

# A New Mac Protocol for Minimizing Energy Consumption in Multi-Hop Wireless Sensor Networks

Naveen Chauhan, Rakesh Bisht

Department of Computer Science & Engineering, National Institute of Technology, Hamirpur, H.P. India  
navenchuhannit@gmail.com, rakeshbisht534@gmail.com

## Abstract

Multi-hop wireless sensor networks are designed for environment surveillance, wherein sensor nodes are deployed in a special environment and are powered by a limited battery. The lifetime of a multi-hop WSN depends on the durability of the sensor nodes battery resources. In this paper, we proposed the designing of a new MAC protocol that allowing the sensor nodes to sleep more under light loads for conserves energy in a multi-hop WSN. The concept of our protocol is quorum-based mechanism and analytical model that can accurately estimating the per-sensor node communication traffic-load of a sensor node. We consider a scenario, wherein the sensor nodes periodically sense the environment and forward the collected data to a sink using greedy geographic routing protocol. We evaluate our implementation of MAC protocol in NS-2. The simulation results showed that our MAC protocol conserved more energy with the low transmission latency and significantly prolong the lifetime of a multi-hop WSNs.

**Keywords**-Grid-based quorum, Greedy geographic routing protocol, Homogenous poisson point process, Medium access control, Per-sensor node communication traffic-loads and Multi-hop wireless sensor networks.

## I. INTRODUCTION

Wireless Sensor Networks (WSNs) have become an active research area for the researchers of this decade (2000-2010) due to their rapidly and widely using range of application areas such as: defence and scientific applications, target detection and tracking, wildlife habitat and environmental monitoring, industrial process

monitoring, medical systems and robotic exploration, climate control and disaster management, as in [1]. WSNs are consist of one or more battery-operated sensor nodes with single chip embedded processor for processing unit, low-power radio for wireless communication unit and small amount of processing memory unit. Usually, these sensor nodes will have to work on their own with their limited energy resources, once they deployed in the remote areas. Problem in WSNs is that the lifetime of these WSNs are limited because there lifetime is directly dependent on lifetime period of battery-powered sensor nodes. Therefore, energy consumption of sensor nodes should be minimize because battery powered is the only energy source to power these sensor nodes, i.e. lower the energy consumption longer the lifetime period of sensor networks. Prolonging the lifetime period of WSNs is our first priority form all types of energy constrained in WSNs because it is often not possible to recharge or replace the exhausted energy resources batteries of sensor nodes. There is two ways to extend the lifetime of networks, one is hardware level and other is software level. At hardware level most of the research is focused on improvements in the design of low-power and low-cost electronic sensor devices. This can also achieve by increasing battery power and by making energy-efficient networks. In order to overcome the limitations in the hardware, researchers work at the software level in which energy-efficiency can be achieved through the design of various energy-efficient protocols. In a sensor node, there are three activities: sensing, computation and radio operations which are main sources of energy consumption. Out of these, most energy consume unit of a sensor node due to wireless radio operation for data transmission is the maximum one, as in [2]. That is why the primary objective in WSNs design is maximizing

sensor network lifetime, leaving the other performance metrics as secondary objectives. During communication sensor node operates in four different state are: transmit, receive, idle and sleep, as in [3]. However, all the active states consume almost the same amount of energy but the most energy is wasted during the idle listening state.

Energy conservation in communication can be performed in different layers of the TCP/IP protocol suit, so researchers have focused on different layers to conserve energy more effectively. Energy conservation at Medium Access Control (MAC) layer is found to be the most effective one due to its ability to control the wireless radio operations directly, as in [4]. Also, MAC layer involves in the function and procedure necessary to transfer data between two or more sensor nodes in the network. This layer is used to coordinate sensor node access to the shared wireless medium. The MAC layer provides fine-grained control of the transceiver, and allows switching the wireless radio on and off. How frequent and when such switching have to be performed is the major goal of an energy saving mechanism of the MAC layer. It should maximize the sleep duration of the sensor node, while preserving the highest throughput, the minimum latency, and the maximum energy conserving in a WSNs. One of the main functions of the MAC protocol is to avoid collisions from interfering sensor nodes. While traditional MAC protocols are designed to maximize packet throughput, minimize latency and provide fairness, but MAC protocol design for WSNs focuses on minimizing energy consumption. If we want to ensure for extend the lifetime of WSNs, this can done by the using of good characteristics energy-saving MAC protocols. This type of MAC protocol reduces the power consumption of sensor node and able to improve energy-efficiency by maximizing sleep duration, minimizing idle listening and overhearing, and eliminating collision of packets. Now there are various MAC protocols exist, but there is no standard energy-saving MAC protocol for WSNs because WSNs are application specific. In this paper, our objective to design a most and efficient energy-saving MAC protocol in which wake-up frequency of each and every sensor node purely directed according to per-sensor node communication traffic-load. Also, we intend to work on energy-saving MAC protocol for

WSNs which takes care of proper limited energy resources, maximize power-efficiency and reduce latency.

