Medium Access Control Protocol for Energy Efficiency in Wireless Sensor Networks

A. Prashant J Bagga, B. Nagendra P Gajjar

***Abstract*--Wireless sensor networks provide wide variety of real time application. It can collect and process vast amount of data from environment like pollution, traffic conditions, weather, industrial process monitoring, and condition based maintenance. But due to lower sensing range of these networks, dense networks are required, which bring the necessity to achieve an efficient medium access (MAC) protocol subject to power constraints. Various MAC protocols with different objectives were proposed for wireless sensor networks. In this paper, we have proposed– MAC protocol for demonstrating saving in the energy consumption from all the sources of energy waste like idle listening, collision, overhearing and control overhead**

***Index Terms*— Environment monitoring, idle listening, Latency analysis, sleep-wake up cycle.. MAC**

I. INTRODUCTION

Researchers in the Life Sciences are becoming increasingly concerned about the potential impacts of human presence in monitoring plants and animals in field conditions. At worst it is possible that chronic human disturbance may distort results by changing behavioral patterns or distributions.

These considerations are of particular importance for studying the bird behavior like Nalsarovar bird sanctuary located in Gujarat. For purposes of automation of data collection and reduction of human intervention in areas of interest, sensor networks can be considered. Deploying sensor networks will not interfere with existing life. Recent developments in wireless network technology and miniaturization now make it possible to realistically monitor the natural environment. Instrumentation of natural spaces with numerous networked micro-sensors can enable long-term data collection at scales and resolutions that are difficult, if not impossible, to obtain otherwise. The intimate connection with its immediate physical environment allows each sensor to provide localized measurements and detailed information that is hard to obtain through traditional instrumentation. The combination of storage and in-node processing enable them to perform triggering functions suitable for some applications and protocols.

Environmental monitoring is a significant driver for wireless sensor network research, promising dynamic, real-time data about monitored variables of an area and so enabling many new applications. Because of this, almost all real experiments were conducted with this application background. In particular, the first published experience with real deployments of sensor networks were about habitat monitoring [3]. Only recently other application backgrounds such as wildfire monitoring were considered in real experiments.

Unfortunately, due to the innovative nature of the technology, there are currently very few environmental sensor networks in operation that demonstrate their value. Examples of such networks include NASA/JPL's project in Antarctica [4], Berkeley's habitat modeling at Great Duck Island [1], the CORIE project which studies the Columbian river estuary [5], deserts [6], volcanoes [7] and glaciers [8]. The research efforts in these projects are constantly thriving to a pervasive future in which sensor networks that would expand to a point where information from numerous such networks (e.g. glacier, river, rainfall and oceanic networks) could be aggregated at higher levels to form a picture of the environment at a much higher resolution.

Sensor nodes are the network components that will be sensing and delivering the data. Node transmits its data to its neighbouring nodes or simply passes the data as it is to the Task Manager. Sensor nodes can act as a source or sink in the sensor field. The function of a source is to sense and deliver the desired information. Thus, a source reports the state of the environment. On the other hand, a sink is a node that is interested in some information a sensor in the network might be able to deliver. Gateways allow the scientists and system managers to access nodes through personal computers (PCs), personal digital assistants (PDA) and Internet. In a nutshell, gateways act as a proxy for the sensor network on the Internet.

The Task Manager will connect to the gateways via some media like Internet or satellite. Task Managers comprise of data service and client data browsing and processing. These Task Managers can be visualized as the information retrieval and processing platform. All information (raw, filtered, processed) data coming from sensor nodes is stored in the task managers for analysis. Users can use any display interface (i.e. PDA, computers) to retrieve or analyze data either locally or remotely.

The wireless sensor networks which have sensing, computation and communication functions to move packets from sensor nodes to final servers, consume quantities of energy that must be taken into account to forecast the life cycle of a network and maximize it.

