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Adaptive Power Control and Duty Cycle based Medium Access Control Protocol for Cluster based Wireless Sensor Network

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Abstract. Energy management has always been a research concern in the domain of wireless sensor networks. Usage of energy in an effective way is helpful to extend the life time of wireless sensor networks in significant manner. Clustering is one of effective solution used to increase the lifetime of sensor networks. Since, primary energy waste in sensor node is idle listening, many medium access protocols are designed to save the energy by keeping the radio in low power sleep mode. In order to save energy of nodes in clustered networks, an a*daptive duty cycle medium access control* (AD-MAC) protocol is introduced in this paper. It is designed to achieve low duty cycle for a cluster and less number of collisions in a network. Sensor nodes in AD-MAC have a very short listening time which would reduce the energy consumption greatly. Also number of collisions, is minimized by introducing the channel access method using hybrid of TDMA and FDMA Algorithm. Besides these features, an adaptive power control is introduced to extend the node's lifetime. In this way, AD-MAC protocol saves the total energy consumption of nodes and prolongs its life time. Simulation results show that our proposed algorithm significantly reduces energy consumption by 18% compared to an existing protocol ML-MAC.

Key-words: Adaptive power control, Energy consumption, Medium Access Protocol, Lifetime, Throughput, Wireless Sensor Networks (WSN)

1. Introduction

A wireless sensor network is a collection of a large number of distributed sensor nodes which are deployed in an ad-hoc manner and are communicating through short range radio [1]. These nodes are usually equipped with limited energy source. In most of the application scenarios, replacement or recharging of power source might not be possible. For these reasons, researchers are currently focusing on the design of energy-aware protocols for wireless sensor networks.

These include efficient signal processing algorithms, energy-efficient medium access control and fault tolerant algorithms and reliable data aggregation algorithms etc [2]. In this paper, the importance is given to contention based protocol, which uses periodic active and sleep schedule to save energy.

In MAC protocol, there are four major sources of energy waste: Collision, overhearing, idle listening and overhead [3]. In 802.11, MAC will spend more energy in idle listening, which is 30% of the total energy consumption [4, 5]. Hence idle listening is considered as the most dominant factor of energy waste. In contention based protocols, one frame is divided into active and sleep period and duty cycle is defined as Tactive / Tactive+Tsleep. It was observed that lower duty cycles lead to more energy saving. S-MAC[5], T-MAC[6], B-MAC[7], ML-MAC[8] and some other protocols try to reduce the duty cycle for higher energy efficiency. In this paper, a new hybrid MAC protocol called AD-MAC is proposed. In this proposed technique, it is attempted to reduce node energy consumption less than that achieved by ML-MAC and S-MAC by reducing idle listening time, number of collisions and by using multiple channels to access the media inside the cluster. AD-MAC is a distributed contention based MAC protocol where nodes discover their neighbours based on the radio signal level and it uses 2 different channel access schemes like TDMA for inter cluster communication and FDMA for intra-cluster communication. For better energy efficiency, adaptive power control is also used based on the nature of node.

This paper is organized as follows, Section II describes related works; explanation of the proposed scheme is discussed in section III; energy consumption analysis and throughput analysis are given in section IV; simulation results are discussed in section V.

2. Related works

Following attributes are to be satisfied by a good WSN MAC protocol: energy efficiency, adaptability to topological changes, latency, throughput, packet delivery ratio and channel utilization [9] . Most of the MAC protocols have been based on conventional CSMA/CA and are shown in evolution of IEEE 802.11 protocol family [10]. S-MAC [5] is a contention based low power MAC protocol. The basic idea is that time is divided into active and sleep periods. Nodes will exchange their synchronization message at the beginning of each active period. After this, in the remaining period the data is transferred using RTS, CTS, and ACK. By reducing the listen period energy efficiency is achieved. T-MAC [6] improves energy efficiency of S-MAC by introducing adaptive duty cycle. After SYNC period and data transfer period in the active period, a timeout window is used. If no activity occurs, the node enters into sleep mode. In var-iable workloads, T-MAC performs better than S-MAC in terms of energy efficiency. B-MAC [7] is also a CSMA based protocol and it allows the application to implement its own MAC protocol through a well defined interface. It also uses low power listening and clear channel assessment in order to achieve higher throughput and energy efficiency. Compared to T-MAC and S-MAC it has higher throughput and energy efficiency.

Another medium access protocol SIFT [8] uses event driven nature of WSN for MAC design. It uses fixed size contention window. In order to reduce latency, a non-uniform probability distribution of transmission is used in each slot. Therefore, SIFT results in good performance for latency, throughput and energy consumption. ML-MAC [9] is designed to reduce power consumption achieved by S-MAC and T-MAC by minimizing the idle listening time and number of collisions. It is a self organizing protocol that does not require a central node to control the operation of nodes. MMSN [11] is a multi frequency MAC protocol for WSN. In this, channel is divided into number of frequencies and each user is assigned with one frequency and many to many traffic pattern is considered. With the help of simultaneous transmissions the energy efficiency is improved in this protocol. MASN [12] is also a multi-frequency MAC protocol for Zigbee. Here, the frequency is allocated to the nodes based on the hierarchical address allocation process used in Zigbee networks and many to one traffic pattern is considered. Compared to MMSN it has higher global throughput and packet delivery ratio. However this method does not concentrate on clustering which increases the network lifetime. Thus, to solve these issues a novel energy efficient medum access protocol AD-MAC is introduced in this paper.