The rest of this paper is organized as follows. In Section II, we present some related work in the area of MAC protocols for WSNs. We describe our system model with assumptions and the problem to be solved is presented in Section III. A detailed description for designing our proposed MAC protocol is presented in Section IV. Section V presents the simulation results and finally, conclusion the paper is drawn in Section VI.

## II. RELATED WORK

MAC is critical for enabling successful network operation in all shared medium networks. The primary task of a MAC protocol is to arbitrate access to a shared medium or channel in order to avoid collision and at the same time to fairly and efficiently share the bandwidth resources among multiple sensor nodes. According to the underlying control mechanism for collision avoidance, MAC protocols can be typically classified into two broad categories: contention-based and contention-free. In this section, we introduce various MAC protocols for WSNs, including contention-based and contention-free MAC protocols.

### A. Contention-Based MAC Protocols

In contention-based MAC, all sensor nodes share a common medium and contend for the medium for transmission. Thus, collision may occur during the contention process. To avoid collision, a MAC protocol can be used to arbitrate access to the shared channel through some probabilistic coordination. Here introduces several contention-based MAC protocols that have been proposed for WSNs.

- Sensor-MAC (S-MAC)

S-MAC protocol is modification of IEEE 802.11 protocol specially designed for the WSNs, as in [5]. In S-MAC, the sensor node periodically goes to the fixed listen/sleep cycle. The time is divided into frames and each frame consists of two parts: listening period and sleeping period. During the listening period, it communicates with the neighbors and sends messages. During sleeping period it turns the radio off to conserve energy. The S-MAC uses

RTS (Request to send), CTS (Clear to send), DATA, and ACK (Acknowledgement) signaling schemes of IEEE 802.11 to reduce the number of collisions. The neighboring nodes synchronize together using the SYNC packet which contains the time of its next sleep. The authors of S-MAC also introduce adaptive listening into its original design to reduce its end-to-end latency by half, as in [6].

- Timeout-MAC (T-MAC)

T-MAC is an adaptive energy-efficient MAC protocol, which is an extension of S-MAC, is to reduce idle listening by automatically adopts a dynamic duty cycle based on the traffic load, as in [7]. The active period is preempted if no activation event has occurred for a time " $T_a$ ". The activation event can be reception of data, start of listen/sleep frame time, end of transmission of a sensor nodes own data packets or acknowledgement, etc. The time  $T_a$  is the minimum amount of idle listening per frame. In this protocol, the sensor nodes often go to sleep too early. It includes two measures to alleviate this so called early sleeping problem but favours energy efficiency over latency much more strongly. The energy consumption in T-MAC protocol is less as compared to the S-MAC protocol.

- Data-Gathering MAC (D-MAC)

D-MAC is an energy-efficient and low-latency MAC protocol for data gathering in WSNs that uses an adaptive duty cycle, as in [8]. By staggering active times along the data-gathering tree, DMAC reduces the transmission latency in a many-to-one communication model. DMAC achieves better performance in transmission latency, throughput, and energy conservation when compared with S-MAC. However, similar to S-MAC and T-MAC, DMAC still has to wake up all the sensor nodes at every cycle. This is not energy efficient since light-loaded nodes may remain idle in most cycles

- Quorum-Based MAC (Q-MAC)

Q-MAC protocol aims to reduce power consumption and determine the sleep frequency for each sensor node based on its own traffic load, as in [9]. Each sensor node randomly and independently selects one row and one

column as its quorum set. In Q-MAC, power saving is achieved by reducing the number of wake-up time frames. It use a quorum set to represent the time frames wherein a sensor node must wake up. However, during these wake-up time frames, a sensor node does not always stay awake for the entire time frame. A sensor node can go to sleep whenever it identifies that another transmission that it is not involved in is activated. By choosing grid sizes based on each sensor nodes individual traffic load, QMAC solves the fixed-listen/sleep-frequency problem.

## B. Contention-Free MAC Protocols

In contention-free MAC, a shared medium is divided into a number of sub-channels in terms of time, frequency or orthogonal pseudo-noise codes. These sub-channels are allocated to individual sensor nodes with each sensor node occupying one sub-channel. This allows different sensor nodes to access the shared medium without interfering with each other and thus effectively avoids collision from different sensor nodes. Here introduces several contention-free MAC protocols that have been proposed for WSNs.

