node by sending a short and dynamic wake-up packet, which is carrying the ID of the intended node.

For network cluster with *N* nodes, the first step in intra-cluster proposed protocol is to count the number of nodes for current transmission $N_c$. Two nodes can directly establish their communication based on their shifts table, which starts with sending wake-up packet in $t_w$ time process. The destination node must be sleeping until it receives a wake-up packet from the sender (refer to Figure 5 and Figure 6).

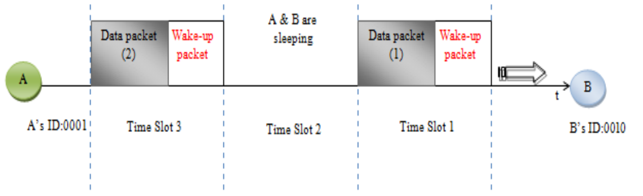


Figure 5: Node A is waking-up and sending to node B at two different slots

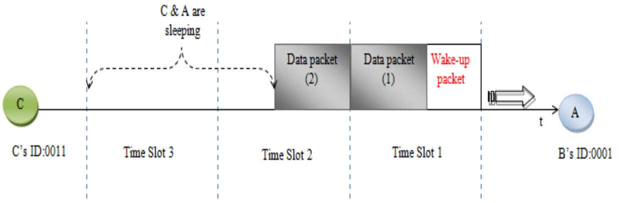


Figure 6: Node C is waking-up and sending to node A at "S1" and sub of slot "S2"

With reference to Figure 6, it is possible for a node to get some extra sub-slots for transmissions as a winning time, since data packet 2 will send to node A without wake-up packets. This process actually increases the sensor performance in terms of avoiding overhead and overhearing cost. The transmission time for sending a single data packet between two nodes is computed by Equation 5. Equation 6 is a generalization to compute the transmission time for the $N_c$ nodes at the same time.

$$t_x = (t_a + t_w) \tag{5}$$

$$t_c = \sum_{i=0}^{N} t_{a-i} + t_{w-i} \tag{6}$$

where $t_x$ is the transmission time for sending a single data packet between two nodes, ta is the time to access node, $t_w$ is the wake-up time, and $t_c$ is the transmission time for the $N_c$ nodes at the same time and *n* is the number of nodes that transmits packets at the same time.

As a distributed shift table based on t transmission time between *N* nodes, the transmission consumption for the *N* nodes is calculated based on Equation 7.

The switching process is also concerned to change the transmission situation between the scheduled nodes. The switching time is defined as ts, and reserved for each transmission situation when the current transmitted nodes are changed.

$$t_N = \sum_{i=1}^{N}((t_{a-i} + t_{w-i}) + t_s) \rightarrow t_N = \sum_{i=1}^{N}(t_c + t_{s-i}) \tag{7}$$

where $t_N$ is the total time to transmit *N* nodes at t time, ta-i is the access time to transmit node *i*, $t_{W-i}$ is the wake-up time node *i* and $t_s$ is the switching time.

However, this case is defined as the best situation since the power consumption is reduced by decreasing over heading problem (refer to Equation 8). This situation is known as a wining case since the communication can win extra time slots.

$$t_{win} = (j-1) \times t_w \,||\, j: \#\text{ of packets} \tag{8}$$

Finally, the power consumption for N communicating nodes is performed by Equation 9. Hence, Toverall is the overall time consumption for N nodes with Q winning cases, where j is the number of the series data packets as mentioned in the winning case.

$$T_{overall} = \sum_{i=1}^{N-[sum(js)]based\ Q} [(t_{a-i} + t_{w-i}) + t_{s-i}] + \sum_{k=1}^{Q} \left[ t_{w-k} + \sum_{i=1}^{j} (t_{a-k-i} + t_{s-k-i}) \right] + \sum_{i=1}^{N} t_{ACK-i} \quad (9)$$

where: *N*: # of the scheduled packets; *Q:* # of the winning cases; the variable *j*: # of packets for the current best case and TACK is the time needed to receive the ACK for all data packets.