3. AD-MAC protocol

AD-MAC is an adaptive duty cycle based hybrid MAC protocol designed for cluster based wireless sensor networks. As shown in Fig. 1 and Fig. 2, time in AD-MAC is divided into number of frames and each frame is divided into two periods, active and sleep. The active period is subdivided into L number of phases and clusters are distributed among these sets whereas nodes are distributed in ML-MAC. Here cluster head (CH) in each phase follow a periodic active/sleep schedule and all the nodes of a cluster will follow the same schedule of its head by using different frequencies.

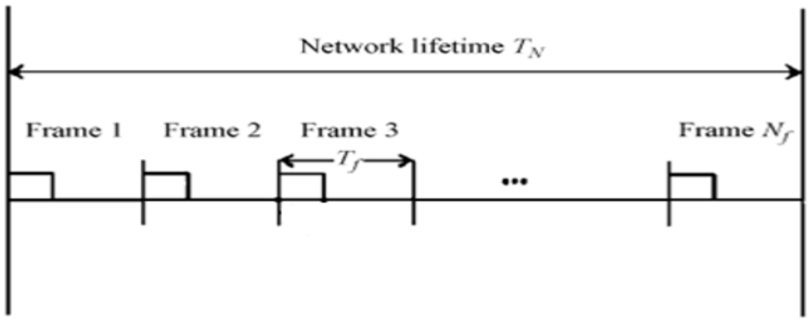

Fig. 1. Network lifetime

Schedule of one phase is skewed in time compared with schedules of other phases. Thus active period of cluster heads (CH) in different phases are non-overlapping. A cluster in AD-MAC protocol wakes up only at its assigned phase. Therefore AD-MAC requires lesser amount of energy compared to ML-MAC and S-MAC, because listen period of a cluster in AD-MAC is less. In clustered networks, the function of CH and member node are different and hence to satisfy this condition in the proposed system the hybrid MAC protocol is used. The member nodes of cluster will follow FDMA and CH will uses TDMA for channel access. Here, the frequencies are allotted to the nodes by using node frequency distribution algo-rithm (NFDA). In this algorithm number of frequencies available should be greater than or equal to number nodes in the cluster. Frequencies are allocated based on equation (1).

$$f(i) = i^{*} mod\left(\frac{N}{K}\right) \tag{1}$$

Where

i — Node id

f(i) — frequency allocated to i^{th} node

N — Number of nodes in the network

K — Number of clusters

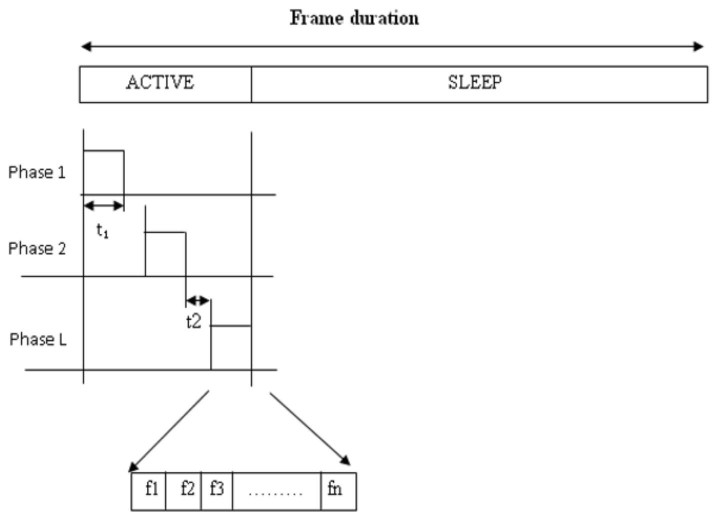

Fig. 2. Structure of one frame in AD-MAC

Cluster head will select the frequency hopping sequence randomly and broadcast this to all members during the cluster setup phase itself. Thus it does not use any additional overhead to send the hopping se-quence.

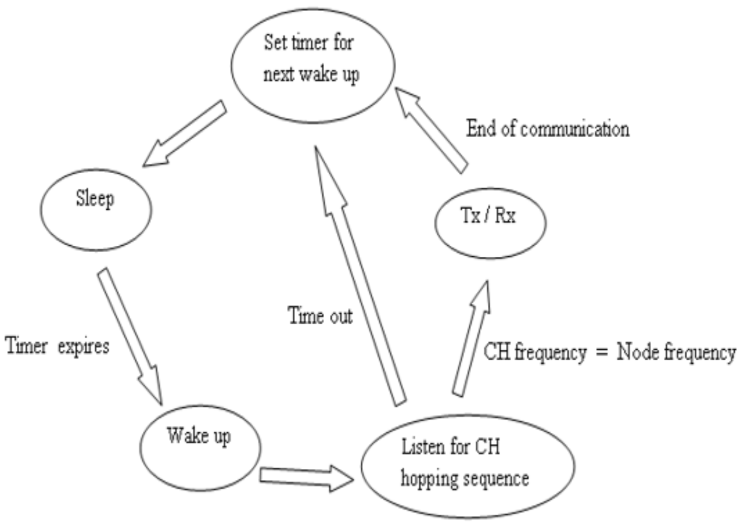

Fig. 3. State Diagram (Moore model) of sensor nodes working in AD-MAC

During the active period, nodes will continuously listen to the hopping sequence of cluster head and transmit data to the head during its assigned frequency. On completion of data transmission the node will enter into the sleep period without waiting for the CH's active period to complete. Thus it saves more en-ergy compared to existing MAC protocols. Different states of cluster head and nodes are described as Moore model and are shown in Fig. 3 and Fig. 4.