- Traffic-Adaptive Medium Access (TRAMA)

TRAMA protocol is a TDMA based MAC protocol proposes to provide energy-efficient collision-free channel access in WSNs while maintaining good throughput, acceptable latency and fairness, as in [10]. In TRAMA, energy-efficiency is achieved by ensuring collision-free data transmissions and allowing sensor nodes to switch to a low-power idle state when they are not transmitting or receiving. To maintain throughput and fairness, TRAMA uses a transmitter-election algorithm that is inherently fair and promotes channel reuse as a function of the competing traffic around a given source or receiver.

- CDMA Sensor MAC (CS-MAC)

CS-MAC protocol is a self-organizing location-aware MAC protocol proposed for DS-CDMA based sensor networks, which is suitable for applications with high traffic and stringent latency requirements, for example, battlefield surveillance, as in [11]. The design objectives

of the CS-MAC protocol include energy-efficiency, low latency, fault tolerance and scalability. The assumptions for the protocol design include the following: (1) each sensor node starts up at approximately the same time, (2) each sensor node is able to estimate its location using GPS or alternate techniques, (3) each sensor node is static during the network lifetime, which implies that the estimation of its location only needs to be performed once and thus the energy consumption for the location estimation can be ignored.

### III. PRELIMINARIES

#### A. Network Model

As a starting point, we consider a bounded circular sensing plan network area with a 2-D planar topology, with the sink at the center of the network area. Mostly MAC protocols are most optimal when there is uniform density of sensor nodes in the sensing network area. So, Fig. 1 shows that sensor nodes are deployed according to a homogeneous poisson point process with a uniform density of  $\rho$  sensor nodes/m<sup>2</sup> all around the sink. Consider, there are 60 sensor nodes which are labeled by 1,2,3,..., 60 and along with a sink labeled 0. The sensor nodes sense the data of interest and transmit these data to the sink. Depending on the distance of a sensor node from the sink and the transmission range of the sensor node, data have to traverse single or multiple hops before being received by the sink.

In this paper, we made the following simplifying assumptions:

- The sensor nodes are randomly and uniformly distributed in a bounded circular plane network area with the common sink situated at the centre.
- Each sensor node has a unique ID.
- All sensor nodes have identical transceivers with same transmission range and the wireless links are assumed to be symmetric.
- Time of an each sensor node is divided into a number of series time frames.
- All sensor nodes are time synchronized and static after deployment.
- All sensor nodes periodically generate their data packets with the same periodicity containing the

relevant sensed data and report the data packet towards the common sink without any data aggregation.

- The network is dense enough such that greedy geographic routing protocol always succeeds in finding a next hop sensor node that forwarded the data packet towards the sink.

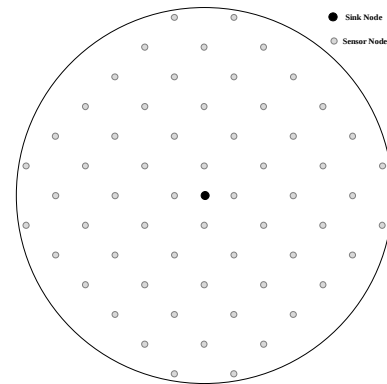


Fig. 1. Sensor Network Setup used for Our Proposed MAC Protocol.

- Packet loss rate is  $q$  and it is uniform for all data transmissions.

#### B. Problem Statement

There are various existing energy-saving MAC protocols for WSNs such as: S-MAC, T-MAC, D-MAC, Q-MAC and TASL-MAC protocols as in [5,7,8,9,12]. These MAC protocols are not most energy-efficient because there is number of limitations in every MAC protocols. Out of these, few MAC protocols (S-MAC, T-MAC and D-MAC) are follow the concept of regular active/sleep mechanism. One of the problems of sensor nodes running in S-MAC, T-MAC, and D-MAC protocols is that they have to wake-up at every time-frame to check if there is pending traffic or not, which is most wastage of energy i.e. idle state. Since each sensor node have different traffic-loads means sensor nodes that are closer to the common sink are the heavy loaded ones and all sensor nodes adopting the same time-frame to active/sleep are not energy-efficient. Where, other MAC protocols (Q-MAC and TASL-MAC protocols) which are able to adjust the sensor nodes sleep duration according to their traffic-loads. Problem is that the traffic-load which is

used by these MAC protocols is not calculated mathematically, it is just an assumption traffic-load. Due to this, these MAC protocols are not purely adjust sensor node active/sleep duration according to per-sensor node communication traffic-loads. Therefore, there is need of an energy-efficient MAC protocol that able to adjust each and every sensor node active/sleep time-frames purely determine according to mathematical calculated per-sensor node communication traffic-loads.