Here an attempt is made to analyze the evaluation of MAC layer protocol for environmental application using simulation tool. S-MAC (Sensor – MAC)[3] uses techniques to reduce energy consumption and support self configuration and also supports low duty cycle operation in a multihop network. Nodes form virtual clusters based on common sleep schedules to reduce control overhead and enable traffic adaptive wake-up. S-MAC uses in-channel signaling to avoid overhearing unnecessary traffic. Finally S-MAC applies message passing to reduce contention latency for applications that require in-network data processing. The report is organized into following section: section II describes the S-MAC protocol for environmental application, section III discusses the simulation of S-MAC protocol, section IV presents the result and analysis of simulation process and section V discusses the conclusion and future work. The paper ends with references in section VI

II. S-MAC PROTOCOL

S-MAC tries to reduce energy wastes from all of sources. To reduce control overhead & latency, S-MAC introduces co-ordinates sleeping among neighbouring nodes. Latency can be important or unimportant depending upon application.

In applications such as surveillance or monitoring, nodes will be vigilant for long time, but largely inactive until something is detected. These applications can often tolerate some additional messaging latency, because the network speed is orders of magnitude faster then the speed of the physical object. S-MAC lets node sleep periodically if they are idle. This design reduces energy consumption but increases latency since sender must wait for the receiver to wake up before it can send data. Another technique, called adaptive listen reduces this latency.

S-MAC re-introduces the concept of message passing to efficiently transmit long messages. Message passing saves energy by reducing control overhead and avoiding overhearing.

Periodic listen and sleep

S-MAC reduces the listen time by putting nodes into periodic sleep state as shown in figure 1 below.

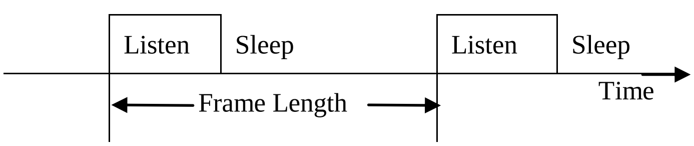

Figure: 1 Periodic Sleep and listen

Neighbouring nodes synchronize their listen / sleep schedule to reduce control overhead. Not all neighbouring nodes can synchronize together in multi-hop network.

Nodes exchange their schedule by periodically broadcasting a SYC packet to their immediate neighbours. A node can talk to its neighbour at their scheduled listen time, thus ensuring that all neighbouring nodes can communicate even if they have different schedules. The period for a node to send a SYNC packet is called a synchronization period.

Nodes form virtual clusters around common schedules. One advantage of this loose coordination is that it can be more robust to topology change than cluster based approaches. Disadvantage of this scheme is increased latency due to periodic sleeping.

Collision avoidance:

S-MAC follows similar procedures as the 80211 does for collision avoidance, including virtual and physical carrier sense and the RTS/CTS exchanges for hidden terminal problem.

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 variable NAV (Network allocation vector) and sets a time for it. Every time when the tuner fires, the node decrements its NAV until it reaches zero. If NAV is not zero, node determines that medium is busy. This is called virtual carrier sense. Physical carrier sense is done at physical layer by listening to channel for possible transmissions. Carrier sense time is randomized within a contention window to avoid collisions & 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 transmission. If a node fails to get a medium it goes to sleep and wakes up when the receiver is free and listening again. Broadcasts packets are send without RTS/CTS and unicast packets follow the sequence of RTS/CTS/DATA/ACK between the sender and receiver. After RTS/CTS, sender and receiver will use their normal sleep time for transmission of data packets. They do not follow sleep schedule until they finish the transmission.

S-MAC effectively addresses energy wastes due to idle listening & collisions.

Advantages of S-MAC:

- Energy waste caused by idle listening is reduced.
- It has simplicity in implementation.
- Overhead of time synchronization is prevented with sleep schedule announcement.

Disadvantages of S-MAC

- Broadcast data packets do not use RTS/CTS which incurs collision probability.
- Adaptive listening incurs overhearing or idle listening if packets are not destined to the listening node.
- Sleep & listen periods are predefined and constants, which decreases the efficiency of the algorithm under variable traffic load.