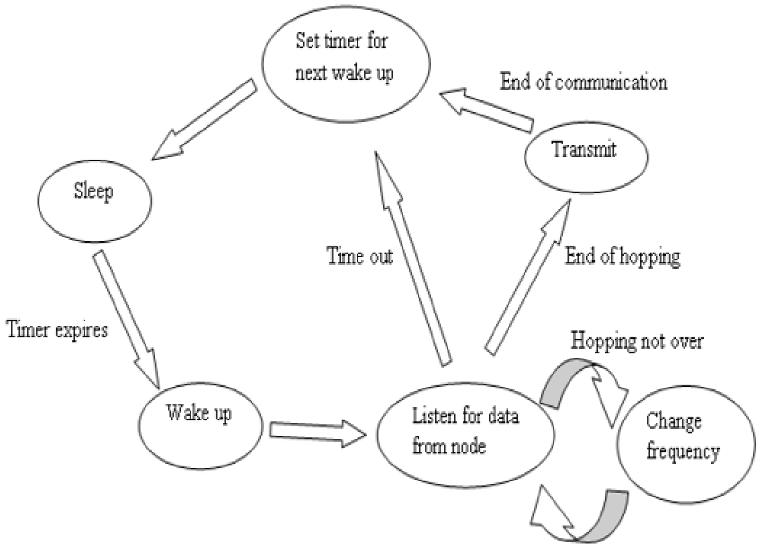

Fig. 4. State Diagram (Moore model) of Cluster Head (CH) working in AD-MAC

Upon deployment each CH will select the phase randomly using uniform random distribution. In ML-MAC, when a new node joins the network, it selects a schedule randomly and broadcast its schedule to other nodes and each and every node has to maintain a schedule table to store the schedules of other nodes. This will increases complexity in node's function. This problem is overcome in the AD-MAC. If a new node joins the network, then it is added with any one of the cluster and it selects the new frequency and follows the cluster head's schedule. No need to use any table to store others schedule. It is not required to broadcast the schedule of one node. Thus AD-MAC provides better scalability compared to ML-MAC and S-MAC.

A. Design

This subsection describes the design parameters required to analyze the performance of AD-MAC. Here the assumptions made in AD-MAC are outlined.

- Nodes in the network are static;
- Nodes are grouped into clusters;
- Sensor nodes are time synchronized;
- Time is divided into number of time slots;
- All nodes are having same radio range;

- Network mission is data collection. All nodes will send the collected information to the sink node via the cluster head node;
- Sensor nodes are randomly and uniformly distributed in the flat surface of sensing environment and the sink is kept at the centre.

T_f - frame duration
t_1 - phase duration
Frame duration must satisfy the following condition

$$T_f < T_R \tag{2}$$

Where T_R is the response time delay.

$$T_f = listen\,time \;+\; sleep\,time \;=\; Lt_1 \;+\; LT_s \tag{3}$$

Number of frames is given by

$$N_f < \frac{T_N}{T_f} \tag{4}$$

Substitute (3) in (4) we get,

$$N_f < \frac{T_N}{Lt_1 + LT_s} \tag{5}$$

And N_f should satisfy the following condition also

$$\frac{T_N}{T_R} < N_f < \frac{T_N}{Lt_1 + LT_s} \tag{6}$$

Equation 6 describes the condition for number of frames to be used in a single network. Listen period of one phase is calculated *i.e.*, t_1.

t_1 (phase duration) depends on:

- battery capacity C;
- average energy consumed by a cluster head P_{av}.

$$P_{av} t_1 L N_f \leq C V_{av} \tag{7}$$

Therefore

$$t_1 \leq \frac{CV_{av}}{P_{av} L N_f} \tag{8}$$

t_1 also depends on

- time required by cluster head to complete its work (*i.e.*),
  time required to (collect data from different nodes + frequency hopping + transmission)

$$t_1 \geq \left(\frac{N}{K} - 1\right) T_{RX} + T_{hop} + T_{TX} \tag{9}$$

Thus the limit for t_1 is given as:

$$\left(\frac{N}{K} - 1\right) T_{RX} + T_{hop} + T_{TX} \leq t_1 \leq \frac{CV_{av}}{P_{av} L N_f} \tag{10}$$

Other specifications and requirements in the application, such as delay limitations and buffer size in the node, can be used to determine the values of these timing parameters and to specify how many phases should deployed to get the best performance.

B. Energy Model

A typical sensor node consists of sensor unit, processor unit, power unit and a radio communication unit that consists of transmitter, receiver, amplifier and an antenna [13]. Fig. 5 describes the energy dissipation model of sensor node.

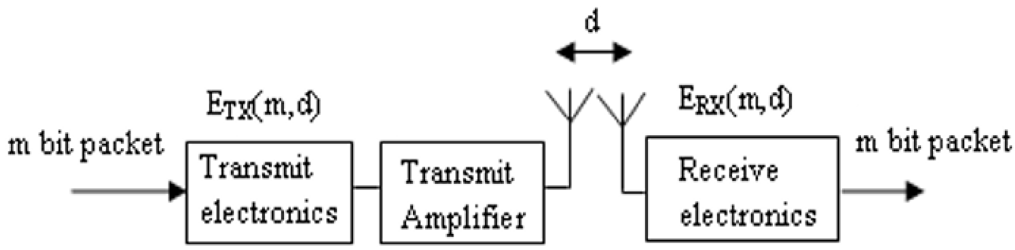

Fig. 5. Radio energy dissipation model

The energy spent by the normal node to transmit a packet to its cluster head is given by

$$E_{TX}(m.d) = mE_{elec} + mE_{fs} d^2 \tag{11}$$

where E_{elec} is the energy spent per bit to run the transceiver circuit, E_{fs} is the free space transmitter amplifier energy. The distance from cluster head to member node is small and the energy dissipation follows the Frii's free-space model *i.e.*, d^2 power loss. For K circular clusters and network diameter M, the mean value of d^2 is given by

$$E(d^2) = M^2/2\pi K \tag{12}$$

By substituting this, equation (6) can be simplified as:

$$E_{TX}(m.d) = mE_{elec} + mE_{fs}(M^2/2\pi K) \tag{13}$$

The cluster head node follows the multi-path model (d^4 model) to transmit a packet for long distance transmission.