#### IV. PROPOSED PROTOCOL DESCRIPTION

In the following section, we first briefly introduce the concept of a grid-based quorum, then analysis of per-sensor node traffic-load and finally, we present the details of our proposed traffic-load adaptive power-conserving MAC protocol achieves power conservation for WSNs.

##### A. Grid-Based Quorum Concept

A quorum is a request set that enables some actions if permission is granted, as in [13]. Typically, there are always non-empty intersections between any two quorum sets. There are many kinds of quorums, here, we use grid-based quorum to implement our MAC protocol, as in [14,15]. In this paper, a quorum time-frames set represents the time-frames wherein a sensor node must wake up. For non-quorum time-frames set, sensor nodes are allowed to enter sleep mode for the entire time-frame to conserve energy. Based on a quorum's properties, therefore it is guarantee that any two sensor nodes can wake up and meet each other at some time-frame.

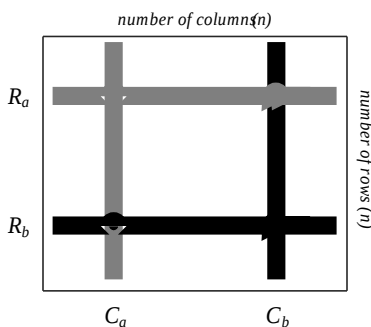


Fig. 2. Example of Grid-Based Quorum

Fig. 2 shows an example of grid-based quorum in which  $n^2$  continuous time-frames represented by an  $n \times n$  grid in a left-to-right and top-to-bottom manner. In a grid-

based quorum, one row and one column are selected from an  $n \times n$  grid as a quorum time-frames set for each sensor node. Example of quorum time-frame selection, where sensor node A selects row  $R_a$  and column  $C_a$  as its quorum time-frames set, while sensor node B selects row  $R_b$  and column  $C_b$ . In this way, we get the quorum time-frames set of each sensor node in which a sensor node must wake up. There are two intersections between sensor nodes A and B, one at  $R_a$  and  $C_b$  and the other at  $C_a$  and  $R_b$ . As mentioned that, sensor nodes must wake up at their chosen quorum time-frames sets. This means that both sensor nodes will wake up at these intersection points, as in [16].

##### B. Calculation of the Per-sensor node Traffic-Load

In this paper, the traffic-load of a per-sensor node is defined as the average number of data packets transmitted by the sensor node at a distance during one time unit, as in [17]. Fig. 3 shows a bounded circular shaped network of radius  $l$  with the sink located at the centre. The traffic-load of a sensor node located at a distance  $d$  from the sink during one time unit,  $f(d)$ , is given by,

$$f(d) = \frac{S_t(d)}{\pi(2d+\epsilon)\epsilon\rho} \frac{1}{1-q} \quad (1)$$

where  $S_t(d)$  is given by,

$$S_t(d) = \begin{cases} \pi(2d+\epsilon)\epsilon\rho & \text{if } d=l, \\ \pi(2d+\epsilon)\epsilon\rho + \sum_{i \in (d,l)} P_{i,d} \int_0^1 (i) & \text{if } 0 < d < l \end{cases} \quad (2)$$

and  $P_{i,d}$  denotes the state transition probability for each radio model. Based on this state transition probability  $P_{i,d}$ , we can calculate the accurate traffic-load incurred at the individual sensor nodes.  $P_{i,d}$  for the ideal and log normal radio model have been derived respectively. Here,  $S_t(d)$  is a recursive function. Since, we know  $S_t(l)$ , the initial value of  $S_t(d)$ , we can calculate  $S_t(l - \epsilon)$  according to using (2). Similarly,  $S_t(l - 2\epsilon)$  and so on can be derived. Finally, for any given  $d$ ,  $S_t(d)$  can be computed, following which, we can calculate  $f(d)$  using (1). Equation (1) derives the traffic-load of all sensor nodes excluding the common sink because the sink exclusively acts as a

receiver. Hence, the traffic-load of the sink is zero. The symbols used are listed in Table I, as in [17].

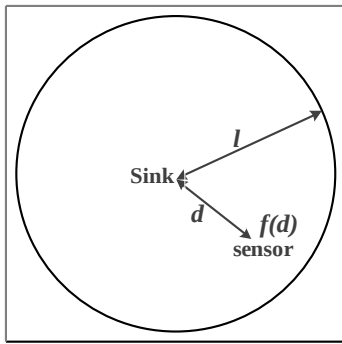


Fig. 3. Example of Circular Shaped Plane Network Area

TABLE I  
LIST OF SYMBOLS USED IN CALCULATION

Symbol	Definition
$\epsilon$	Quantization interval
$\rho$	Node density, i.e. the number of nodes per unit area
$i, j, d$	Euclidean distance from a sensor node to the centrally located sink
$P_{i,d}$	State transition probability, i.e. the probability that a sensor node at distance $i$ from the sink can forward its packets to the sensor node at distance $d$

Finally, we reach where we know the exact traffic-load of per-sensor node in WSNs. Now with the help of this mathematical calculated traffic-load we select the accurate grid size of each sensor node. As a result, it increases the sleep duration of each sensor node by which we save a lot of energy wastage in idle state.

