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Evaluation of Energy Saving Medium Access Control Protocol for Wireless Sensor Networks

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Abstract-Wireless sensor networks (WSN) present wide-ranging variety of real time applications for advance purposes. WSN can collect and process enormous amount of data from environment like weather, pollution, traffic conditions, industrial process monitoring, and condition based maintenance. But due to lower sensing range of these networks, dense networks are required, this bring the necessity to attain a well-organized medium access (MAC) protocol subject to power constraints. In this paper, Sensor – MAC protocol have been simulated for demonstrating saving in the energy consumption from different sources of energy waste like idle listening, collision, overhearing and control overhead.

Keywords— WSN, MAC, Idle listening, Latency analysis, Sleep-wake up cycle

I. INTRODUCTION

Researchers are fetching increasingly concerned about the prospective impact of human presence in monitoring plants and animals in field conditions. By changing behavioral patterns or distributions, the results may distort by human disturbances. WSN worn for automation of data collection and reduction of human intrusion in areas of interest. The existing life is not interfering with deploying sensor networks.

Now it make possible to monitor the natural environment with recent developments in wireless network technology and miniaturization. Long-term data collection at scales and resolutions can be enabled by instrumentation of natural spaces with several networked micro-sensors 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. 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 understanding with real deployments of sensor networks were about habitat monitoring [3].

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. The network components that used for sensing and delivering the data are Sensor nodes. Node transmits its data to its neighboring 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 and reports the state of the environment. On the other side, a sink is a node that is interested in some information in which a sensor might be able to deliver in the network. Gateways allow the scientists and system managers to access nodes through personal computers (PCs), personal digital assistants (PDA) and Internet. For the sensor network, gateways act as a proxy in a nutshell on the Internet.

The gateway is connected with task manager via some media like Internet or satellite. Data service, client data browsing and processing consists the Task managers and these 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. To retrieve or analyze data either locally or remotely any display interface i.e. PDA, computers etc can be used.

The WSN which have sensing, computation and communication functions to move packets from sensor nodes to final servers. Simulation tool is used to analyze the evaluation of MAC layer protocol for environmental application to reduce energy consumption, in-channel signaling to avoid overhearing unnecessary traffic and support self configuration, S-MAC techniques is used (Sensor – MAC) and it also supports low duty cycle operation in a multi hop network. To reduce control overhead and enable traffic adaptive wake-up, nodes form virtual clusters based on common sleep are scheduled.

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.

II. S-MAC PROTOCOL

S-MAC tries to reduce energy wastes from all of sources and to reduce control overhead & latency; S-MAC introduces co-ordinates sleeping among neighboring nodes. 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 than the speed of the physical object.

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.

To reduce control overhead neighboring nodes synchronize heir listen / sleep schedule. Nodes exchange their schedule by periodically broadcasting a SYC packet to their immediate neighbors.

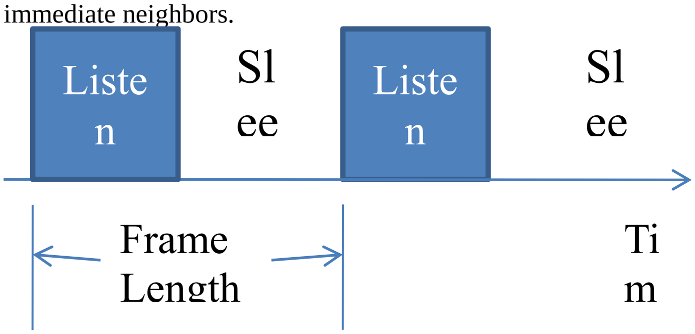

Figure 1 Periodic Sleep and listen

A node can talk to its neighbor at their scheduled listen time, thus ensuring that all neighboring nodes can communicate even if they have different schedules. The period for a node to send a SYNC packet is called a synchronization period.

Collision avoidance: For collision avoidance, including virtual and physical carrier sense and the RTS/CTS exchanges for hidden terminal problem S-MAC follows similar procedures as the 80211 does. 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 uncast 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 MACPROTOCOL FOR ENVIRONMENTAL APPLICATION

It requires continuous sampling of data at defined rate for the environmental application.. 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:
(a) The number of samples to take in a given period of time is known in advance and
(b) 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 behavior of the protocol for suitability of environmental application.
Following are the assumptions made for energy analysis:

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

Characteristics of visualized Network:
• 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.

