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Adaptive Duty Cycle Medium Access Control Protocol for Wireless Sensor Networks

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ABSTRACT

To increase the network lifetime of WSNs is a major concern. Network lifetime can be increased by reducing energy consumptions through MAC protocols periodic and a- periodic sleep mode mechanisms. The short duty cycle makes sensors have low energy consumption rate but increases the transmission delay and long duty cycle makes the sensor to increase the energy consumption and reduce the delay. Duty cycle need to be adaptively varied to reduce the idle listening. In the proposed Adaptive Duty cycle MAC (ADMAC) protocol, duty cycle is varied by taking nodes rate of energy consumption and filled queue length in account. It reduces the delay and energy spent by reducing the idle listening. ADMAC is realized in NS2 and its performance is compared with SMAC.

Keywords: Adaptive duty cycle, WSNs, MAC

1. Introduction

Wireless Sensor Networks (WSNs) have emerged as a new computing paradigm within the past few years. The small size of sensors can be deployed physically, where each can sense information from the phenomena and they can communicate each other or sink node. Interested users can extract useful information about the environment from the WSNs[1][2][3].

A sensor node would drain its battery faster in the absence of energy efficient techniques. This fact triggered researchers to design protocols and mechanisms to reduce energy utilization in the WSNs. Many researchers proposed study on energy efficiency techniques in MAC layer, routing layer, transport and application layer separately.
Most of the node energy is spent in the communications compared to data sensing and processing. The maximum energy is spent in the communication process (transmit (14.88mW) & receive mode (12.50mW)), then, next to it is the energy spent in idle mode (12.36mW) [5]. Although, a minimum amount of energy is spent in sensing, sleeping & processing mode, still they consume some energy. These processes need to be energy-efficient.

To prolong the operational network lifetime of WSNs optimum use of limited available power source is needed. In WSNs, the energy expense can be minimized in all the layers of the protocol stack. In Physical layer, the node energy can be saved through reducing the data size, effective data rate and efficient energy model. In MAC layer, designing energy efficient MAC duty cycle mechanisms and packet scheduling [2]. Energy efficient routing protocol can be designed to reduce the energy consumption in the network layer. In transport layer, effective congestion control, congestion avoidance and load sharing mechanisms contribute in enhancing the network lifetime

Data placement and asynchronous multicasting techniques attempts to reduce energy expense at application layer. Energy spent in sensor nodes is much in communication compared to sensing and data processing.
The MAC layer has to be responsible for reliability, energy efficiency, high throughput & low access delay to optimally utilize the energy-limited resources of sensor nodes. Maximum amount of energy wasted in MAC protocol operations like collision, overhearing, control packet overhead and interference. To minimize the energy expenditure at WSNs energy efficient MAC techniques like duty cycling, packet scheduling adaptive transmission range, and adaptive transmission period [6][7][8][9].

Many research attempted to save the power in WSNs through MAC layer protocols [10][11][12][13][14[15][16][17][18][19]. Active mode is used for data transmission and in sleep mode sensors turns off their radios to save the power. In SMAC, sensor nodes operate at low duty cycle and frequently toggles between active and sleep modes. In static duty cycle MAC protocols it does not adapt to the traffic through the node. It introduces additional delay in the processing of data at MAC layer. A dynamic duty cycle scheduling is needed to improve the energy efficiency and reduce the delay in the WSNs.

In this paper, we propose an adaptive duty cycle adjustment MAC protocol named “ADMAC” which can adjust sensor’s duty cycle adaptively according to status buffer filled queue length, node rate of energy consumption. After the information of a sensor is obtained, the sensor adaptively adjusts the duty cycle for sending and receiving packets. This protocol focus on to reduce the energy spent and end to end delay. Each node adaptively varies its duty cycle if the node has data to transmit. The sensors that which failed to send data due to radio channel competition, these sensors will go to sleep state for energy conserving and wait for next wake-up time to compete the radio channel again for transmitting data.

The rest of the paper is organized as follows. Section 2 describes the related works. Section 3 presents the proposed Adaptive duty cycle MAC protocol. Section 4 presents the results and its analysis. Section 5 concludes the proposed MAC scheme.

