Comparative Analysis of Contention Based Medium Access Control Protocols for Wireless Sensor Networks

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Abstract. Wireless sensor "motes" is small or tiny embedded systems equipped with radios for wireless communication in the networks, which depend on batteries as a power source. The development of Medium Access Control (MAC) protocols which search is for to minimize the energy consumption in the wireless sensor network. Recent contention based MAC protocols reduce energy usage by placing the radio in a low power sleep state when not sending or receiving the message. In this paper the main emphasis is on the analysis of the Contention Based MAC Protocols and energy consumption in the networks. Based on the work done by various researchers conclude that S-MAC is the backbone of all the MAC protocols for wireless sensor networks. Our proposed work investigated the energy usage and compared the performance of IEEE 802.11 MAC protocol with S-MAC protocol on different modes like without periodic sleep and with periodic sleep on different performance metrics like Remaining Energy vs Time, Energy consumption vs global packet id and Average End to End Delay vs Time. The performance of S-MAC protocol improves on the basis of duty-cycle parameter, which determines the length of sleep period in a frame and this parameter is a variable. So changing the duty cycle will change the performance of S-MAC protocol. Finally, we have used the different routing protocol with S-MAC to evaluate the energy consumption. The experimented worked done on Network Simulator Ns2- 2.34.

Keywords: Medium Access Protocol, Wireless Sensor Network, Idle listening, Sleep State, S-MAC, Energy Consumption, Duty cycle.

1 Introduction

Wireless communications start from the late 1800s, when M.G. Marconi did the pioneer work establishing the first successful radio communication systems have been developing and evolving with a furious pace. In the early stages, wireless communication systems were dominated by military usages and supported accordingly to military needs and requirements. Over the past few years, the world

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has become increasingly mobile. As a result traditional ways of networking the world have proven inadequate to meet the challenges posed by our new collective lifestyle. Recent advances in processing, storage, and communication technologies have advanced the capabilities of small-scale and cost-effective sensor systems, which are composed of a single chip with embedded memory, processor, and transceiver.WSN has a great ability of obtaining data and it can work under any situation, at any time, in any place, which makes it useful in many important fields. So, the military department, industrial circle and academic circle of many countries all over the world are paying great attention to it. It also becomes a hot issue in research at home and abroad today, and it is regarded as one of the ten influencing technology in the 21st century [33].

1.1 Wireless Sensor Networks (WSNS)

Wireless sensor networks are consisting of thousands of extremely small and cheap devices that can sense the environment and communicate the data as required. Wireless sensor networks have emerged as one of the first real applications of ubiquitous computing. Sensor networks play a key role in bridging the gap between the physical and the computational world by providing reliable, scalable, fault tolerant and accurate monitoring of physical phenomena. A Wireless sensor network is defined as being composed of a large number of nodes, which are deployed densely in close proximity to the phenomenon to be monitored. As shown in fig. 1 many sensor nodes are scattered in a sensor field and each of these nodes collects data and its purpose is to route this information back to a sink [13]. The network must possess self-organizing capabilities since the positions of individual nodes are not predetermined. Cooperation among nodes is the dominant feature of this type of network, where groups of nodes cooperate to disseminate the information gathered in their vicinity to the user [28].

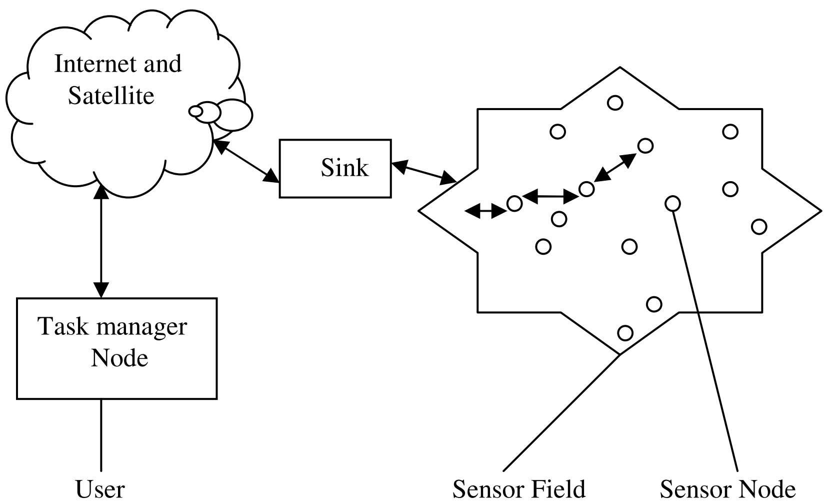

Fig. 1. Sensor nodes scattered in a sensor field

1.2 Features of Wireless Sensor Networks

The design of Wireless Sensor Networks is determined by the sensor nodes characteristics and its application. The important features of WSNs are discussed below.