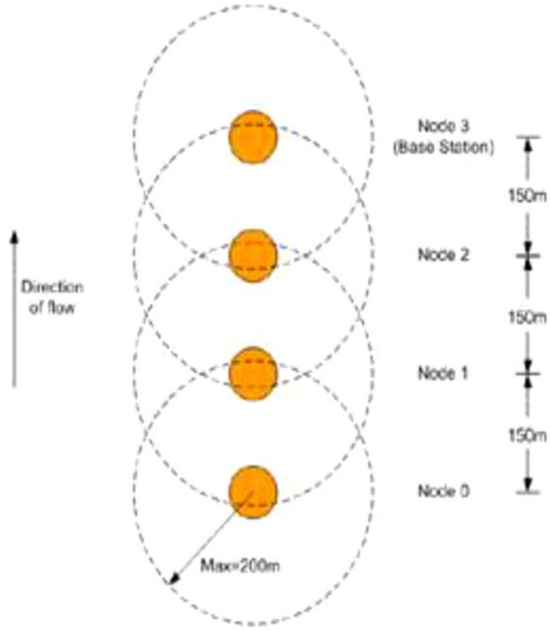

Figure: 2 Initial Node set as visualized in Network

All nodes must have the same listen/sleep schedule, forming a single virtual cluster due to the number of nodes used in the simulation. 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. 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 [8]. 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:
The Average delay per packet is calculated as:

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

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

% Duty Cycle	End to end delay	% Duty Cycle	End to end delay
20	860	60	388
30	651	70	308
40	550	80	292
50	442	90	234

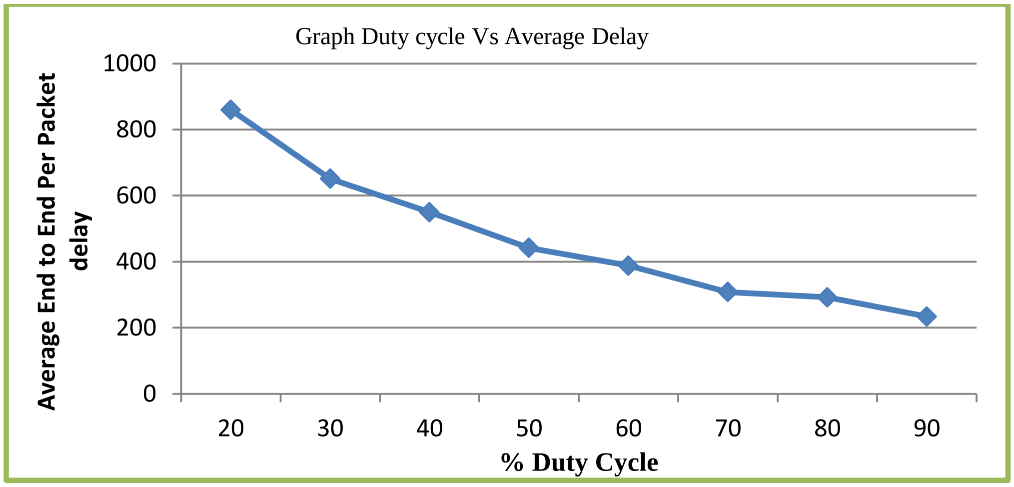

Figure 3 End-to-end delays for each packet for various duty cycles

From figure3, it is observed that 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 II to IV. 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 II

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	8112	9395	9494	9571	9574
Node 1	7866	9242	9358	9434	9495
Node 2	7975	9279	9385	9454	9520
Node 3	7898	9215	9367	9417	9492
Total	31851	37131	37604	37876	38081

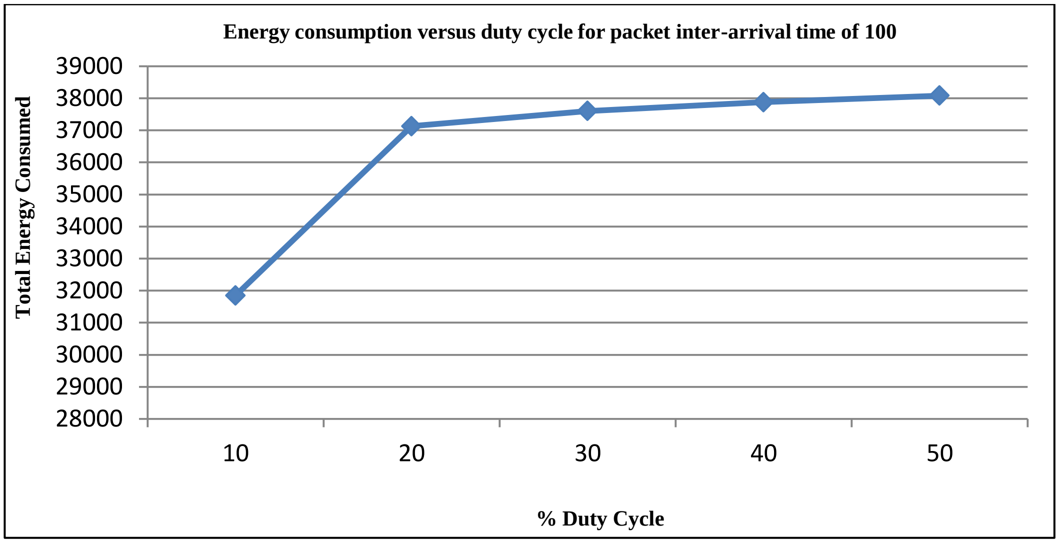

Figure 4: Energy consumed for inter-arrival time of 100

Table III
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	6310	9355	9472	9596	9664
Node 1	6032	9197	9349	9454	9545
Node 2	6183	9234	9381	9480	9573
Node 3	6195	9188	9336	9453	9542
Total	24720	36974	37538	37983	38324