2. Related Works

A duty cycling in MAC layer involves the sensor node to sleep/wake up mechanisms to conserve energy. Sleep/wake up mechanisms involves in putting the radio transceiver in the (low-power) sleep mode whenever communication is not required. Ideally, the radio should be switched off as soon as there is no more data to send/receive, and should be resumed as soon as a new data packet becomes ready. The mechanism which makes the sensor nodes to alternate between active and sleep periods depending on network activity can be referred as duty cycling.
SMAC stands for Sensor MAC[20]. SMAC contains the original duty cycling concept to reduce the overhead of idle listening. SMAC is more energy efficient than the full wake IEEE 802.11 MAC protocol. SMAC reduce energy consumption due to overhearing, idle listening and collision. SMAC has two states, sleep state and active state. SMAC adopts a periodic wake up scheme. In listen period, a node can either receive or transmit data. SMAC synchronizes the listen periods of neighboring nodes. The listen period of a node is divided into three phases as shown below. The listen period is the time during which a node is awake, rest of the time node is sleeping. SMAC has fixed sleep and listen intervals.

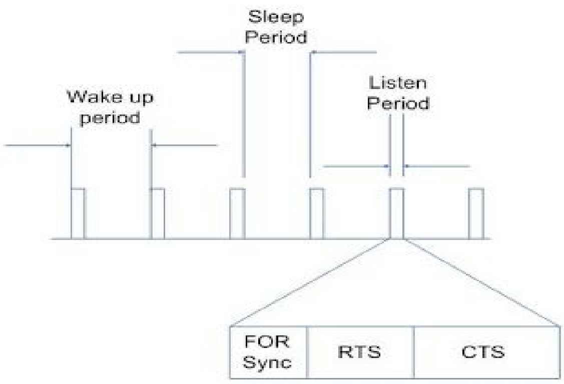

Fig. 1 Duty Cycle in SMAC

The listen period has sync phase, RTS phase and CTS phase. The neighboring node synchronizes their listen periods in sync phase. In RTS phase, a node which wishing to send data sends RTS and destination node acknowledges RTS in CTS even when node is in sleep mode. A common sleep schedule is setup in neighboring nodes using virtual cluster. SMAC results in idle listening and overhearing, when two nodes present in adjacent virtual clusters. It also increases energy consumption and introduces high end to end delay. Sensor nodes in the network may not have same traffic through the node. Maintaining uniform duty cycle acoree the network results in idle hearing which leads to energy waste and end to end delay.

Shuetal proposed RMAC [21]. RMAC uses setup control frame called PION can travel across multiple hops and schedule the upcoming data packet delivery along that route. Each intermediate relaying node for the data packet along these hops sleeps and intelligently wakes up at a scheduled time, so that its upstream node can send the data packet to it and it can immediately forward the data packet to its downstream node. An operational cycle of a sensor node in RMAC can be divided into three stages: SYNC, DATA, and SLEEP. Most importantly, a node transmits a single PION to confirm receipt of a PION from its upstream node and to simultaneously request communication from a downstream node. This dual function makes the multihop relaying of PIONs very efficient. RMAC reduces end-to-end delivery latency with a duty cycle. Most importantly, a node transmits a single PION to confirm receipt of a PION from its upstream node and to simultaneously request communication from a downstream node. This dual function makes the multihop relaying of PIONs very efficient. RMAC suffers improper duty cycle synchronization among the nodes on the routing path between source node and sink node. It increases idle hearing and waiting for the next duty cycle in the neighboring node increases delay.

Yang et al[22] proposed Utilization based-MAC protocol (U-MAC). U-MAC fixes duty cycle according to the traffic loads of sensor nodes. U-MAC evaluates utilization function of a sensor node based on its traffic handling.
The nod adopts its duty cycle according to the calculated node utilization and then communicates it to its neighboring through broadcasting. and then broadcasts the new schedule to its neighbors.
UMAC saves more energy than SMAC when traffic loading is low. If the sender's duty cycle is higher than the receiver, then data may in the queue of the receiver or it may be lost when its queue is full. It not only reduces the throughput but also increases delay.

In the most of adaptive dynamic duty cycle mechanisms attempted to vary the sleep time or active time of the sensor node. As we know that sensor node operates in active, idle and sleep mode. Dynamic duty cycle MAC tried to reduce the energy utilization in the network. However, many researchers proposed they fails to consider filled queue length, rate of energy consumption and common duty cycle assignment between source and next hop node on the path to the sink node. It effectively adapts the duty cycle period which reduces energy expenditure and end to end delay in the network.