### C. *Adaptive Protocol (AP)*

For energy efficiency, the protocol switches the nodes to sleep state whenever possible, and attempts to re-use the slots. In case of selected node by shifts tables that do not have any packets to send, it may give up its transmission slot, and this slot could then be used by another node.

Possible states for each sensor nodes in the network are transmit ($T_X$), receive ($R_X$), and sleep (SL). This means that at any given slot *t* a node A is in the TX mode if achieved one or both of the following conditions: (1) A has the highest priority to send its packet i.e., prio (A, *t*) among its competing set; and (2) A has packet to send. Regarding the $R_X$ mode achieved when node A is the intentional destination of the current transmitter. Other than that, a node is switched off to the sleep at SL state. Therefore, each node that executes AP has to decide its current mode ($T_X$, $R_X$, or SL) based on the current node priorities and also on announced schedules.

However, the proposed MAC protocol takes into account the nodes, which could use extra slots to send their sensed data, especially the set of nodes that can possibly transmit at the current time slots computed by an admin node. If the node has followed its shifts table, then it can transmit without collisions in traffic.

## IV. SIMULATION-BASED PERFORMANCE EVALUATION

In this section, the performance of the proposed approach is evaluated through simulation. A simulation is designed and implemented in MATLAB [11] in order to investigate the efficiency of the proposed protocol. The proposed MAC protocol is evaluated and compared against both contention-based and scheduling-based protocols. SMAC [12] is considered as an example of contention-based protocols and WiceMAC [1] is an example of preamble based protocols. TRAMA [7] is used as an example of scheduling-based protocols.

### A. *Performance Metrics and Simulation Parameters*

The proposed protocol is analyzed in terms of packet delivery ratio, network lifetime, delivery delay to the BS, consumed energy and percentage sleep time, in the case of MAC mechanism for various traffic loads. The load is expressed as the average number of new packets per slot. It can be easily expressed as a function of λ, an inter-arrival period of messages for a node. In the experiment, varying λ the traffic load can be changed. If λ = 5s, a message is generated every 5s by each source node. In this experiment, λ are varied from 1s to 5 s. In the case of the highest rate that a 1-s inter-arrival time; the wireless channel is nearly fully utilized because it has low bandwidth.

The paper assumes the same energy consumption is needed to send k-bits from A to B and vice versa. Table 1 summarizes the parameters used in the MATLAB simulator.

Table 1
Simulation Parameters

| Parameter | Value |
|---|---|
| Number of sensor nodes | n= 20 |
| Packet size | k = 4000 *bits* |
| Area | A= M×M = 100×100 |
| GW-node Location | Centre BS (50,50)<br>Corner BS (10,10) |
| Communication model | Bi-direction |
| Transmitter/Receiver Electronics | $E_{elec}$ = 50 *nJ/bit* |
| Initial energy for normal node | $E_o$ = 0.5 *J* |
| Data aggregation energy | $E_{DA}$ = 5 *nJ/bit/message* |
| Transmit amplifier | $\varepsilon_{amp}$ = 10 *pJ/bit/m²* |

### B. *Proposed MAC Protocol Performance Evaluation*

MAC algorithm protocol is tested for the applications of data gathering that are considered as typical of sensor networks. The simulated network is composed of 20 nodes. Although this size of the network is not a typical size for WSN, it is used to enable comparison of the results with those reported in the previous works [1, 7 and 12].