III. SIMULATION OF MAC PROTOCOL FOR ENVIRONMENTAL APPLICATION

The environmental application requires continuous sampling of data at defined rate. There are two types of data: sampling and triggered. Sampling data is obtained by sampling a certain parameter a given number of times every day while triggered data is disseminated after a certain event has happened. For energy saving purposes, it is important to differentiate between these two types of data. The S-MAC protocol is proposed to exploit the advantages that sampling data has from an energy saving perspective and, at the same time, cope with latency requirements of triggered data.

Sampling data has two great advantages: first, the number of samples to take in a given period of time is known in advance and second, instants to take the samples are also known. This fact leads us to the idea that between two consecutive sample instants, the communication functions of two nodes is almost null. In this way, the S-MAC protocol exploits this fact to save energy by turning off its radio between two consecutive sample instants for data transmissions. Significant energy savings can be achieved by this operation as idle listening is the most energy consuming operation. However, if the radio is simply turned off, no triggered packets can be transmitted from originating nodes to the base station in a reasonable time. In such situation, triggered packets would be queued up and would also wait for the next available active time slot to be transmitted; what would create a long delay for triggered data, which would ideally have to be transmitted without delay. Furthermore, collisions would increase dramatically because all nodes in the network would content for the medium when the next time slot started. The S-MAC uses RTS/CTS/DATA/ACK mechanism for exchange of packets between nodes protocol.

Here, S-MAC protocol is simulated using Ns-2 to study the behaviour of the protocol for suitability of environmental application. Following are the assumptions made for energy analysis:

- Sampled packets are small enough to be transmitted in a single listen interval.
- Only one node in the network generates sampled packets.
- There is a single route to Base Station.
- Each node has only two neighbors.
- There are no collisions.
- There are no retransmissions.

Network configuration shown in Figure 1has the following characteristics:

- The four nodes (0, 1, 2, 3) are on a straight line with 150m in apart.
- Node 0 can reach only node 1, 1 can reach 0 and 2, 2 can reach 1 and 3 and 3 only 2.
- The objective of each node is to transmit its data packets to node 3 (Base Station).
- The synchronization and control information is also exchanged between neighbors.

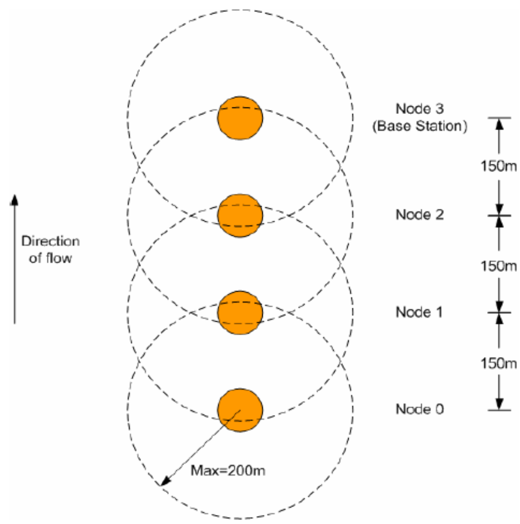

Figure: 1 Initial Node set as visualized in Network

Due to the number of nodes used in the simulation, all nodes must have the same listen/sleep schedule, forming a single virtual cluster. At 100 second, node 0 starts sending 10-byte data packets with a Exponential traffic generator at a mean sending rate. This rate of transmission can also be expressed as the mean time between consecutive packets that we call message inter-arrival time. Each simulation is run at constant duty cycle. For each given constant rate the duty cycle is changed from 10% to 50%. At the end of each simulation, the remaining energy a node is saved for further computations. Then, to compute the total energy consumed in each simulation, the remaining energy is subtracted from initial energy configured to get the energy consumed in a node.