Energy Limitations. In wireless sensor networks energy is the main issue, whiles the design of the wireless sensor networks. The chip devices which are used in the sensor nodes depend on the battery which provides the energy. Batteries are the most commonly used sources of energy. Thus, we need a mechanism polices for the efficient utilization of the energy resources for long time.

Resistance to Node Failure. The node failure is also the major cause of energy wastage in wireless sensor networks. WSN is dynamic systems and resistance to node failures. There may be changes in the network topology, may be caused by node failure due to various factors such as depleted batteries, environmental factors (fire, flood), an intruder's attack etc.

Scalability. Wireless Sensor Networks may contain hundreds or even thousands of sensor nodes. The WSN should be scalable, meaning that the performance of these networks should be minimally affected by a change in network size. In most of the cases, recharging or replacing batteries is not possible, and adding new sensor nodes is the only way to prolong the lifetime of the network.

Deployment. The deployment of can be in various ways it depend on the requirement, application and environmental condition. It can be deployed randomly over the monitoring field or sensor field. After deployment, the sensor nodes in most applications remain static. Depending on the deployment strategy, suitable communication protocols should be developed based on the existing network topology in order to support the WSN functionality.

Quality of Service (QoS). Quality of service is the most important parameter of the network which gives the information about the reliability of the networks. It means satisfying the application goals by meeting the quality of service requirements which is one of the basics requirements.

1.3 Mac Protocols

There are many existing MAC protocols for wireless sensor networks. In this section a wide range of the MAC protocols is listed with their comparison [10].

- Sensor-MAC (S-MAC)
- WiseMAC
- Traffic-Adaptive MAC Protocol (TRAMA)
- Data gathering-MAC (D-MAC)

- Timeout-MAC (T-MAC)
- Dynamic Sensor-MAC (DSMAC)

One fundamental task of the MAC protocol is to avoid collisions from interfering nodes. The MAC sub-layer uses MAC protocol to ensure that signals sent from different stations across the same channel don't collide. There are many MAC protocols that have been developed for wireless Voice and data communication networks.

Existing MAC protocols can be divided into two broad categories-

- Scheduled based protocols e.g. TDMA, FDMA, CDMA etc.
- Contention based protocols e.g. IEEE 802.11, CSMA etc.**Mac Protocol Design Consideration**

The medium access control protocols for the wireless sensor network have to achieve two objectives.

- The first objective is the creation of the sensor network infrastructure. A large number of sensor nodes are deployed and the MAC scheme must establish the communication link between the sensor nodes.
- The second objective is to share the communication medium fairly and efficiently. To design the efficient MAC protocol for wireless sensor networks, the following characteristics are to be considered [31].

Energy Efficiency. The energy is the most important factor in the wireless sensor nodes. The sensor nodes are battery powered and it is often very difficult to change or recharge batteries for these sensor nodes.

Latency. Latency requirement basically depend on the application in the sensor network.

Throughput. Throughput requirement are also varies with different application in the wireless sensor network.

Duty Cycling. Duty cycling is also one of the important mechanisms is used for energy efficient MAC protocol in sensor network.

1.5 Sources of Energy Consumption at the MAC Layer

From the point view of energy dissipation, four major sources of energy waste are caused by MAC layer problems [39]. Retransmission of process is due to the collision or congestion. In WSNs, all nodes are capable of transmitting data through the same broadcast channel. As a tiny communication device, each sensor node may have only one receiving antenna; therefore, if two or more transmissions from multiple sources arrive at the same time, a collision will happen, and none of transmitted packets can be received correctly.

Idle channel sensing In order to eliminate or reduce collisions, nodes must sense the channel continuously to obtain scheduling information or wait before sending data until the channel is detected idle. In either case, extra sensing energy is needed.

Overhearing is sharing a common wireless medium; the data transmitted by one node can reach all the other nodes within their transmission range. A node then may receive packets not destined for it. This is referred to as overhearing and it also wastes energy.

Overhead due to control messages, a lot of MAC protocols operate by exchanging control messages for signaling, scheduling, and collision avoidance, which will consume extra energy. Therefore, in order to design an energy-efficient MAC protocol, collisions must be avoided as much as possible. Many approaches have been proposed, but it is difficult to achieve all energy-conserving objectives at the same time.