$$E_{TX}(m.d) = mE_{elec} + mE_{mp} d^4 \tag{14}$$

where E_{mp} refers to multi-path transmitter-amplifier energy. To receive a m-bit packet, energy spent by the receiver radio is given by:

$$E_{RX}(m.d) = mE_{elec} \tag{15}$$

C. Energy analysis

This subsection compares the energy saved in protocols S MAC, ML-MAC and proposed method AD-MAC. Energy saved in these protocols is given in Fig. 6. Energy saved in the proposed system is (N/K) times higher than the energy saved by ML-MAC.

$$E_{saved-AD\ MAC} = \left(\frac{N}{K}\right) E_{saved-MLMAC} \tag{16}$$

Here one phase is allocated to one cluster. Therefore energy spent by one cluster is the energy spent on one phase.

$$E_{phase} = E_{cluster} \tag{17}$$

$$E_{cluster} = E_{CH} + \left(\frac{N}{K} - 1\right) E_{non-CH} \tag{18}$$

The cluster head will receive data from its member nodes *i.e.*, (N/K – 1) nodes and transmit it after the processing. So the energy consumed by the cluster head is given by,

$$\begin{aligned} E_{CH} &= \left(\frac{N}{K} - 1\right) E_{RX}(m,d) + \left(\frac{N}{K} - 1\right) E_{da}(m,d) + E_{TX}(m,d) \\ &= \left(\frac{N}{K} - 1\right) mE_{elec} + \left(\frac{N}{K} - 1\right) E_{da} + mE_{elec} + mE_{mp}d^4 \end{aligned} \tag{19}$$

The member nodes will transmit the sensed data to the cluster head and the energy spent is given

$$\begin{aligned} E_{non-CH} &= E_{TX}(m,d) \\ &= mE_{elec} + mE_{fs}(M^2/2\pi K) \end{aligned} \tag{20}$$

By substituting equation (19) and (20) in equation (18) we get the energy spent in one phase.

$$\begin{aligned} E_{phase} = &\left(\frac{N}{K} - 1\right) mE_{elec} + \left(\frac{N}{K} - 1\right) E_{da} + mE_{elec} + mE_{mp}d^4 + \\ &+ \left(\frac{N}{K} - 1\right) \Big[mE_{elec} + mE_{fs}(M^2/2\pi K) \Big] \end{aligned}$$

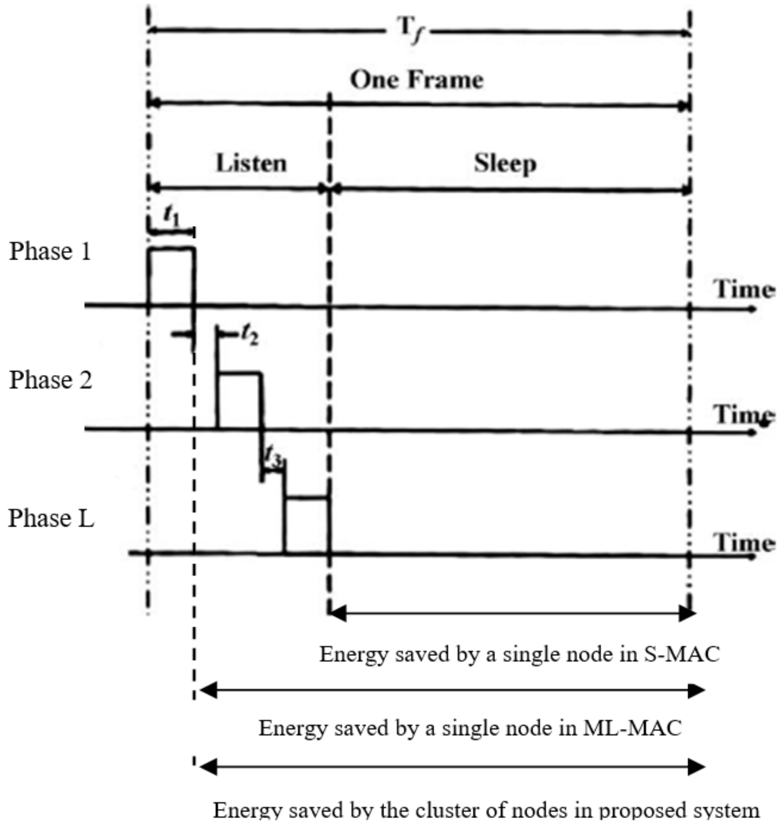

Fig. 6. Energy saving AD-MAC

The total energy spent in one frame by K number of clusters is given by

$$\begin{aligned} E_{frame} &= KE_{phase} \\ &= K\Bigg\{\left(\frac{N}{K}-1\right)mE_{elec}+\left(\frac{N}{K}-1\right)E_{da}+mE_{elec}+mE_{mp}d^4+ \\ &\qquad +\left(\frac{N}{K}-1\right)[mE_{elec}+mE_{fs}(M^2/2\pi K)]\Bigg\} \end{aligned} \tag{21}$$