IV. RESULTS AND ANALYSIS

Latency Analysis

Average delay per packet is calculated as:

$$\frac{Average\ delay}{packet} = \frac{Total\ end\ to\ end\ delay\ for\ all\ received\ packets}{Total\ packets\ received}$$

TABLE 1

Average delays (ms) per packet for range of duty cycles

% Duty Cycle	End to end delay	Duty cycle	End to end delay
20	864	60	382
30	645	70	303
40	544	80	288
50	435	90	229

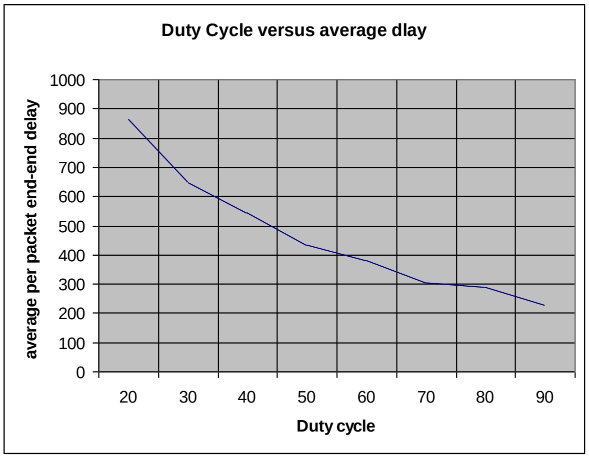

Figure: 2 End-to-end delays for each packet for various duty cycles

Following observation can be made from the above figure 2: As duty cycle is increased the average end-to-end delay time of a packet decrease.

At lower duty cycle, the energy consumed is less but the latency is increased.

In our application of environmental monitoring, time criticality of data is not important. There is no real time quality of service requirements. Hence in less time critical applications like environmental applications, the S-MAC gives more energy savings at the cost of increased latency. The applications like surveillance system or disaster management system, where real time availability of data is critical, the S-MAC with fixed duty cycle will prove to be less effective.

Energy Analysis

The results obtained are organized into Tables 2 to 4. In such tables, for each message inter-arrival time, five simulations results are listed. The message inter-arrival period can help us calculate the mean sending rate at which node 0 sends its 10-byte packets:

TABLE: 2
ENERGY CONSUMED (mJ) IN EACH NODE AT THE END OF SIMULATION USING THE MAC PROTOCOL AT INTER-ARRIVAL TIME OF 100

Energy consumed (mJ) in each node with S-MAC protocol					
Message inter-arrival time Node 0 = 100 ms	Duty Cycle = 10%	Duty Cycle = 20%	Duty Cycle = 30%	Duty Cycle = 40%	Duty Cycle = 50%
Node 0	8104	9384	9483	9562	9574
Node 1	7856	9233	9348	9424	9492
Node 2	7966	9275	9381	9444	9510
Node 3	7897	9205	9357	9407	9482
Total	31823	37097	37569	37837	38058

TABLE: 3
ENERGY CONSUMED (mJ) IN EACH NODE AT THE END OF SIMULATION USING THE MAC PROTOCOL FOR INTER-ARRIVAL TIME OF 200

Energy consumed (mJ) in each node with S-MAC protocol					
Message inter-arrival time Node 0 = 200 ms	Duty Cycle = 10%	Duty Cycle = 20%	Duty Cycle = 30%	Duty Cycle = 40%	Duty Cycle = 50%
Node 0	6305	9350	9462	9592	9653
Node 1	6022	9187	9339	9450	9537
Node 2	6173	9224	9371	9470	9563
Node 3	6185	9178	9326	9443	9533
Total	24685	36939	37498	37955	38286

TABLE: 4
ENERGY CONSUMED (mJ) IN EACH NODE AT THE END OF SIMULATION USING THE MAC PROTOCOL AT INTER-ARRIVAL TIME 0F 300

Energy consumed (mJ) in each node with S-MAC protocol					
Message inter-arrival time Node 0 = 300 ms	Duty Cycle = 10%	Duty Cycle = 20%	Duty Cycle = 30%	Duty Cycle = 40%	Duty Cycle = 50%
Node 0	4376	9303	9497	9537	9664
Node 1	4234	9102	9359	9455	9572
Node 2	4296	9135	9368	9471	9577
Node 3	4405	9105	9331	9438	9570
Total	17311	36645	37555	37901	38383