2 Related Works

According to the work done by [13] in this they discussed the present communication architecture for sensor networks and proceed to survey the current research pertaining to all layers of the protocol stack that is physical, data link, network, transport and application layers. They defined sensor network as being composed of a large number of nodes, which are deployed densely in close proximity to the phenomenon to be monitored. Each of these nodes collects data and its purpose is to route this information back to a sink. They propose that sensor network must possess self-organizing capabilities since the positions of individual nodes are not predetermined [17]. The author [3] examines that how CSMA based medium access can be adapted for sensor networks. However, these approaches are not directly applicable due to the following characteristics of sensor networks-

- Network operates as a collective structure
- Traffic tends to be periodic and highly correlated
- Equal cost per unit time for listening, receiving and transmitting

The authors outline a CSMA-based MAC and transmission control scheme to achieve fairness while being energy efficient. The adaptive rate control proposed uses loss as collision signal to adjust transmission rate in a manner similar to the congestion control in TCP [3].

In 2002 another author [39] gives the novel technique about S-MAC, a medium-access control (MAC) protocol designed for wireless sensor networks. S-MAC uses three novel techniques to reduce energy consumption and support self-configuration. To reduce energy consumption in listening to an idle channel, nodes periodically sleep. Neighboring nodes form virtual clusters to auto-synchronize on sleep schedules.

Inspired by PAMAS, S-MAC also sets the radio to sleep during transmissions of other nodes. Unlike PAMAS, it only uses in-channel signaling. Finally, S-MAC applies message passing to reduce contention latency for sensor-network applications that require store-and-forward processing as data move through the network. Finally the authors point out that the experiment results show that, on a source node, an 802.11-like MAC consumes 2–6 times more energy than S-MAC [39]. The authors [40] include significant extensions in the protocol design, implementation, and experiments of S-MAC work. This paper presents S-MAC, a medium access control protocol specifically designed for wireless sensor networks. Energy efficiency is the primary goal in the protocol design. Low-duty-cycle operation of each node is achieved by periodic sleeping. This paper proposes adaptive listening, which largely reduces such cost for energy savings. It enables each node to adaptively switch mode according to the traffic in the network [40].

According to the author, Huan Pham, A new adaptive mobility-aware Sensor MAC protocol (MS-MAC) for mobile sensor applications. In S-MAC protocol, a node detects its neighbor's mobility based on a change in its received signal level from the neighbor, or a loss of connection with this neighbor after a timeout period. By propagating mobility presence information, and distance from nearest border node, each node learns its relative distance from the nearest mobile node and from nearest border node. Depending on the mobile node movement direction, the distances from mobile and border nodes, a node may trigger its neighbor search mechanism to quicken the connection setup time [12].

The author critically evaluated the topology changes and presents a mobility-adaptive, collision-free MAC protocol for mobile sensor networks. MMAC caters for both weak mobility (e.g. topology changes, node joins and node failures) and strong mobility (e.g. concurrent node joins and failures, and physical mobility of nodes). Finally authors point out that this protocol adapts the time frame, transmission slots, and random-access slots according to mobility [26].

The author Zhiwei Zhao et al. states that at present, most MAC protocols use the same transmission power when sensor nodes send packets. However, the deployment of the sensor nodes is asymmetrical in wireless sensor networks, which will bring more energy consumption and unnecessary collisions. This paper, proposed a transmission power control protocol for WSNs based on SMAC protocol. Power control at the MAC layer selects the minimum amount of transmitting energy needed to exchange messages between any pair of neighboring nodes. The simulation results show that, compared with SMAC protocol, proposed protocol has improved a lot in the delay of packets, reception rate, energy consumption and throughput of the networks [44]. R.Yadav and S. Verma present the challenges in the design of the energy efficient medium access control (MAC) protocols for the wireless sensor network. Authors describe several MAC protocols for the WSNs emphasizing their strength and weakness wherever possible. Finally, discuss the future research directions in the MAC protocol design [33].

Authors [43] have provided some good comparisons on some of the prominent protocols that use power management mechanism topology control. The key idea of power control is that, instead of transmitting using the maximum power, nodes in a

WSN collaboratively determine their transmission power while preserving some required properties. The basic idea of sleep scheduling is to save energy by putting redundant nodes into the sleeping mode.

A. Roy and N. Sharma critically evaluate the different parameter for saving the energy in wireless sensor network. Wireless sensor networks have been widely used in many important fields such as target detection and tracking, environmental monitoring, industrial process monitoring, and tactical systems. As nodes in wireless sensor networks typically operate unattended with a limited power source, energy efficient operations of the nodes are very important. Although energy conservation in communication can be performed in different layers of the TCP/IP protocol suit, energy conservation at MAC layer is found to be the most effective one due to its ability to control the radio directly. In this author have investigate the available energy-efficient MAC protocols for sensor networks emphasizing their energy saving methods [1]. In this they give the energy model in MAC Layer of wireless sensor network and different parameter used in the ns 2 simulation Trace file.