The optimum number of clusters K for minimum power dissipation of one frame for the proposed protocol is obtained by setting the derivative of E_{frame} with respect to K is equal to zero.

$$\frac{dE_{frame}}{dK} = 0 \tag{22}$$

$$K_{opt} = \sqrt{\frac{NmM^2E_{fs}}{2\pi(mE_{mp}d^4 - mE_{elec} - E_{da})}} \tag{23}$$

Equation (23) gives the optimum number of clusters to be accommodated in one frame. If Nf denotes number of frames then the amount of energy consumed by the entire network is given by:

$$E_{total} = N_f X E_{frame} \tag{24}$$

D. Throughput analysis

Here, the packet length is fixed and represented by m. Active time is represented by t_{active}. Actual data transmission takes place only during the active time. Hence, throughput is given by:

$$Th = \frac{number\ of\ packets\ transmitted\ during\ t_{active}}{t_{active} + t_{sleep}} \tag{25}$$

S-MAC:

In S-MAC, a node can communicate n packets to only one node within a frame time, so the throughput is given by:

$$Th_{S-MAC} = \frac{n}{t_{active} + t_{sleep}} \tag{26}$$

ML-MAC:

In ML-MAC, within the frame time, L number of nodes can transmit n packets, so the throughput is given by,

$$Th_{ML-MAC} = \frac{nL}{t_{active} + t_{sleep}} \tag{27}$$

AD-MAC:

In AD-MAC, a cluster head can collect data from ((N/K) – 1) nodes and forward it to one sink node with-in the frame time. Therefore throughput is given by:

$$Th_{AD-MAC} = \frac{n\left(\frac{N}{K} - 1\right)}{t_{active} + t_{sleep}} \tag{28}$$

From these equations it is clear that AD-MAC gives better throughput compared to S-MAC and ML-MAC.

4. Adaptive Power Control (APC)

Since the energy consumption depends on the transmission distance, the distance should also be consid-ered. The distance between member node and cluster head is very less compared to the distance between cluster head and sink node. In other protocols, same amount of energy is used irrespective of the distance, whereas in proposed AD-MAC protocol energy varies with distance. Compared to inter cluster communi-cation, less energy is used for intra cluster communication.

Fig. 7 shows the flow chart of the adaptive energy allocation. If the node is a cluster head node then it requires more energy to forward its data to sink node. Therefore the energy required must be greater than optimal energy level *i.e.*,

$$E_1(in\ dB) = optimal\ energy\ level + 1 \tag{29}$$

If the node is member node then it requires less energy compared to cluster head node. *i.e*,

$$E_2(in\ dB) = optimal\ energy\ level - 1 \tag{30}$$

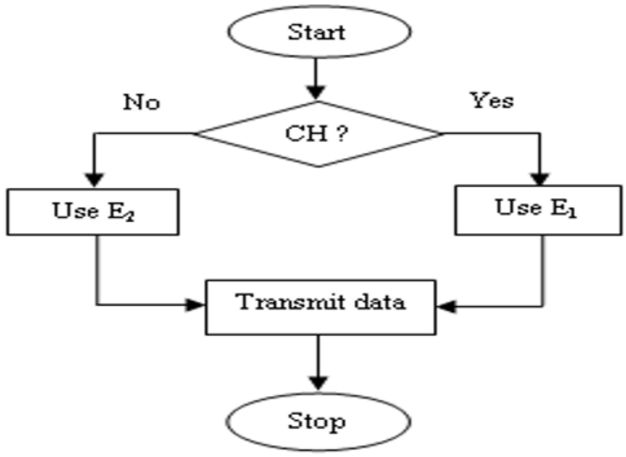

Fig. 7. Flow chart of APC algorithm

5. Simulation and Results

The performance of AD-MAC is simulated and the results are compared with other MAC protocols like S-MAC and ML-MAC. The parameters used in the simulation are given in table 1. In order to perform simulation following assumptions are considered.

- Time is divided into frames and each frame is composed of active and sleep period;
- Each node has three states: active, sleep and transmit;
- Node generates the packet by following Poisson distribution;
- Nodes have unlimited transmit and receive buffer sizes;
- All nodes follow the IEEE 802.11MAC;
- The wireless channel has no bandwidth constraint;
- The radio transceiver of the node is TR 1000 from RF monolithic [16].

Table 1. Simulation Parameters

Parameter	**Value**
Electronics energy (E_{elec})	50 nJ/bit
Amplifier energy in free space (E_{fs})	10 pJ/bit
Amplifier energy in multi-path (E_{mp})	0.0013 pJ/bit
Aggregation energy (E_{da})	5 nJ/bit
Number of nodes(N)	100
Network diameter (M)	100 m
Distance to base station (d)	150 250 m
Packet size (m)	4000 bits
Number of access phases (L)	1-10
Number of Frequencies(F)	1-5
Frame duration (T_f)	1 sec
Phase duration (t_1)	12 msec
Node transmitting power	24.75 mW
Node listening power	13.5 mW
Node sleeping power	15 μW
Simulation time	200 sec

According to simulation parameters, time is divided into frames of 1 second duration and the simulation time is 200 seconds. The duty cycle is 40% which makes the active period of 400 milli seconds for S-MAC. However, for AD-MAC with L phases, the listen period is 400/L milli seconds. The data packet size is fixed to 38 bytes and it requires 20 milli second to transmit in a typical radio channel [15]. By advancing the time index and checking the packets until the end of simulation, the traffic is analyzed. In this simulation time index is set to be frame duration/1000, *i.e.*, frames are divided into 1000 slots. Table 2 shows the generation of traffic by all nodes in one cluster. It shows the arrival time of each packet. For a simulation time 20 seconds, each node would have around 4 packets. The average inter arrival time of these packets is 5 seconds.

