Reducing Power Consumption in Sensor Network Using Sensor MAC Protocol

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Abstract- ***Wireless sensor networks are quickly gaining popularity due to the fact that they are potentially low cost solutions to a variety of real world challenges. Their low cost provides a means to deploy large sensor arrays in a variety of conditions capable of performing both military and civilian tasks. This technology consists of some of the electronic devices which work to run this system successfully and all those have some amount of power consumptions. It is a challenge of maximizing the processing capabilities and energy reserves of Wireless sensor nodes while also securing them against attackers. So, finally we have decided to work on finding out the optimum solution for controlling the power and saving energy. There are number of ways to reduce power consumption and MAC protocol is one of them. So we describe Sensor MAC protocol to reduce power consumption.***

I. INTRODUCTION

A sensor network is a group of specialized transducers with a communications infrastructure intended to monitor and record conditions at diverse locations. Commonly monitored parameters are temperature, humidity, pressure, wind direction and speed, illumination intensity, vibration intensity, sound intensity, power-line voltage, chemical concentrations, pollutant levels and vital body functions. A sensor network consists of multiple detection stations called sensor nodes, each of which is small, lightweight and portable. Every sensor node is equipped with a transducer, microcomputer, transceiver and power source. The transducer generates electrical signals based on sensed physical effects and phenomena. The microcomputer processes and stores the sensor output. The transceiver, which can be hard-wired or wireless, receives commands from a central computer and transmits data to that computer. The power for each sensor node is derived from the electric utility or from a battery.

Sensory data comes from multiple sensors of different modalities in distributed locations. The smart environment needs information about its surroundings as well as about its internal workings; this is captured in biological systems by the distinction between exteroceptors and proprioceptors. The challenges in the hierarchy of: detecting the relevant quantities, monitoring and collecting the data, assessing and evaluating the information, formulating meaningful user displays, and performing decision-making and alarm functions are enormous.

The information needed by smart environments is provided by Distributed Wireless Sensor Networks, which are responsible for sensing as well as for the first stages of the processing hierarchy. The importance of sensor networks is highlighted by the number of recent funding initiatives, including the DARPA SENSIT program, military programs, and NSF Program Announcements.

A. *Problem Identification*

In wireless network it is an important task to make a system in such a way where power consumption is decrease and efficiency should be increase. As almost all equipment used in this technology or task are run by an electricity or saved power (energy). This technology used in such a way where energy consumption has to me minimum in terms of getting more efficient, accurate and cost effective output. Power is very important in wireless sensor network so it is required to find out some solution to minimize energy consumption in wireless sensor network.

There are number of nodes involved in WSN all nodes are likely to relay on limited battery power. Transmitting at unnecessary high power not only reduces the life time of nodes and network but also introduce excessive interferences.

II. RELATED WORK

Now we will emphasis on Medium Access Control Protocol for wireless network manage the usage of the radio Interface. A medium-access control (MAC) protocol designed for wireless sensor networks. Wireless sensor networks use battery-operated computing and sensing devices. A network of these devices will work together for a common application such as environmental monitoring.

We expect sensor networks to be deployed in an ad hoc fashion, with individual nodes remaining largely inactive for long periods of time, but then becoming suddenly active when something is detected. These characteristics of sensor networks and applications prompt a MAC that is different from traditional wireless MACs in almost every way: energy conservation and self-configuration are primary goals, while per-node fairness and latency are less important. 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. 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. Wireless sensor networks have an additional aspect: as sensor nodes are generally battery-operated, energy consumption is very important. The radio on a sensor node is usually the component that uses most energy. Not only transmitting costs energy; receiving, or merely scanning the air for communication, can use up to half as much, depending on the type of radio.

III. PROPOSED SOLUTION

A. *PAMAS (Power Aware Multi-Access Protocol)*

In this paper we develop a new multi-access protocol for ad hoc radio networks. The protocol is based on the original MAC protocol with the addition of a separate signaling channel. The unique feature of our protocol is that it conserves battery power at nodes by intelligently powering off nodes that are not actively transmitting or receiving packets. The manner in which nodes power themselves off does not influence the delay or throughput characteristics of our protocol. We illustrate the power conserving behavior of PAMAS via extensive simulations performed over ad hoc networks containing 10--20 nodes. Our results indicate that power savings of between 10% and 70 % are attainable in most systems.

B. *Sensor-MAC (S-MAC): Medium Access Control for Wireless Sensor Networks*

S-MAC is a medium-access control (MAC) protocol designed for wireless sensor networks. Wireless sensor networks use battery-operated computing and sensing devices. A network of these devices will work together for a common application such as environmental monitoring. We expect sensor networks to be deployed in

TABLE I
TYPICAL POWER CONSUMPTION OF WSN

Modes	Typical current	Power consumption
Transmit	32mA	95mW
Receive	18mA	55mW
Ideal	8mA	25mW
Sleep	20mA	60mW

an ad hoc fashion, with individual nodes remaining largely inactive for long periods of time, but then becoming suddenly active when something is detected. These characteristics of sensor networks and applications motivate a MAC that is different from traditional wireless MACs such as IEEE 802.11 in almost every way: energy conservation and self-configuration are primary goals, while per-node fairness and latency are less important.