The literature survey gives the details about the research area and briefly discusses the paper with its conclusion. After doing the literature survey we came to know about the major sources of energy wastages and different routing protocols. It is found that there are many existing MAC protocols for wireless sensor networks including S-SMAC. S-MAC is the most popularly used MAC protocols for wireless sensor networks. In this still there is open issues discuss by the researcher even found in the survey about the energy and their causes like idle listening, collusion , overhearing , problem in synchronization and message passing. So, this paper would take S-SMAC as the problem area and we will discuss in details.

3 S-Mac Protocols

S-MAC protocol was proposed by SCADDS project group at USC/ISI (Scadds, available online). S-MAC is most popularly used protocol designed specifically for WSN. S-MAC is designed aiming at the requirement of saving energy of WSN according to 802.11 MAC. The main goal of S- MAC protocol is to reduce energy consumption, while supporting good scalability and collision avoidance [39]. This protocol tries to reduce energy consumption from all the sources that have been identified to cause energy waste, i.e., idle listening, collision, overhearing and control overhead.

3.1 Periodic Listen and Sleep

As stated above, in many sensor network applications, nodes are idle for long time if no sensing event happens. Given the fact that the data rate is very low during this period, it is not necessary to keep nodes listening all the time. S-MAC reduces the listen time by putting nodes into periodic sleep state. The basic scheme is shown in Fig.2. Each node sleeps for some time, and then wakes up and listens to see if any other node wants to talk to it. During sleeping, the node turns off its radio, and sets a timer to awake itself later. All nodes are free to choose their own listen/sleep schedules.

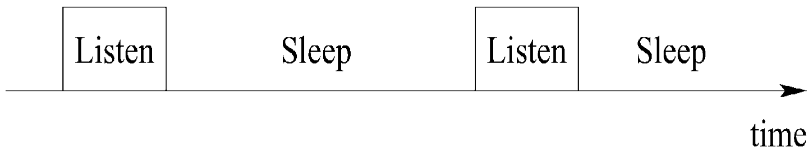

Fig. 2. Periodic listens and sleeps

3.2 Collision Avoidance

If multiple neighbors want to talk to a node at the same time, they will try to send when the node starts listening. In this case, they need to contend for the medium. Among contention protocols, the 802.11 does a very good job on collision avoidance. S-MAC follows similar procedures, including virtual and physical carrier sense, and the RTS/CTS exchange for the hidden terminal problem [37].There is a duration field in each transmitted packet that indicates how long the remaining transmission will be. If a node receives a packet destined to another node, it knows how long to keep silent from this field. The node records this value in a variable called the Network Allocation Vector (NAV) [42].

Carrier sense time is randomized within a contention window to avoid collisions and starvations. The medium is determined as free if both virtual and physical carrier sense indicates that it is free. All senders perform carrier sense before initiating a transmission. If a node fails to get the medium, it goes to sleep and wakes up when the receiver is free and listening again. Broadcast packets are sent without using RTS/CTS. Unicast packets follow the sequence of RTS/CTS/DATA/ACK between the sender and the receiver. After the successful exchange of RTS and CTS, the two nodes will use their normal sleep time for data packet transmission. They do not follow their sleep schedules until they finish the transmission.

3.3 Adaptive Listening

The scheme of periodic listen and sleep is able to significantly reduce the time spent on idle listening when traffic load is light [39]. However, when a sensing event indeed happens, it is desirable that the sensing data can be passed through the network without too much delay. When each node strictly follows its sleep schedule, there is a potential delay on each hop, whose average value is proportional to the length of the frame.

S-MAC follows an important technique, called adaptive listen [40] to improve the latency caused by the periodic sleep of each node in a multi-hop network. The basic idea is to let the node who overhears its neighbor's transmissions (ideally only RTS or CTS) wake up for a short period of time at the end of the transmission. In this way, if the node is the next-hop node, its neighbor is able to immediately pass the data to it instead of waiting for its scheduled listen time. If the node does not receive anything during the adaptive listening, it will go back to sleep until its next scheduled listen time.