3. Adaptive Duty cycle Mechanism in MAC (ADMAC) for WSNs

The proposed Adaptive Duty cycle Mechanism in MAC for WSNs is designed under the following assumptions:

i. Each node consists of the communication module and sensing module.
ii. The energy consumption during sensing is negligible compared to wireless communication.
iii. All the nodes in network synchronizes for active and sleep mode operation.
iv. In the wireless communication, the main energy consumption is used for idle listening, instead of packet transmission and reception.

"ADMAC" that can adjust duty cycle adaptively according to status of sensor's sending/receiving buffer, rate of energy consumption and traffic loading. The proposed adaptive duty cycle MAC protocol fairly updates the duty cycle to the maximum level which has the enough battery capacity and its rate of energy consumption is lower than the threshold rate of energy consumption and taking number of packets in the buffer into account. This mechanism increases the network lifetime by spending the node energy uniformly among the nodes which may participate in the routing. It also avoids network to get partitioned by a node which has minimum residual energy and maximum rate of energy consumption. The sender and receiver need to synchronize their active state and duty cycle to reduce the end to end delay. It also reduces idle listening of the Neighboring or next hop node.

The working of the Adaptive Duty cycle MAC is assumed to be source node knows the complete path to the destination or sink node. Along the control packet which synchronizes the next hop node duty cycle also carries the complete path to the destination. Adaptive duty cycle MAC protocol designed in 2 phases.
First, the duty cycle setting at the current node and next hop node. The current node or source node changes its duty cycle by reading at the current node buffer fill capacity, rate of energy consumption, and working rate of the sensor node. Secondly, duty cycle for all the nodes is set to be minimum.

Adaptive duty cycle MAC Algorithm

<u>At sender:</u>

```
Initial DC :DCmin and SC=∑_{i=1}^{n} SC_i/N
  while a SYNC packet is sent do
    WR = Ttx +Trx/(Ttx +Trx +Tidle)
      if FQL ≥ Qmax&& DC <DCmax and REC>RECThreshold&& WR ≥ WRhighthen
        DC = DC * (1 + (FQL/REC)*WR)
    else if WR ≤ WR1ow and DCmax>DC >DCmin&& SC<SCThresholdthen
        DC = DC * (1 –(FQL/REC)*WR)
        Unicast-to-nexthop-node(DC)
```

```
        end if
end while
```

At receiver

```
SC=∑_{i=1}^{n} SC_i/N
while a SYNC packet is received do
If  DC>DCcurrent and REC<RECThreshold and FQL <Qmax and WR ≤ WR1ow then
   DCcurrent=DC
End if
   if WR ≥ WR1ow and DCmax>DCcurrent>DC && SC<SCThresholdthen
      DCcurrent = DCcurrent□ (1 - (FQL/REC)*WR)
   end if
end while
```

A synchronization packet is sent to next hop node and with updated duty cycle from current node. If the filled queue length of the buffer is more than the maximum queue capacity, current duty cycle less than the duty cycle maximum and rate of energy consumption is greater than the its threshold value and working rate is lesser than its upper limit, Then duty cycle is increased by a ratio of its capacity which can handle the current traffic with current residual energy and its rate of energy consumption. The duty cycle is reduced by ratio of filled queue length, and the rate of energy with the working rate of the sensor node. Then the modified duty cycle is communicated to next hop node.

The next hop node which received the modified duty cycle and checks its duty cycle is less than the received duty cycle and their residual energy and rate of energy consumption is lower than the its threshold and filled queue length is lesser than the queue length, working rate of the receiving sensor node is lesser than the working rate threshold than its duty cycle is updated to received duty cycle. If the received duty cycle is lesser than its current duty cycle, and its sleep cycle is lesser than the threshold its duty cycle is reduced according to the rate of its energy consumption, filled queue length and working rate.

4. Performance Evaluation

To evaluate the performance of the proposed adaptive duty cycle MAC for WSNs, NS2 (Network Simulator - 2) is used. It is a discrete event simulator. There is 100 nodes are organized in grid fashion. The transmission range of the sensor node is set to be 20 meters. The bandwidth is fixed to 100kbps. Each data packet size is 100 bytes and 4 bytes for control packets including RTS, CTS, and SYNC. Table 1 shows the different parameters set during the simulation, It is set as similar TA-MAC.