### C. Traffic Adaptive Power-Conserving MAC Protocol

In our proposed MAC protocol, we select accurate grid size of sensor node purely according to its communication per-sensor node communication traffic-load (PSCT), which is calculated mathematically. The idea behind our proposed MAC protocol is to increase a sensor node grid size, in order to prolong its sleep duration when its traffic-load is light and to decrease its grid size, making it wake up more frequently, when its

traffic-load is heavier. In our protocol, to facilitate implementation, we defined six (may be more, user depended) traffic-load thresholds: Threshold<sub>1</sub>, Threshold<sub>2</sub>, Threshold<sub>3</sub>, Threshold<sub>4</sub>, Threshold<sub>5</sub> and Threshold<sub>6</sub>, which mean seven grid sizes can be selected for the sensor nodes in our proposed MAC protocol as shown below:

If  $PSCT \geq \text{Threshold}_1$ , we select  $1 \times 1$  grid size,

If  $\text{Threshold}_1 \geq PSCT \geq \text{Threshold}_2$ , we select  $2 \times 2$  grid size,

If  $\text{Threshold}_2 \geq PSCT \geq \text{Threshold}_3$ , we select  $3 \times 3$  grid size,

If  $\text{Threshold}_3 \geq PSCT \geq \text{Threshold}_4$ , we select  $4 \times 4$  grid size,

If  $\text{Threshold}_4 \geq PSCT \geq \text{Threshold}_5$ , we select  $5 \times 5$  grid size,

If  $\text{Threshold}_5 \geq PSCT \geq \text{Threshold}_6$ , we select  $6 \times 6$  grid size,

And If  $\text{Threshold}_6 \geq PSCT$ , we select  $7 \times 7$  grid size.

In our MAC protocol, at some point the latency increased dramatically when every sensor node packet arrival rate exceeded, says 10 Kbps, as in [16]. We considered the network environment to be overloaded when each sensor node traffic load was more than 10 Kbps; thus, we set grid size to  $1 \times 1$  when its traffic-load exceeded 10 Kbps. That is, we set Threshold<sub>1</sub> to be 10 Kbps. The number of thresholds and their values can be adjusted according to different per-sensor node communication traffic-loads (PSCT).

When the per-sensor node traffic-load decreases, a sensor node wake-up time-frames should also be reduces. Above describe thresholds Threshold<sub>2</sub>, Threshold<sub>3</sub>, Threshold<sub>4</sub>, Threshold<sub>5</sub> and Threshold<sub>6</sub> are defines as being proportional to the wake-up frequency, when compared to a  $1 \times 1$  grid size. In an  $n \times n$  grid, for each sensor node we select  $2n-1$  time-frames among the total number of  $n^2$  time-frames as the quorum set. That is, a sensor node with a grid size of  $n \times n$  wake-up at the fraction of  $(2n-1)/n^2$ , compared to a sensor node with a  $1 \times 1$  grid size. When a sensor node packet arrival rate is reduced to  $(2n-1)/n^2$ , when compared to being overloaded, we should also increase its grid size to  $n \times n$ ; this implies

$$\text{Threshold}_2 = 10 \times \frac{2 \times 2 - 1}{2^2} = 10 \times \frac{3}{4} = 7.5 \text{Kbps}$$

$$\text{Threshold}_3 = 10 \times \frac{2 \times 3 - 1}{3^2} = 10 \times \frac{5}{9} = 5.555 \text{Kbps}$$

$$\text{Threshold}_4 = 10 \times \frac{2 \times 4 - 1}{4^2} = 10 \times \frac{7}{16} = 4.375 \text{Kbps}$$

$$\text{Threshold}_5 = 10 \times \frac{2 \times 5 - 1}{5^2} = 10 \times \frac{9}{25} = 3.6 \text{Kbps}$$

and

$$\text{Threshold}_5 = 10 \times \frac{2 \times 5 - 1}{5^2} = 10 \times \frac{9}{25} = 3.6 \text{Kbps}$$

With these settings, a sensor node can select the best grid size, purely according to per-sensor node traffic-load, in order to achieve most and efficient power-conserving MAC protocol. Also, the grid allocation rules must still be followed and with legal grids, two sensor nodes with different grid size will intersect with each other, as in [16]. Means, sensor node with small grid size wakes up more frequently than sensor node with large grid size, therefore sensor node with small grid size have intersections during sensor node with large grid size quorum group.