3.4 Message Passing

This section describes how to efficiently transmit a long message in both energy and latency. A message is the collection of meaningful, interrelated units of data. The receiver usually needs to obtain all the data units before it can perform in network data processing or aggregation. The disadvantages of transmitting a long message as a single packet are the high cost of re-transmitting the long packet if only a few bits have been corrupted in the first transmission. However, if we fragment the long message into many independent small packets, we have to pay the penalty of large control overhead and longer delay. It is so because the RTS and CTS packets are used in contention for each independent packet. This protocol fragments the long message into many small fragments, and transmits them in a burst. Only one RTS and one CTS are used. They reserve the medium for transmitting all the fragments. Every time a data fragment is transmitted, the sender waits for an ACK from the receiver. If it fails to receive the ACK, it will extend the reserved transmission time for one more fragment, and re-transmit the current fragment immediately.

4 Research Methodologies

The simulation methodology used to perform our experiment work on Network Simulator Ns2-2.34. This work would analyze the performance of MAC and S-MAC protocol on different parameters with the NS-2 (Network Simulator-2) version 2.34 is chosen for simulation purpose.

4.1 Proposed Work

The proposed work would compared the performance of IEEE 802.11 MAC protocol with S-MAC protocol on different parameters that is without periodic sleep and with periodic sleep on different performance metrics like remaining Energy vs Time, Energy consumption vs Global packet id and Average End to End Delay vs Time. And determine the length of sleep period in a frame using duty cycle parameter to show the fundamental tradeoffs on energy and latency. Finally, investigate how the performance of S-MAC protocol improves on the basis of duty-cycle and different routing protocol to save more energy, through the simulation studies.

5 Results and Discussion

5.1 Simulation Environment

This section presents the topology and different parameters used in the simulation process. Fig.3 shows the topology which is having 11 nodes with one source and one sink. The first node is the source and the last node is the sink which is static and of 10 hop linear network.

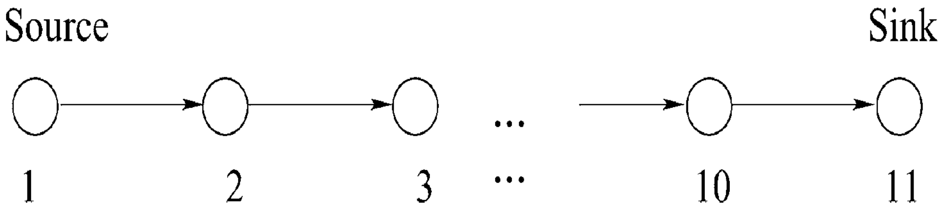

Fig. 3. 10-Hop linear network with one source and one sink

This simulation process considered a wireless network of 11 static nodes which are placed within a 500m x 500m area. CBR (constant bit rate) traffic is generated among the nodes. The simulation runs for 100 Seconds. Table 1 shows the important simulation parameters used in the simulation process.

Table 1. Important Simulation Parameters

Parameters	Values
Simulation time	100 Sec
Simulation area	500m x 500m
Antenna	Omni antenna
No. of nodes	11
Packet size	512 Bytes
Max queue length	50
Traffic	CBR
Routing protocol	AODV
Energy	100j
Idle Power	1j
Rx Power	1j
Tx Power	1j
SMAC duty cycle	10 %

5.2 Experimented Results

Remaining Energy

The Value of MAC protocol Trace from Tr. file generated by the Ns2 simulator. We have analyzed and evaluated the trace file and trace the value of remaining energy and compare the energy of MAC and S-MAC without sleep and with sleep with same time approximately. Fig. 4 shows the measured remaining energy at the node and energy consumption in network with time changing. In this case, the graph shows the remaining energy in the network at the node. In this we have experimented that 802.11 MAC uses more than twice the energy used by S-MAC with periodic sleep. Since idle listening rarely happens, energy savings from periodic sleeping is very limited. S-MAC achieves energy savings mainly by avoiding overhearing and efficiently transmitting long messages.