Table 1 Simulation parameters set

Queue	100
Sleep power	0.02mA
Transmission power	10mA
Receive power	4mA
Simulation time	300 s
Bandwidth	100 Kbps
Data packet size	100 byte
SYNC period	10 s
Frame time	1 s
Initial duty cycle	10%
DCmax	40%
DCmin	10%
Transmission range	20M
Node	10 to 100
Uhigh	0.08
WRhigh	8%
Ulow	0.04
WRlow	4%
DCmax	1.8
Residual Energy	3J

End to end delay is the cumulative average delay by all the packets to reach the destination or sink node. Fig 2 shows that end to end delay comparison between SMAC and proposed ADMAC. The delay is analyzed by varying the number of nodes between 10 to 100 nodes. It is observed that end to end delay is keep on increasing as the number of number of nodes are increased. It is due to as the number of nodes increases the number of hops between source and destination also increases and results in delay. There is a reduction of 46.72 % of delay in ADMAC compared with SMAC. It is because of the complete path to the destination is sent along with sync packets and It also synchronizes the next hop node active mode before sending the data packet.

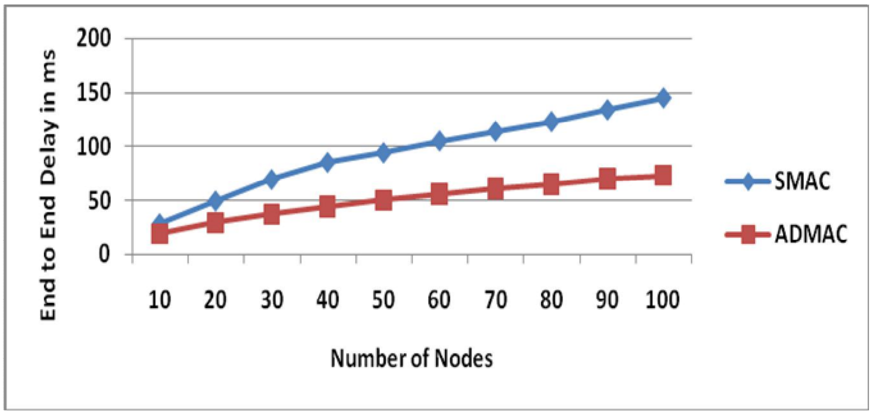

Fig 2 . Number of Nodes Vs End to End Delay in ms

Fig 3 shows that end to end delay in SMAC and ADMAC when the number of hops between source node to destination is taken into account. It is observed from the Fig 3 that the end to end delay is increasing when the number of hops is increasing. The reduction of delay when the number of nodes between source and destination is considered it is 44%. Since the SMAC follows the periodic sleep and wake up scheme, it makes the source node to wait for the next active mode to receive the data. As the number of hops is increasing, the number of waiting for the active mode nodes is also increasing.