## V. SIMULATION RESULTS

In this section, we implemented a simulator using ns-2 to evaluate the performance of proposed MAC protocol, as in [18]. In our simulations, 60 sensor nodes were randomly placed within a bounded circular sensor network of radius  $l = 100\text{m}$  and assume that sensor nodes are deployed with a sensor node density  $\rho = 0.0019$ . The average radio transmission range of each sensor node is  $R = 25\text{m}$ , with the channel capacity being 10 kbps. All the sensor nodes after deploy were assumed to have no mobility and a sink is situated at the center of the sensor network. Packet size was set to 128 bytes and each sensor node generates a one new packet in every 2.5 seconds. A spot in the following figures shows an average of 5 simulations, with each simulating for 600 seconds. We employed the energy consumption model described in [8], where the parameters used in the simulations are listed in Table II.

Below, we made observations from different aspects.

### A. Comparison between proposed MAC protocol and SMAC w.r.t. following factors.

- Energy Consumption Comparison

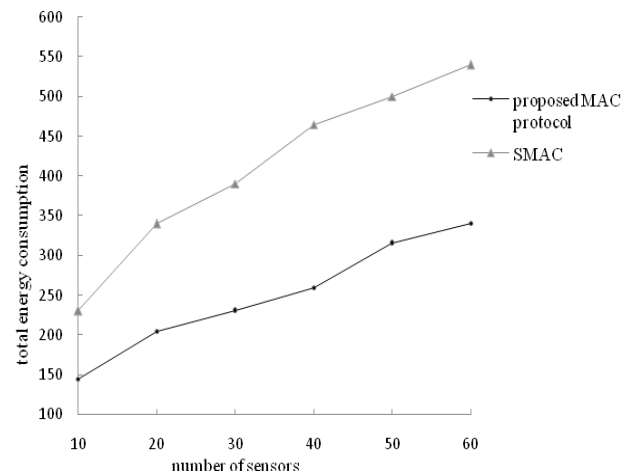
We compare the energy consumption of proposed MAC protocol and SMAC with different number of sensor nodes (10,20,30,40,50,60).

TABLE II

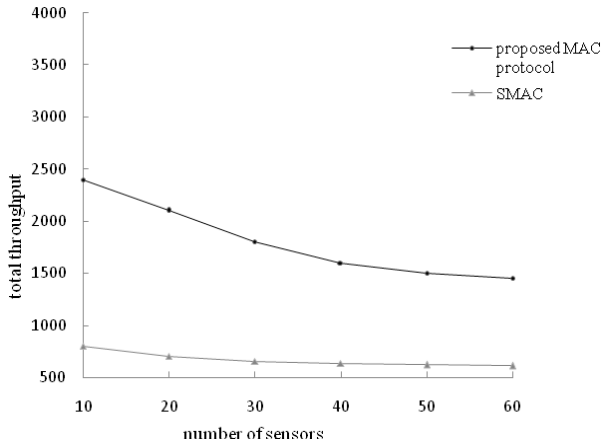
RADIO PARAMETERS USED IN OUR SIMULATIONS

Parameter	Value
Initial energy of each sensor node	50 Joules
Transmission power	0.66 Watts
Receiving power	0.42 Watts
Idle power	0.34 Watts
Sleep power	0.0 Watts

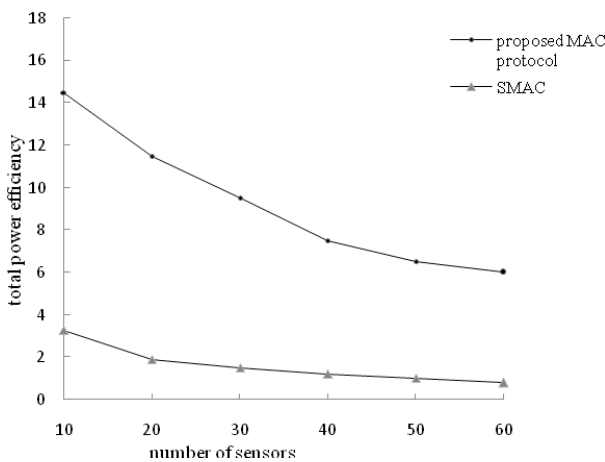
The total energy consumption is measured using the sum of energy consumed by all the sensor nodes on the data transmission. All the sensor nodes generate data packets and transmit to the sink in multi-hop communication manner, which is located at the center of the sensor network. Fig. 4(a) shows SMAC consume more energy than our proposed MAC protocol.