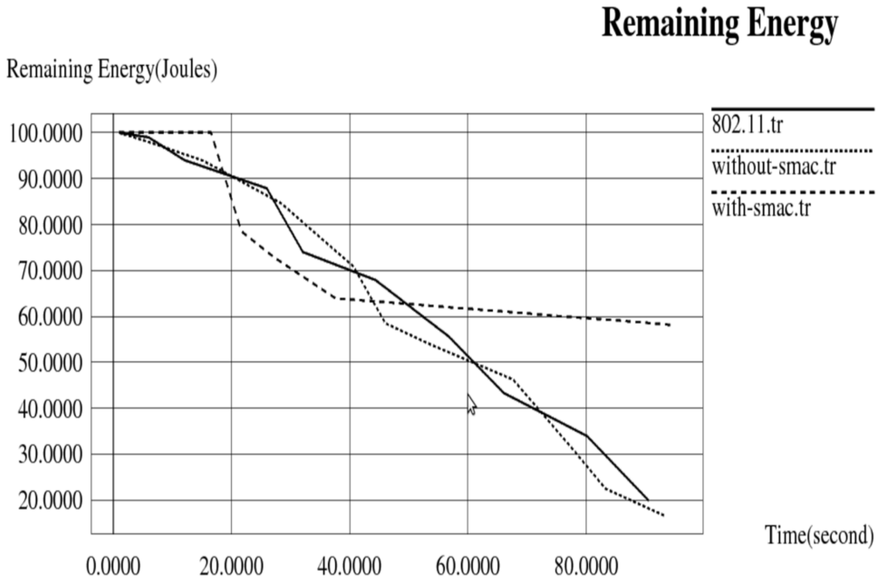

Fig. 4. Remaining Energy vs Time in Network

The S-MAC protocol with periodic sleep has the best energy performance than 802.11 MAC. S-MAC without periodic sleep also performs better than 802.11MAC. However, as shown in the figure, when idle listening dominates the total energy consumption, the periodic sleep plays a key role for energy savings.

Energy Consumption at Source Node

We change the traffic load by varying the inter-arrival period of messages. If the message inter-arrival period is 10s, a message is generated every 10s by each source node. In this experiment, the message inter-arrival period varies from 1 to 10s. Duty cycle parameter for S-MAC with periodic sleep mode is kept 10%. For each traffic pattern, we have done five independent tests when using different MAC protocols. In fig.5 we have shown the consumed energy from the trace file of MAC and SMAC without sleep and with sleep. So, from the figure it has been concluded that SMAC consume less energy than the MAC protocol which prolong the sensor node life for long time. Fig.5 shows the measured average energy consumption at source node in network. In above case, the S-MAC with periodic sleep protocol has the best energy performance, and far outperforms IEEE-802.11 MAC and S-MAC without periodic sleep.

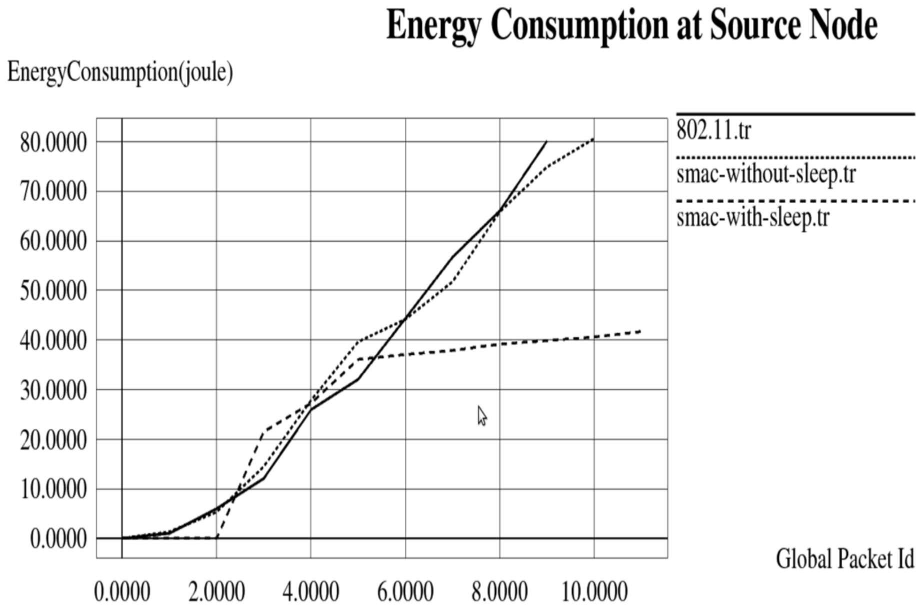

Fig. 5. Energy Consumption on Radios at Source Node

Measurement of Average End to End Delay

In fig.6 we have evaluated delay result from trace file. Since S-MAC makes the tradeoff of latency for energy savings, we expect that it can have longer latency in a multi-hop network due to the periodic sleep on each node. To quantify latency and measure the benefits of S-MAC, we use the same ten-hop network topology. In fig.6 we measure latency of IEEE-802.11 and S-MAC protocols.