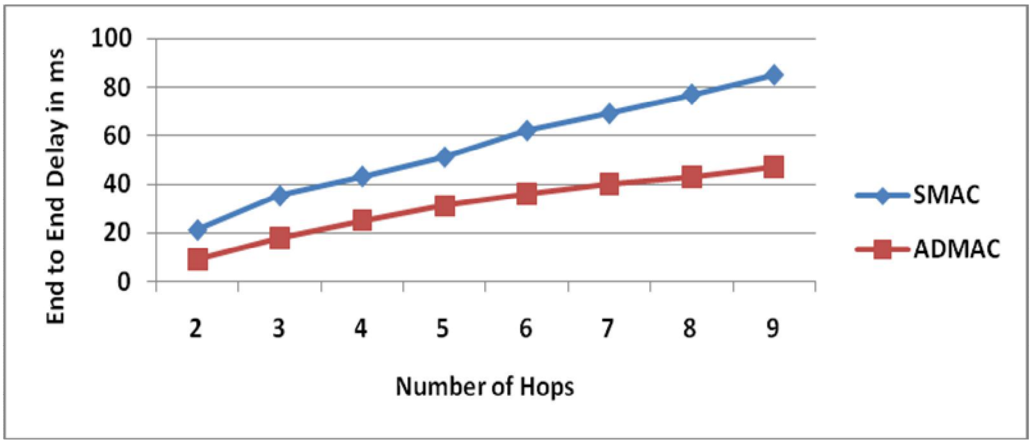

Fig 3. Number of Hops Vs End to End Delay in ms

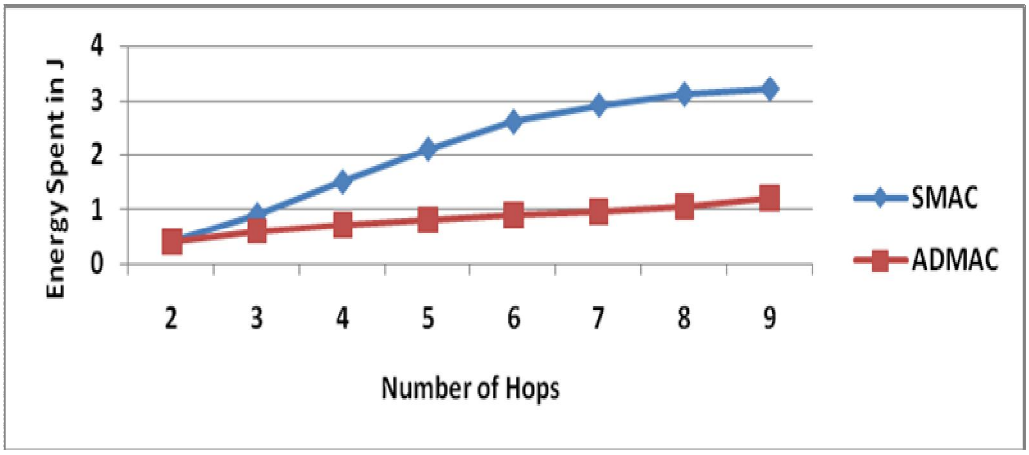

Fig 4. Number of hops Vs Energy spent in J

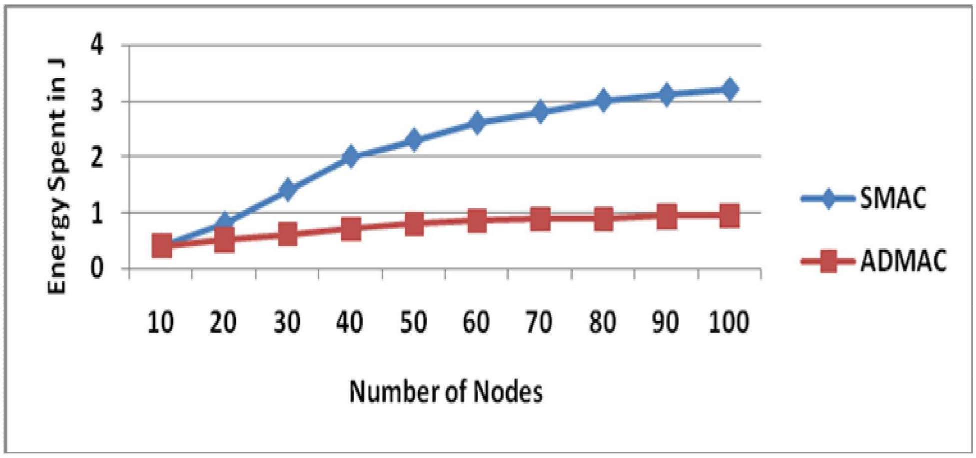

Fig 5. Number of Nodes Vs Energy Spent in J

Energy spent is the average cumulative expenditure of energy among all the nodes in the network. Fig 4 and 5 shows that energy spent in the network are compared with SMAC and ADMAC. When the number of nodes is increasing energy spent in SMAC grows in steep compared to ADMAC. There is a reduction of reduction of 44.9% energy spent in ADMAC when compared with SMAC. It is because of SMAC follows periodic listen and sleep scheme to reduce idle listening. When the node need to transmit the next hop node in the sleep state, then source node need to wait till next active mode. The energy is spent in idle sensing the next hop node availability is reduced. As the number of hops is increasing energy spending the idle listening is reduced. Node with highwork load will notbe considered as intermediate node to forward the data in ADMAC. Hence energy spent in such nodes is reduced.

5. Conclusion

To increase the network lifetime of WSNs is a major concern. It can be increased by reducing energy consumptions through MAC protocols periodic and a- periodic sleep mode mechanisms. In the proposed ADMAC duty cycle is varied by taking nodes rate of energy consumption and filled queue length in account. It allows the nodes which have data to send and if the node has less data to communicate its duty cycle is reduced accordingly. It reduces the delay and energy spent by reducing the idle listening. ADMAC is compared with SMAC for performance parameters like energy spent and end to end to delay. ADMAC reduces 46.72% of end to end delay and 44.9% of energy spent in the network. The performance of the ADMAC still needs to be analyzed for various scenarios and performance metrics.

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