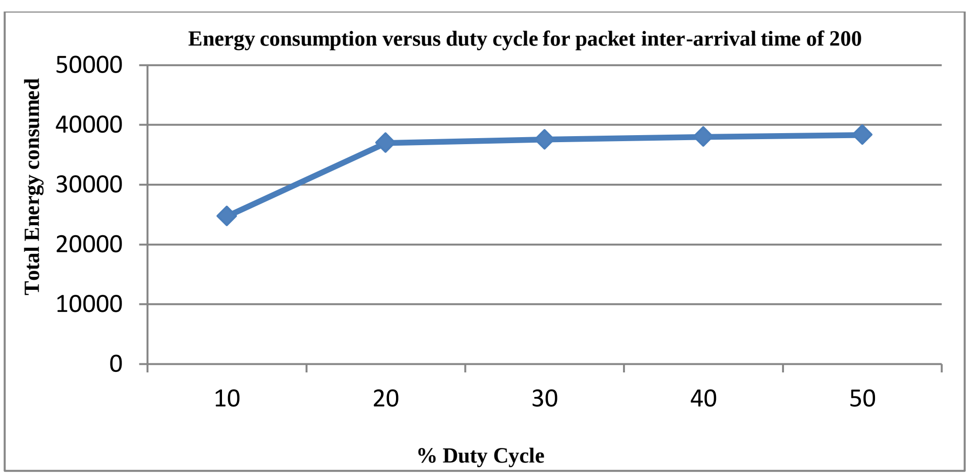

Figure: 5 Energy consumed for inter-arrival time of 200

Table IV
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	4386	9313	9507	9547	9674
Node 1	4244	9112	9369	9465	9582
Node 2	4306	9145	9378	9481	9587
Node 3	4415	9115	9341	9448	9580
Total	17351	36685	37595	37941	38323

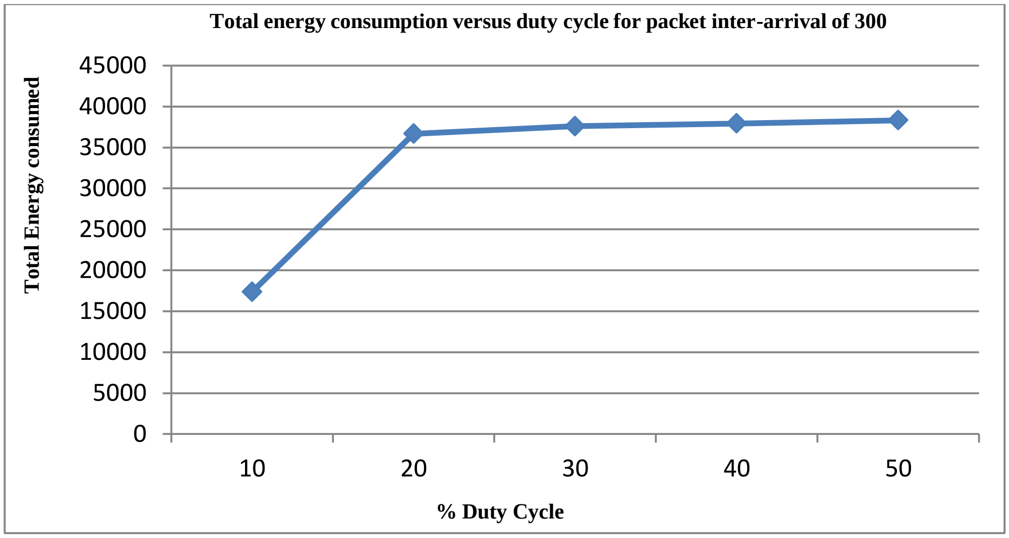

Figure: 6 Energy consumed for inter-arrival time of 300

Following observations are made from above figures 4 to 6 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 affect the total energy consumption by the system, with changes in duty cycle.

CONCLUSIONS

To assemble data for wide-area large scale environmental monitoring application, S-MAC protocol for wireless sensor networks can be used. In this paper S-MAC protocol is simulated using NS-2 simulator. The scheme saves energy by organizing the networks usage changing the running synchronization. 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.

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Authors Biography

Rajbir Singh, is a PG Scholar and Completed his Master of Technology in Electronics and Communication Engineering from UIET MDU, Rohtak (India) in year 2017. Research interests are in WSN, optical and wireless communication.