(a) Comparison of Total Energy Consumptions



(b) Comparison of Total Throughput



(c) Comparison of Power Efficiency

Fig. 4. Comparison of energy consumptions, throughput and power efficiency between proposed MAC protocol and SMAC with various network size

- Throughput Comparison

Here, we compare the total throughput of proposed MAC protocol and SMAC with different number of sensor nodes (10,20,30,40,50,60). The throughput is the ratio of the traffic-load arrived at the sink to the traffic-load sent by the sources. Fig. 4(b) shows that our proposed MAC protocol achieves a much higher throughput than SMAC. This is because in SMAC, sensor nodes have to go to sleep periodically even when the traffic-load is heavy.

- Power Efficiency Comparison

Power efficiency, which is the throughput achieved per unit of energy consumed, is given as: Power efficiency= (total throughput)/(total energy consumption). Fig. 4(c) compares proposed MAC protocol and SMAC in terms of their power efficiency with different number of sensor nodes (10,20,30,40,50,60).

### B. Impact on live sensor nodes

Next, we investigated the performance of the proposed MAC protocol in terms of how much they can extend the network lifetime. The criterion used here was the fraction of alive sensor nodes. Our simulation was carried out for 600 seconds and the number of living sensor nodes was recorded every 50 seconds. Here, we want to explore the best results that each energy-saving MAC protocols could archive, under a zero traffic-load. Fig. 5 shown the results, our proposed MAC protocol significantly extended the potential network lifetime, when compared to the SMAC. SMAC does not conserve much energy because a lot of idle listening is produced, but in the case of our proposed MAC protocol a lot of energy is saving at the state of idle listening by reducing the number of time period of idle listening. At a simulation time of 150 seconds, some sensor nodes running SMAC have depleted their energy. For sensor nodes running proposed MAC protocol, energy depletion does not happen until a simulation time of 200 seconds. Moreover, most of our proposed MAC protocol conserved more energy than the SMAC. Also, sensor nodes that run SMAC exhaust their energy at a time of 350 seconds. At the same time, all sensor nodes that run proposed MAC protocol remain alive.



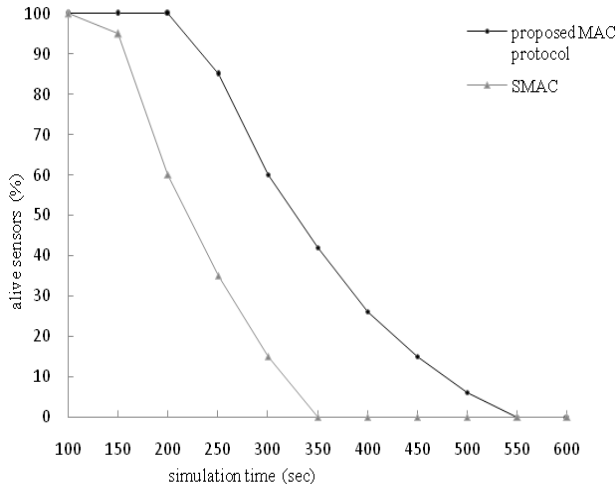


Fig. 5. The effect of proposed MAC protocol and SMAC on the fraction of alive sensor nodes

## VI. CONCLUSION

In our research, energy conservation and transmission latency is crucial issues in multi-hop WSNs. In multi-hop WSNs, sensor nodes closer to the sink are expected to drain their energy at a faster rate because the traffic-loads of a sensor node continuously increases with the proximity to the sink. In this paper, we have focused to solve the problem of idle listening in multi-hop WSNs. We have proposed a new energy conserving MAC protocol that focus on to minimizing energy consumption. In our scenario, sensor nodes have different traffic-loads due to their different distances to the sink, we have utilizing the quorum property to enable sensor nodes to allow their sleep durations continuously for a long period of time based on their traffic-loads. Here, we use a grid-based quorum to implement our MAC protocols and a mathematical model that analyzes the per-node communication traffic load of an individual sensor node. Our MAC protocol was successfully able to dynamically adjust the grid size accurately according to the per-sensor node data communication traffic loads, thereby improving the energy-efficiency. Simulation results showed that our MAC protocol is achieves energy efficiency to extend the lifetime of a static and non-mobile WSN. We compare the performance of our proposed MAC protocols in terms of alive sensor nodes, energy consumption and power-efficiency properties with SMAC protocol. In future, we will compare the more performance of various protocols

in terms of latency, successful delivery ratio and signaling overhead with our proposed MAC protocol. Also, we experiment our proposed MAC protocol with the workload, to explore the actual practical performance. In conclusion, the proposed MAC protocol is simple, power-efficient and highly reliable for various applications which make promising energy saving for prolonging the lifetime of wireless sensor networks.