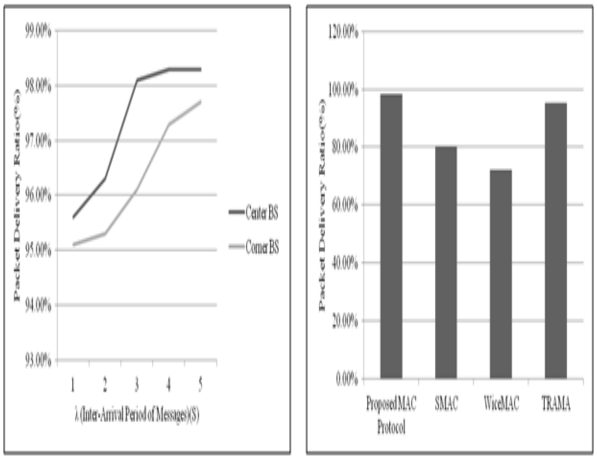
#### 1) *Simulation Results*

Figure 7 (a) shows the packets delivery ratio for the corner BS and centre BS scenarios. Figure 7(b) shows that the schedule-based MAC protocols perform better than contention-based protocols in all cases. Figure 8 (a) and 8(b) show the average end-to-end delay for all protocols.

In terms of delay, the proposed MAC protocol outperforms scheduling-based protocols because the scheduling introduces better latency.

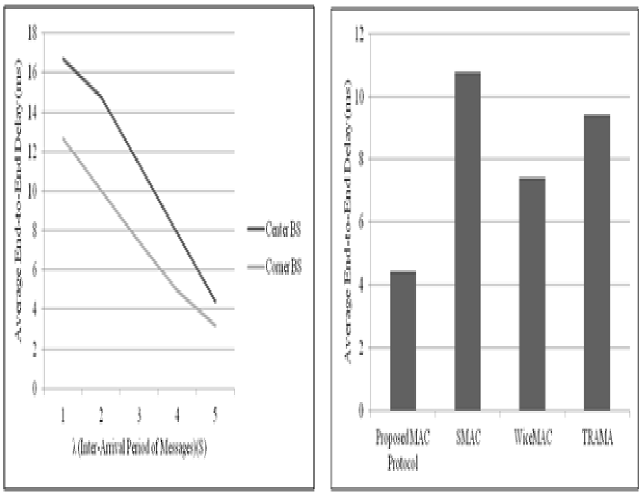
Figure 9 shows the percentage of sleep time. When the traffic load is decreased the sleep time, the percentage of sleep mode for the nodes increases.

The percentage sleep time is quite high (20%) for the corner BS scenario. This clearly shows the benefit of proposed MAC algorithm traffic adaptability compared to TRAMA and S-MAC protocols.



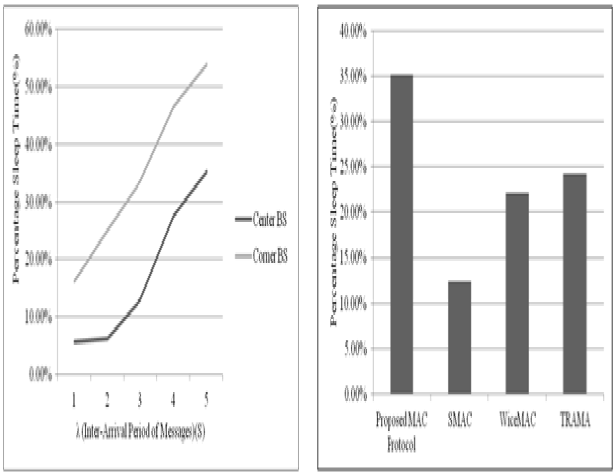
(a) (b)

Figure 7: Packets delivery ratio. (a) Delivery ratio for centre BS and corner BS. (b) Delivery ratio for MAC protocols