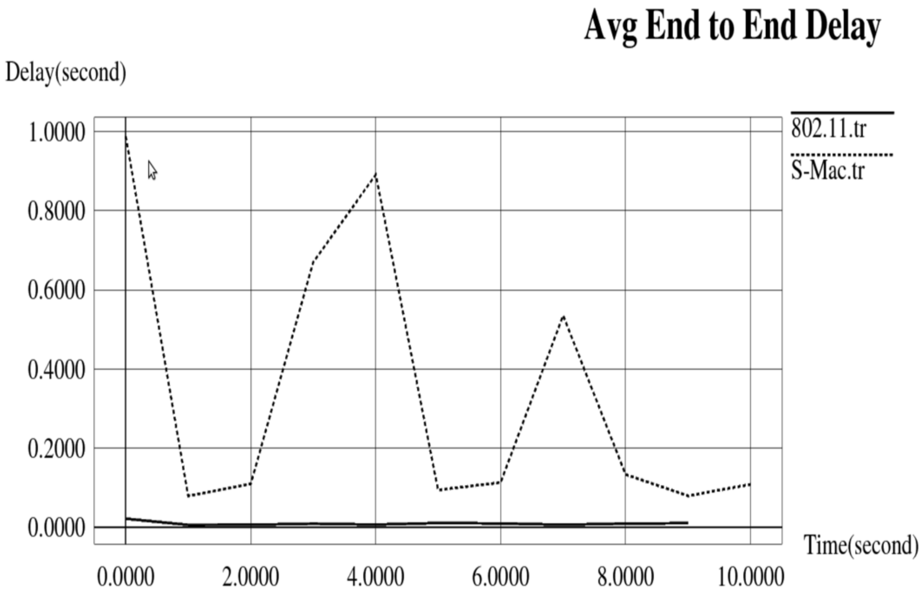

Fig. 6. Average Delay vs Time

5.3 Modification for Heavy Traffic Load With 20% Duty Cycle

This section presents the topology and different parameters used in the simulation scenario in Table 2. In this, the topology is having of two nodes with one source and one sink. This simulation process considered a wireless network of two static nodes, CBR (constant bit rate) traffic is generated among the nodes. The simulation runs for 50 seconds, used for heavy traffic load with 20% duty cycle. Table 2 shows the important simulation parameters used in the simulation process. In this we have changed the different parameter and analyze the trace file value and its performance with the duty cycle.

Table 2. Important Simulation Parameters with 20%Duty Cycle

Parameters	Values
Simulation time	50 Sec
Simulation area	500m x 500m
Antenna	Omni antenna
No. of nodes	02
Packet size	512 Bytes
Max queue length	50

Table 3. (*Continued*)

Parameters	Values
Traffic	CBR
Routing protocol	AODV
Energy	50j
Idle Power	1j
Rx Power	1j
Tx Power	1j
SMAC duty cycle	20 %

Remaining Energy with 20% Duty Cycle

We evaluate the value with the last second of the simulation that how much energy remains in the sensor node. Fig.7 shows the measured remaining energy in network with time changing. In this case, 802.11 MAC uses more than twice the energy used by S-MAC with periodic sleep. Since idle listening rarely happens, energy savings from periodic sleeping is very limited. S-MAC achieves energy savings mainly by

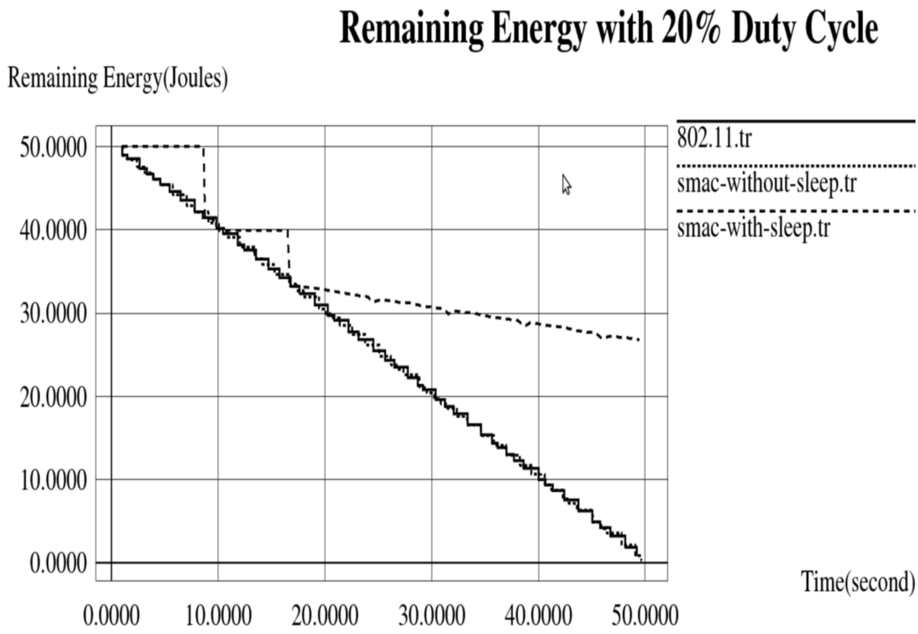

Fig. 7. Remaining Energy vs Time in Network

avoiding overhearing and efficiently transmitting long messages. The graph below show the remaining energy with 20% duty cycle which shows that S-Mac with sleep state consume less energy and save energy for long life of the sensor node. 802.11 MAC protocol and S-MAC without sleep state shows the common remaining energy.