A. Protocol performance

The main advantage of deploying multiple phases in AD-MAC is the reduction in node energy consumption and probability of collisions as following subsection illustrates. Reduction in number of collisions also reduces energy consumption by reducing number of retransmissions. Table 2 shows the assigned phase and frequency of all nodes for 2 frames *i.e.*, (1, 3) means first phase 3rd frequency. Performance of AD-MAC is improved better than S-MAC and ML-MAC and is discussed in subsequent sections.

B. Energy consumption

An average energy consumed by a node in S-MAC, ML-MAC and AD-MAC for various message inter arrival time is compared in Fig. 8. In this simulation coherent case is considered. It shows that AD-MAC consumes 70% less energy than S-MAC and 15% less energy than ML-MAC when the traffic is heavy, *i.e.*, the message inter-arrival time is less than about 5 seconds. When the traffic is light, *i.e.*, the message inter arrival time is greater than about 5 seconds, the AD-MAC consumes 74% less energy than S-MAC and 18% less energy than ML-MAC.

Table 2.a. Phase and frequency number of nodes in frame 1

Frame No.	Node number									
	1	2	3	4	5	6	7	8	9	10
1	1,1	1,2	1,3	1,4	1,5	2,1	2,2	2,3	2,4	2,5

Table 2.b. Phase and frequency number of nodes in frame 2

Frame No.	Node number									
	11	12	13	14	15	16	17	18	19	20
2	1,1	1,2	1,3	1,4	1,5	2,1	2,2	2,3	2,4	2,5

Fig. 9 shows the total energy consumed by the node for the whole simulation time, as the number of phases L changes from 1 to 10. Traffic is generated with an average inter arrival time of 5 seconds, *i.e.*, $\lambda = 0.2$ packets/s. When the number of phases is less than five, the average energy consumed decreases dramatically by adding number of phases. When number of phases is more than 5, energy consumption will not be reduced that much since the active time of one frame is increased and sleep time is reduced.

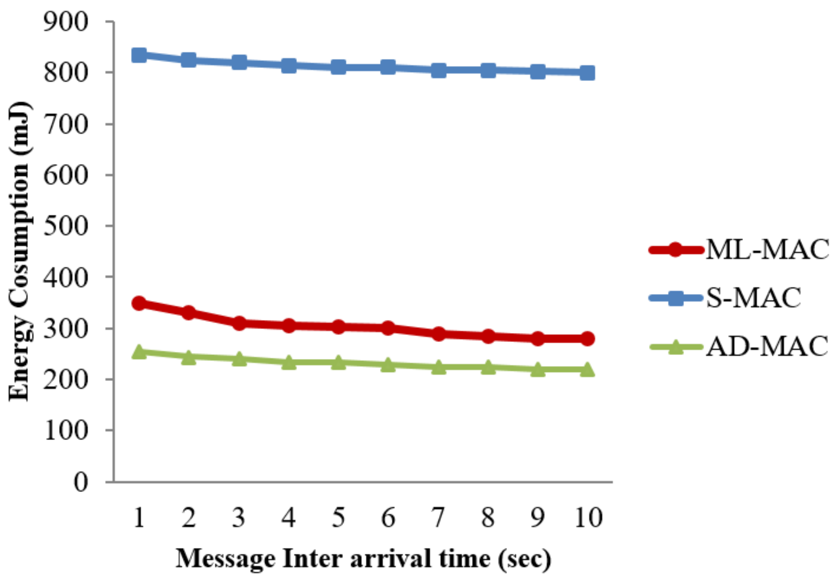

Fig. 8. Total energy consumption per node for S-MAC, ML-MAC and AD-M AC with F = 5

Fig. 10 shows the total energy consumed by the cluster in AD-MAC for the whole simulation time, with change in the number of frequencies F from 1 to 5 in coherent case. As the number of frequencies in-crease, the energy consumed by the cluster increases due to increase in the number of hops. Still there is a save in energy by 18% compared to ML-MAC.

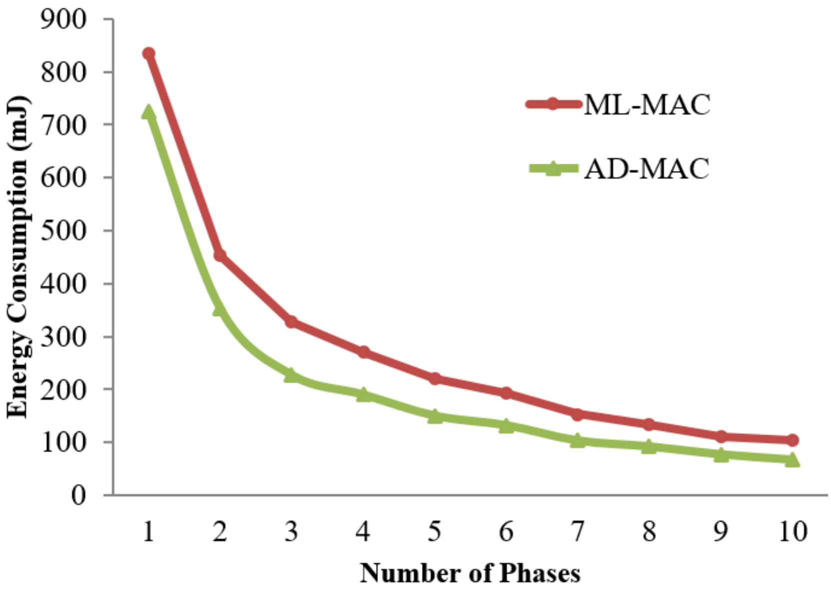

Fig. 9. Energy consumption per node for ML-MAC and AD-MAC, traffic is fixed: λ=0.2 packets/sec and F= 5