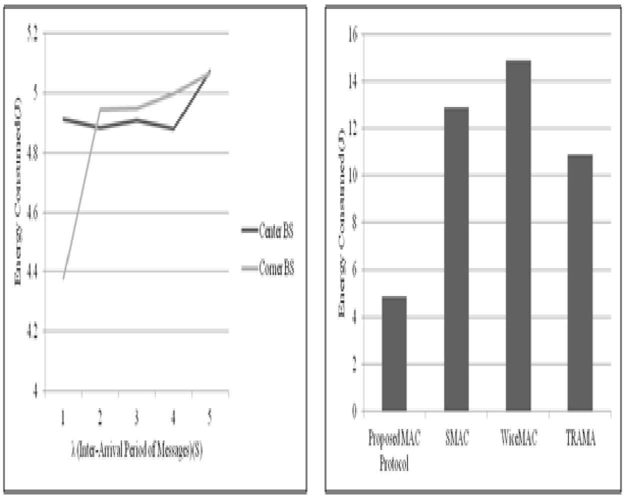
(a) (b)

Figure 8: The average end to end delay. (a) The average end to end delay for centre BS and corner BS. (b) The average end to end delay for MAC protocols.



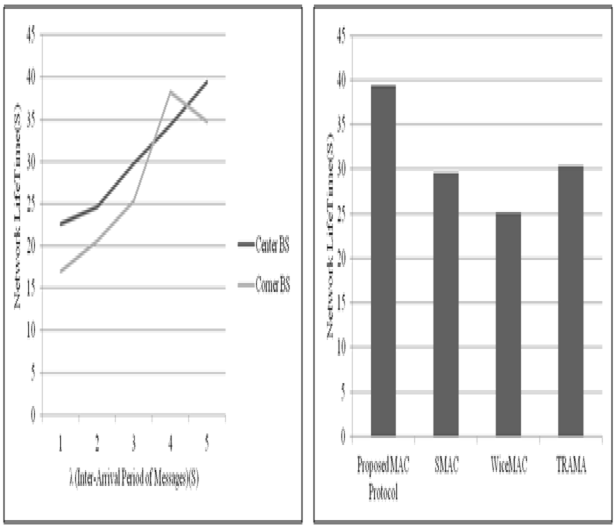
(a) (b)

Figure 9: The percentage of sleep time. (a) The percentage of sleep time for centre BS and corner BS. (b) The percentage of sleep time for MAC protocols.



(a) (b)

Figure 10: The energy consumed. (a) The energy consumed for centre BS and corner BS. (b) The energy consumed for MAC protocols.



(a) (b)

Figure 11: The network lifetime. (a) The network lifetime for centre BS and corner BS. (b) The network lifetime for MAC protocols.

Figure 10 (a) shows the energy consumption for the corner and centre BS scenarios. This energy is approximately equal for both scenarios. Figure 10 (b) shows that the proposed MAC scheme outperforms the schedule-based and contention-based MAC protocols.

Finally, Figure 11 shows the lifetime of the network. Our proposed MAC algorithm has the longest lifetime among other protocols, principally in the case where the BS is in the center.

## V. CONCLUSION AND FUTURE WORK

One of the main serious problems faced wireless sensor networks is providing an efficient communication method, which is considered in this paper. The proposed MAC protocol considered in this paper provides an efficient communication method for WSNs.

The protocol is based on reducing energy consumption and turns the transceiver of sensor nodes into a sleep state when it is not used. The results of the simulation experiment show the efficiency of the proposed MAC protocol in terms of energy consumption and latency. Other interesting characteristics of the proposed MAC protocol is that it allows to reduce some problems, such as idle listening and collision, which possibility cause the sources of energy wastage. From the simulation results, it is clear that a significant energy savings can be achieved by the proposed MAC protocol (where the nodes can sleep for up to 53% of the time) depending on the offered load. The protocol also achieves higher throughput (around 18% over S-MAC and around 26% for CSMA) when compared to contention-based protocols since it avoids collisions due to hidden terminals. The overall conclusion is that the proposed MAC protocol is proven the best performance for applications like the military where energy consumption is not much to be bothered and more performance is required.

As future work, an admin node selection mechanism that may improve the protocol can be investigated. Further, we would like to propose cross-layer designs that consider the proposed MAC protocol at the medium access control layer.

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