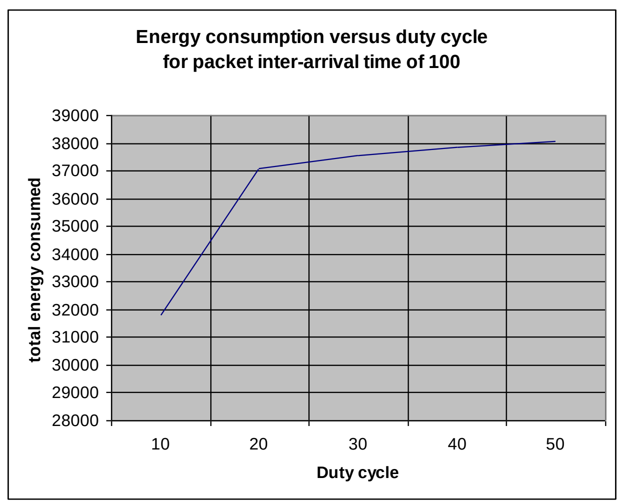

Figure: 3 Energy consumed for inter-arrival time of 100

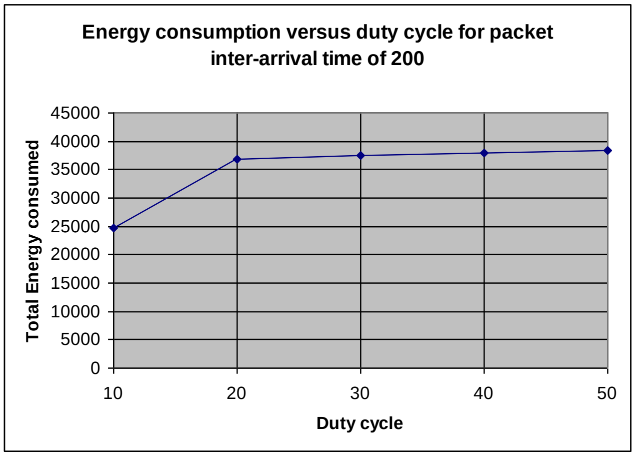

Figure: 4 Energy consumed for inter-arrival time of 200

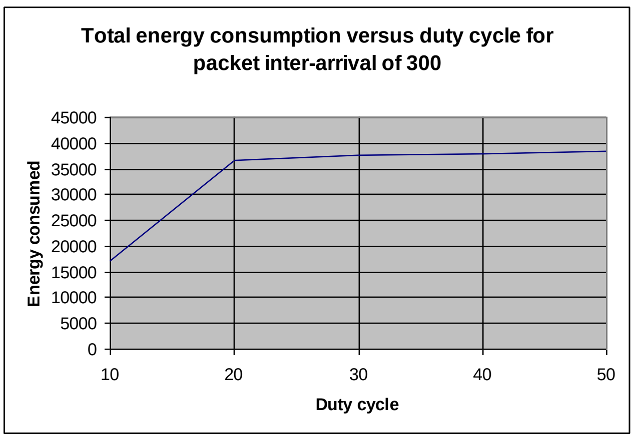

Figure: 5 Energy consumed for inter-arrival time of 300

Following observations are made from above figures 3 to 5:

Energy consumed at low duty cycle is less, as compared to higher duty cycle. This is due to the fact that, the radio is in sleep mode most of the time which reduces energy consumed in idle listening.

The energy consumption is increased as the duty cycle is increased. This is due to the fact that the packet size (10 bytes) is kept small enough; so that it can be send in one cycle time. Hence, if the duty cycle is increased, the sleep time will decrease. This will cause the idle listening by the radio. The idle listening consumes approximately same power as transmitting or receiving. In the simulation setup, the idle power, receive power and transmission power are kept to same 1.0 unit. The fixed duty cycle for S-MAC protocol has a drawback. This calls for adaptive duty cycle, which can adapt to the changes in traffic scenario.