Performance Evaluation Using Different Routing Protocol with SMAC Protocol
The energy consumption is also depending on the different routing protocol. In this simulation we have used the routing protocol AODV,DSDV and DSR with S-MAC.

Remaining Energy

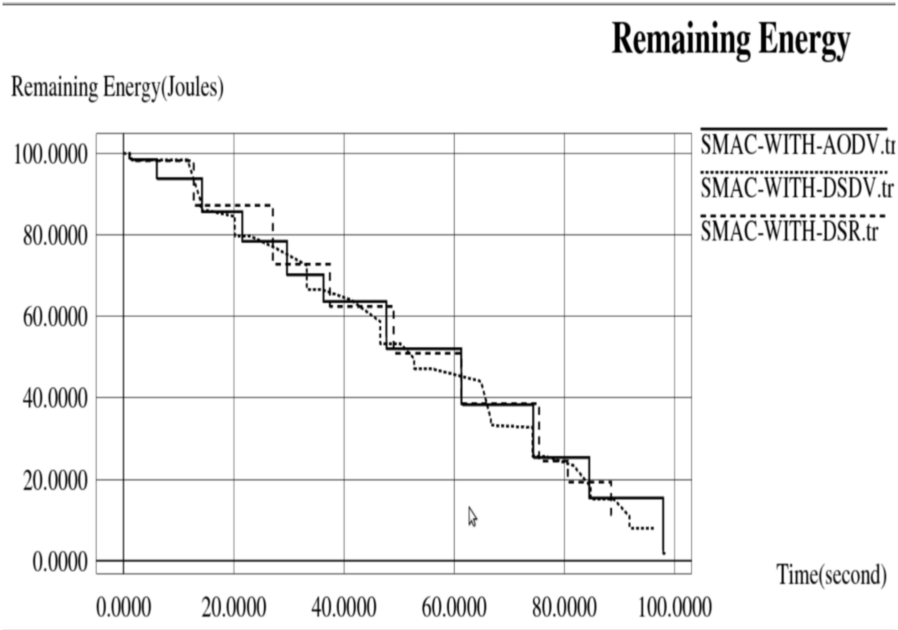

Fig. 8. Remaining Energy with Time between AODV, DSR and DSDV routing protocol

In the above simulated graph we analyze the remaining energy in the sensor node with different routing protocol. In this we have simulated SMAC protocol with AODV routing protocol. Then we analyze the S-MAC protocol with DSDV routing protocol and we analyze that the remaining energy with DSR routing which result is slightly different from AODV on different simulation time. Finally we analyze that the S-MAC protocol with DSDV and AODV which gives better energy saving.

Form fig.8, we can conclude that SMAC with DSR and SMAC with DSDV give the similar result with minor difference. The remaining energy of SMAC with AODV remains the more energy for long life of the sensor node.

6 Conclusion

The energy is most important to run the wireless sensor nodes in network for long time. In this paper we have discussed the different issues of energy wastage and energy consumption parameter. We discuss how the wireless network and wireless sensor networks consume energy in transferring the message. The main problem is collision in S-MAC protocols which have been removed with the mechanism sleep state for some time and wake up when it sense the message or data. S-MAC and MAC protocol discuss in details, it has been concluded that S-MAC is the most popularly used MAC protocol for wireless sensor networks. In our work we have compared the performance of IEEE 802.11 MAC protocol with S-MAC protocol on energy consumption in network. S-MAC obtains significant energy savings compared with 802.11 IEEE protocol without sleeping, which is clearly discussed in the experimented result section.

It has been found that at the end of the simulation time we see 5% to 15% energy saving and some time it more or less. It depends on the design of the network scenario. The simulation conclusion shows that the S-MAC with periodic sleep obtains more energy savings compared with IEEE-802.11 protocol and S-MAC without periodic sleeping protocol. The duty cycle parameter plays an important energy saving mechanism which is variable and change up to 20%, which determines the length of sleep period in a frame. It is able to greatly prolong the network lifetime, which is critical for real world sensor network applications. Periodic sleeping provides excellent energy performance at light traffic load. It makes S-MAC with periodic sleep and adaptive listening ideal for sensor networks where traffic is intermittent. Finally, we compare the S-MAC protocol with different routing protocols like DSR, DSDV and AODV.

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