C. Probability of Collision

Fig. 11 shows the decreased probability of collision in AD-MAC compared to ML-MAC. The basic reason for reduction in probability of collision in AD-MAC is that the nodes of one cluster are assigned with different frequency. Therefore fewer collisions will occur and more number of packets are transmitted successfully. However, it stops decreasing significantly after about 6 phases because packet requests per phase spread out enough such that the probability of collision is reduced for this type of traffic. The two traffic parameters λ and σ values are 0.2 and 0.25 packets/sec. Because of close values of λ and σ, all nodes generate packets that have around same arrival times. As a result the number of collision is high.

D. Throughput

Transmission buffer for a node is treated as an M/M/1 queue as shown in Fig. 12. An infinite size buffer is assumed to reduce the analysis parameters. To compare the throughput between ML-MAC and AD-MAC number of packets transmitted in single frame has been calculated. Fig. 13 shows how the throughput is increased in AD-MAC for fixed traffic. In this, throughput of AD-MAC is 5 times higher than S-MAC and is 2 times higher than ML-MAC. The basic reason for this improvement of network throughput is that more number of nodes are transmitting data in a single frame using different frequencies. Therefore fewer collisions occur and more packets are transmitted successfully.

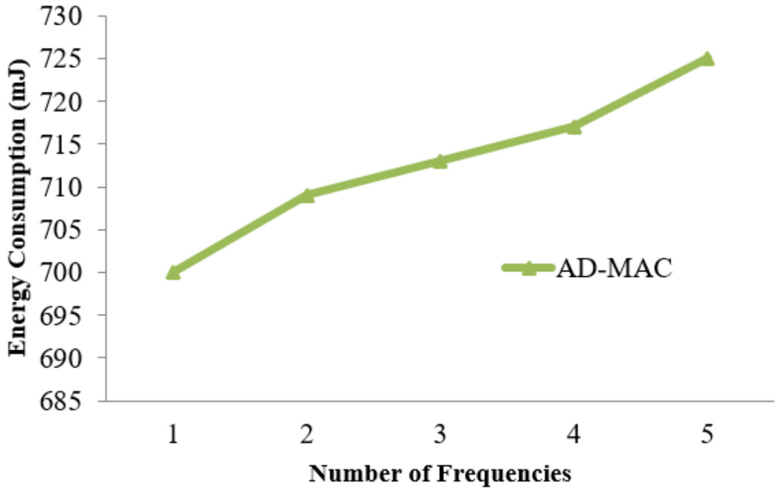

Fig. 10. Energy consumption of AD-MAC for different frequencies.

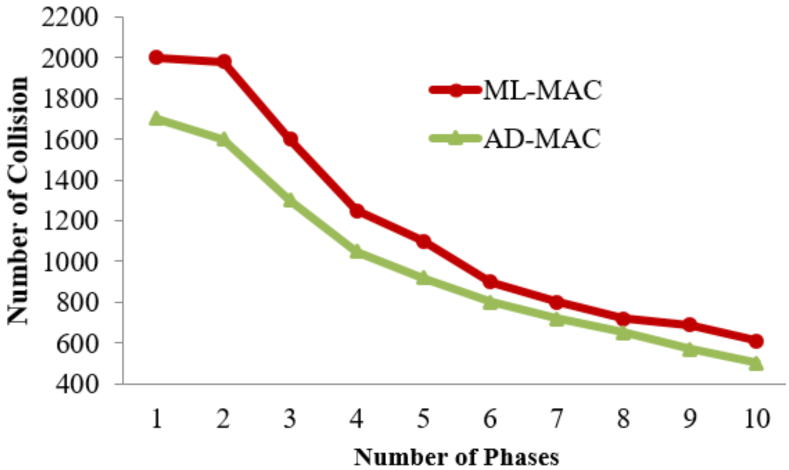

Fig. 11. Probability of collision for AD-MAC with F=5 and ML-MAC.

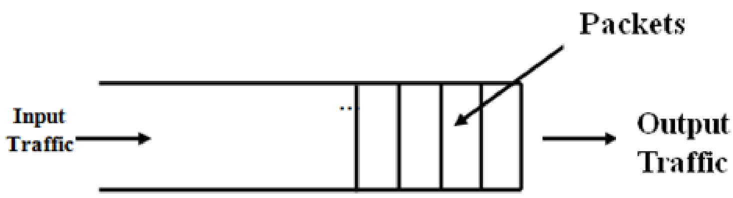

Fig. 12. Unlimited size buffer in the node.