It is also observed that as the message inter-arrival time is increased, bit rate is reduced. This does not effect the total energy consumption by the system, with changes in duty cycle.

V. CONCLUSIONS AND FUTURE WORK

Conclusion

As the experimental evaluation of protocols for wireless sensor networks is a costly affair, simulating the protocols for wireless sensor networks with available simulator can provide a better option for to study different aspects.

Network simulator, Ns-2 is a fairly good candidate to simulate wireless sensor networks. Ns-2 comes with rich set of library functions to simulate the protocols for wireless sensor networks. As a case study, S-MAC protocol was simulated using NS-2 simulator to correlate the theoretical background with the simulation results. S- MAC protocol for wireless sensor networks can be used to gather data for wide-area large scale environmental monitoring application. The scheme saves energy by organizing the networks usage changing the running synchronization. Specifically, the proposed protocol uses, a sleep/listen schedule running in top of a previously negotiated one. It can be also concluded that a MAC protocol can be more efficient if it has some information available in Network layer such as number of hops to the Base Station, data arrival rate, etc so that nodes wake up only when a sample is to be taken. This schedule saves more energy by avoiding idle listening. According to simulation results, the proposed scheme is observed to perform better in terms of achievable network lifetime with low duty cycle for the proposed application.

Developing the protocols on sensor nodes with sensor specific network platform and evaluate its performance through simulation and real experiments can provide better understating of this new technology

Future Work

The documentation for simulating the wireless sensor networks is less explored area. This difficulty was felt when trying to simulate algorithms for wireless sensor networks. Except for direct diffusion, there is no specific documentation available to develop simulation program for wireless sensor networks

The network simulator Ns-2 can be documented to simulate various protocols available for wireless sensor networks.

In future, developing a mechanism to wake-up nodes when a node has the urgency to transmit a triggered packet, which met the requirements of low latency, can be simulated. The experimental evaluation of these protocols for the proposed environmental application can help to validate the simulation results.

REFERENCES

[1] Medium Access Control With Coordinated Adaptive Sleeping for Wireless Sensor Networks Wei Ye, Member, IEEE, John Heidemann, Member, IEEE, and Debor IEEE/ACM transactions on networking, vol. 12, no. 3, June 2004 ah Estrin, Fellow, IEEE

[2] MEMS Come to Oz Wine Industry", Electronic News June 2004

[3] A. Cerpa, J. Elson, M. Hamilton, J. Zhao, Habitat monitoring: application driver for wireless communications technology, ACM SIGCOMM'2000, Costa Rica, April '01

[4] K.A. Delin, R.P. Harvey, N.A. Chabot, S.P. Jackson, Mike Adams, D.W. Johnson, and J.T. Britton, "Sensor Web in Antarctica:

Developing an Intelligent, Autonomous Platform for Locating Biological Flourishes in Cryogenic Environments," 34th Lunar and Planetary Science Conference, 2003.

[5] D.C. Steere, et al., "Research Challenges in Environmental Observations and Forecasting Systems," Proc. ACM/IEEE Int. Conf. Mobile Computing and Networking (MOBICOMM), 2000, pp. 292-299.

[6] K.A. Delin, S.P. Jackson, D.W. Johnson, S.C. Burleigh, R.R. Woodrow, M. McAuley, J.T. Britton, J.M. Dohm, T.P.A. Ferré, Felipe Ip, D.F. Rucker, and V.R. Baker, "Sensor Web for Spatio-Temporal Monitoring of a Hydrological Environmental," 35th Lunar and Planetary Science Conference, League City, TX, 2004.

[7] K. Lorincz, D. Malan, Thaddeus R. F. Fulford-Jones, A. Nawoj, A. Clavel, V. Shnayder, G.Mainland, S. Moulton, and M. Welsh, "Sensor Networks for Emergency Response: Challenges and Opportunities", Special Issue on Pervasive

[8] Martinez, K., Hart, J.K., Ong. R. (2004). Environmental Sensor Networks. Computer, 37 (8), 50-56.