## REFERENCES

- [1] I. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci: A Survey on Sensor Networks, IEEE Communication Magazine, August 2002, pp. 102-114.
- [2] I. Demirkol, C. Ersoy, and F. Alagoz, MAC Protocols for Wireless Sensor Networks: A Survey, IEEE Communication Magazine, Vol. 44, Issue 4, pp.115-121, April 2006.
- [3] C. K. Nguyen and A. Kumar, "An energy-aware medium-access-control protocol with frequent sleeps for wireless sensor networks", Computers and Communications, 2005. ISCC 2005, Proceedings,10th IEEE Symposium on 27-25 June 2005 Page(s):386 – 391.
- [4] A. Liu, Hongyi Yu, and Lin Li, "An energy-efficiency and collision-free MAC protocol for wireless sensor networks", Vehicular Technology Conference, 2005. VTC 2005-Spring, 2005 IEEE 61st, Volume 2, 30 May-1 June 2005 Page(s):1317 – 1322 Vol. 2.
- [5] W. Ye, J. Heidemann, and D. Estrin, "An energy efficient MAC protocol for wireless sensor networks", in Proceedings of IEEE INFOCOM'02, New York, NY, June 2002, pp. 1567-1576.
- [6] W. Ye, J. Heidemann, and D. Estrin, "Medium access control with coordinated adaptive sleeping for wireless sensor networks", IEEE/ACM Transactions on Networking, vol. 12, no.3, June 2004, pp. 493-506.
- [7] T. V. Dam and K. Langendoen, "An adaptive energy efficient MAC protocol for wireless sensor networks", in Proceedings of 1st ACM Conference on Embedded Networked Sensor Systems

- (SenSys'03), Los Angeles, CA, Nov. 2003, pp. 171-180.
- [8] G. Lu, B. Krishnamachari, and C. S. Raghavendra, "An adaptive energy-efficient and low-latency MAC for data gathering in wireless sensor networks", in Proceedings of 18th International Parallel and Distributed Processing Symposium (IPDPS'04), Santa Fe, NM, Apr. 2004, pp. 224-231
- [9] C.-M. Chao and Y.-W. Lee, "A quorum-based energy-saving MAC protocol design for wireless sensor networks," IEEE Trans. on Vehicular Technology, vol. 59, no.2, pp. 813–822, Feb. 2010.
- [10] V. Rajendran, K. Obraczka, and J. J. Garcia-Luna-Aceves, "Energy-efficient, collision-free medium access control for wireless sensor networks", in Proceedings of 1st ACM Conference on Embedded Networked Sensor Systems (SenSys'03), Los Angeles, CA, Nov. 2003, pp. 181-192.
- [11] B. Liu, N. Bulusu, H. Pham, and S. Jha, "CSMAC: A novel DS-CDMA based MAC protocol for wireless sensor networks", in Proceedings of IEEE Global Telecommunications Conference (Globecom'04) Workshops, Dallas, TX, Nov.-Dec. 2004, pp. 33-38.
- [12] Y. Yang, F. Zhen, T.-S. Lee and M.-S. Park, "TASL: A traffic-adapted sleep/listening MAC protocol for wireless sensor network," International Journal of Information Processing Systems, Vol.2, No.1, pp. 39-43, March 2006.
- [13] M. Singhal and N. G. Shivaratri, Advanced Concepts in Operating Systems. New York: McGraw-Hill, 1994, p. 345.
- [14] S.-Y. Cheung, M. H. Ammar, and M. Ahamad, "The grid protocol: A high performance scheme for maintaining replicated data," IEEE Trans. Knowl. Data Eng., vol. 4, no. 6, pp. 582–592, Dec. 1992.
- [15] M. Maekawa, "A  $\sqrt{N}$  algorithm for mutual exclusion in decentralized systems," ACM Trans. Comput. Syst., vol. 3, no. 2, pp. 145–159, May 1985.
- [16] C.-M. Chao, J.-P. Sheu, and I.-C. Chou, "An adaptive quorum-based energy conserving protocol for IEEE 802.11 ad hoc networks," IEEE Trans. on Mobile Computing, vol. 5, no. 5, pp. 560–570, May 2006.
- [17] Q. Chen, S.-S. Kanhere, and M. Hassan, "Analysis of per-node traffic load in multi-hop wireless sensor networks," IEEE Transactions on Wireless Communications, Vol. 8, No. 2, pp. 958-967, February 2009.
- [18] The Network Simulator—ns-2, <http://www.isi.edu/nsnam/ns/>, 2005.