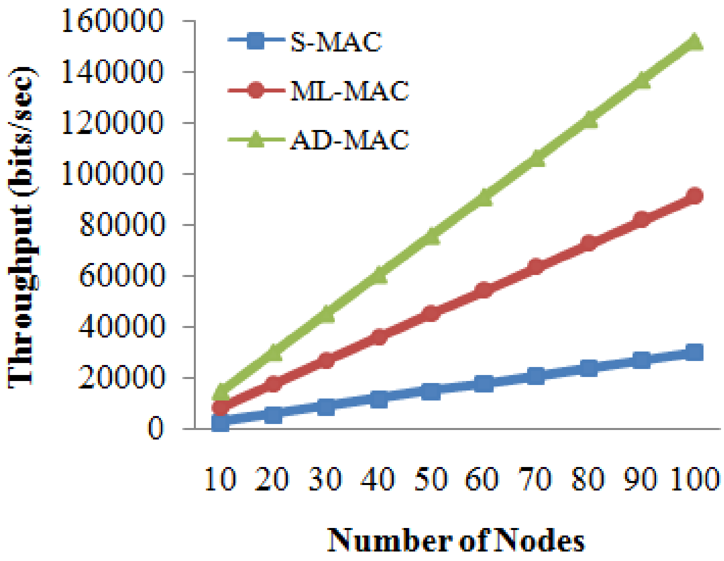

Fig. 13. Throughput of S-MAC, ML-MAC and AD-MAC.

6. Conclusion

In this paper, a cluster based adaptive duty cycle hybrid MAC protocol AD-MAC, for wireless sensor network is introduced. In this protocol, cluster heads (CH) are distributed into L phases to reduce idle listening time by L times and the listen periods of these CHs are non-overlapping. This will reduce energy consumption from two sources of energy inefficiency: idle listening and collision. By combining TDMA and FDMA techniques and introducing adaptive energy allocation for data transmission, AD-MAC becomes more energy efficient, more robust to topological changes and fairer in resource allocation. The performance of overall MAC scheme is evaluated through simulation and the results show significant improvement compared to S-MAC and ML-MAC, in energy efficiency, throughput and packet delivery ratio.

In future, we endeavor to achieve better performance of AD-MAC through a more dynamic and efficient mechanism of frequency allocation. Also we look forward to implement it over test bed and to validate the simulation results provided here.

References

[1] AKYILDIZ I.F., SU W., SANKARASUBRAMANIAM Y., CAYIRC E. *Wireless sensor networks: a survey*, The International Journal of Computer and Telecommunications Networking **30**(4), pp. 393–422, 2002.

[2] S. MEHTA AND K.S. KWAK , *H-MAC: A hybrid MAC protocol for wireless sensor network*, International Journal of computer networks and communications (IJCNC) **2**(2), pp. 108–117, 2010.

[3] YE W, HEIDEMANN J, ESTRIN D, *An energy-efficient MAC protocol for wireless sensor networks*, Proc. INFOCOM 2002 **3**, pp. 1567–1576.

[4] IAN F. AKYILDIZ, W. SU, Y. SANKARASUBRAMANIAM, AND E. CAYIRCI, *A survey on sensor networks*, IEEE Com-munications Magazine **40**(8), pp. 102–116, 2002.

[5] YE W, HEIDEMANN J, ESTRIN D, *Medium Access Control with Coordinated, Adaptive Sleeping for Wireless Sensor Net-works*, IEEE/ACM Transactions on Networking **12**(3), pp. 493–506, 2004.

[6] VAN DAM T, LANGENDOEN K, *Energy-efficient MAC: an adaptive energy-Efficient MAC protocol for wireless sensor net-works*, Proc. SenSys 2003.

[7] J. POLASTRE, J. HILL, AND D. CULLER, *Versatile Low Power Media Access for Wireless Sensor Networks*, Proc.ACM Sen-Sys 2004.

[8] K. JAMIESON, H. BALAKRISHNAN, AND Y. TAY, *Sift: A MAC protocol for event-driven wireless sensor networks*, Massa-chusetts Institute of Technology, Tech. Rep., May 2003.

[9] MANISH KUMAR JHA,, ATUL KUMAR PANDEY, DIPANKAR PAL, ANAND MOHAN, *An energy-efficient multi-layer MAC (ML-MAC) protocol for wireless sensor networks*, International Journal of Electronics and Communications (AE), pp. 209-216, 2011.

[10] F. CALÌ, M. CONTI, E. GREGORI, *Dynamic tuning of the IEEE 802.11 protocol to achieve a theoretical throughput limit*, IEEE/ACM Transactions on Networking (TON) **8**(6), December 2000.

[11] G. ZHOU, C. HUANG, T. YAN, T. HE, J.A. STANKOVIC AND T.F. ABDELZAHER, *MMSN: Multi-Frequency Media Access Control forWireless Sensor Networks*, Proc.IEEE INFOCOM2006, 2006.

[12] STÉPHANE LOHIER, ABDERREZAK RACHEDI, ISMAIL SALHI, ERWAN LIVOLANT, *Multi channel Access for Band-width Improvement in IEEE 802.15.4 Wireless Sensor Networks*, Proc. IFIP/IEEE Wireless Days 2011 (IEEE WD'2011).

[13] MIT μ-AMPS Project:[Online] Available at http://www.mtl.mit.edu/researchgroups/icsystems /uamps/

[14] BALAKRISHNAN CHANDRASEKARAN, *Survey of network traffic models* [Onine]http://www.cse.wustl.edu/ jain/cse567-06/ftp/traffic_models3/index. html

[15] A. WOO AND D. CULLER, *A transmission control scheme for media access in sensor networks*, Proc. ACMLEEE Intemational Conference on Mobile Computing and Networking (Mobicom), Rome, Italy, pp. 221–235, 2001.

[16] ASH transceiver TRlOOO data sheet, RF Monolithics Inc. [Online]. http://www.rfm.com.