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.

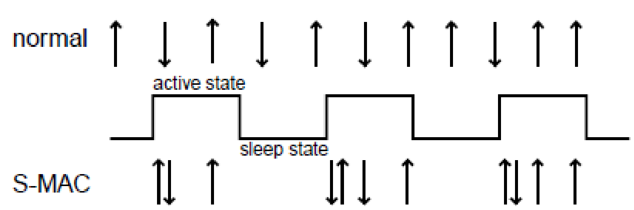

Fig. 1 (a). The S-MAC duty cycle, the arrow indicates transmitted and received messages

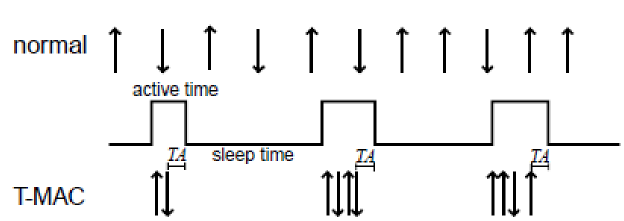

Fig. 2(b). T-MAC with adaptive active times

C. T-MAC Protocol

Above figure shows the basic scheme of the T-MAC protocol. Every node periodically wakes up to communicate with its neighbors, and then go to sleep again until the next frame. Meanwhile, new messages are queued. Nodes communicate with each other using a Request-To-Send RTS), Clear-To-Send (CTS), Data, Acknowledgement (ACK) scheme, which provides both collision avoidance and reliable transmission. This scheme is well known and used, for example, in the IEEE 802.11. A node will keep listening and potentially transmitting, as long as it is in an active period. An active period ends when no activation event has occurred for a time TA.

Now we discuss about S-MAC Protocol which is called sensor MAC protocol and try to minimize energy consumption using sleep/listen schedule. There are three main energy wastage events occur at a MAC layer and are follows: (i) collision (ii) overhearing and (iii) idle listing. Collision result in energy waste due to re transmission of crashed packets. Overhearing occur when a particular node listening for transmission which is not for it. And idle listening occurs when a node is looking for any possible data. All these cause waste of unnecessary energy. So power wasted by overhearing and idle listing is also important as collision. The main idea of S-MAC protocol is to put a node to sleep mode time to time to reduce energy wasted when above event occurs. A particular node goes into sleep mode when it is not engaged in any kind of transmission and when its neighbors are involve in transmission and moreover this will reduce collision and overhearing. This cause reduces in listing time resulting saving the power.

A cycle of S-MAC have listen and sleep state. A sensor node follow pre-define schedule to wakeup or sleep in following condition(i)when a neighbor is communicating (ii)node wakeup when a neighbor finish communication if it need to relay packet. This is done by only overhearing neighbor‘s RTS (Ready To Send) and CTS (Clear To Send) exchange before a node goes to sleep to reduce latency caused by sleeping.

D. Queuing Model for S-MAC

We consider a system made up of N interfacing nodes. And a traffic arrival is at the rate of λ packets per unit time. But in WSN events are sensed randomly. So the total arrival rate to the channel is Nλ. The number of packets are serviced per unit time is called channel service rate and it is denoted by μ by shared channel. In this way the service time is calculated by the sum of delay components which is sleep delay due to lost transmission,

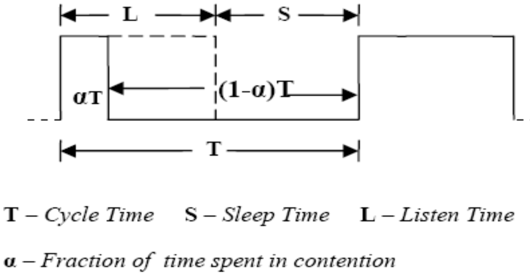

Fig 2. The sleep/listen cycle.

contention time and transmission delay. Now we discuss sleep delay encountered by a packet.

E. Sleep Latency

Sleep delay can be occur in two situation that the packet is new arrival or it’s from the queue.If an incoming packet sees empty queue then the packet is serviced as current cycle only when it arrives within current contention window(αT),otherwise it has to wait for next cycle as shown in figure below.

Now let say if packet is arrived at random time then arriving packet sees am empty queue and still it suffers from sleep delay and it caused by unfortunate combining of two independent events: empty queue and missing contention period. this event is given by

$$P_1 = (1-\rho)\times(1-\alpha) \quad \textit{Where } \rho = N\lambda/\mu.$$

This is the probability that a node’s queue is non-empty, and T is total cycle time. If the packet arrives at any time instant equally likely after the contention period then the delay caused by sleep can be calculated as

$$S_1 = \left(\frac{1-\alpha}{2}\right)T \tag{1}$$

If the packer is from queue than the sleep delay can be avoided if adaptive listening causes the next hop node by overhearing neighbor’s RTS/CTS exchanges, to wake up in time to relay the packet queued and scheduled to transmit from previous hop node. But adaptive listing works only in alternative hopes, so sleeping will cause a node to miss its neighbor’s RTS/CTS exchanges. Considering the effect of adaptive listening and the probability that an incoming packet sees a non-empty queue and encounters a sleep delay is given as:

$$P_2 = \beta\rho \tag{2}$$

Where $\beta = \frac{h/2}{h}$ and h is number of hops traversed from the source to destination. The delay encountered here calculated as:

$$S_2 = \left(\frac{1-\alpha}{2}\right)T \qquad (3)$$

And so overall sleep latency is given by

$$S = P_1S_1 + P_2S_2 \qquad (4)$$

F. *Total Latency*

In addition to sleep delay a packet suffers from contention delay and transmission delay, which are computed as follows. Contention delay is the time a node spends to win contention, which is also called channel access delay. The number of times a node will attempt to contend for the channel before success in a given backoff stage, is a geometrical random variable with a probability 1/C. Thus the expectation of the total time required to win contention is given by,

$$C = \frac{1 + W + pW\sum_{1=0}^{m-1}(2p)^{i}}{2} \qquad (5)$$

Where, W denotes minimum contention window size and m is the maximum number of backoff stages. The probability of packet collision, p, is defined as the probability that two or more nodes transmit in the same slot time and is derived in as:

$$P = 1 - \left\langle 1 - \frac{1}{C} \right\rangle^{N-1} \qquad (6)$$

where N is the number of interfering nodes. Equations (5) and (6) can be solved numerically to obtain the values of p and C. Transmission delay (T*)* is just the time for the radio to transmit a packet, which is a function of channel data rate. The total service time is given as:

$$\frac{1}{u} = S + C + T \qquad (7)$$

And the overall latency encountered by a packet is given by the sum of service time and the queuing delay obtained

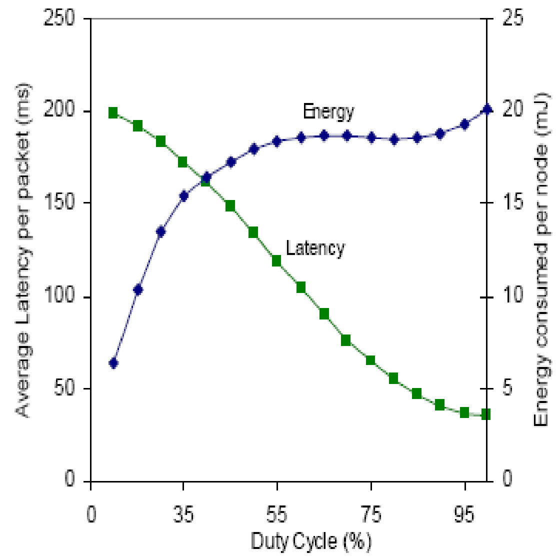

Fig 3.Latency and energy consumption results of SMAC obtained from queuing modeling.

for an M/G/1 system by applying the Pollaczek-Khinchin formula. The average latency is written as:

$$L = \left(\frac{1}{u}\right) + \frac{N\lambda\left(\sigma_s^{\,2} + 1/u^2\right)}{s(1-\rho)} \qquad (8)$$

Where, σ^2 is the variance of the service time distribution and ρ is equal to $N\lambda/\mu$

IV. PERFORMANCE EVALUATION

Numerical results are obtained using the formulation described in the previous section and Table I lists the important parameters used in the analysis. For instance the following configurations are used in the simulation: Channel bandwidth is 20 Kbps, N= 5, and Data Packet size 50Bytes.

Figure 3 shows the performance of SMAC for varying duty cycle values. Duty cycle is defined as the fraction of total cycle time that a node listens, i.e., *L/T* in Figure 2.From Figure 3, as expected, average latency per packet is high at low duty cycles, because nodes sleep for longer duration of time and introduce large sleep delay. However energy consumed by a node increases with duty cycle since the node ideally listens for extended period of time. The details for all the configuration parameters are presented in Table II. All simulation and experiments have performed based on the mathematical equations derived in the previous section along with these parameter values.

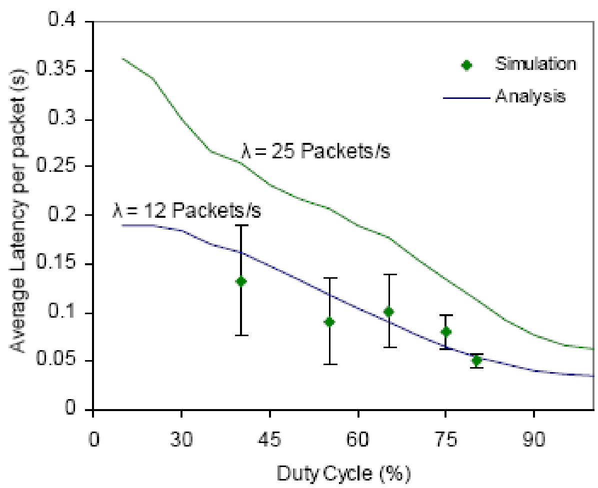

Fig.4 Latency results for SMAC obtained from queuing analysis and simulation

A. *Simulation Environment*

To validate our results, we simulated the performance of SMAC. A simple five-node network topology was used. Four nodes generate exponentially distributed traffic to a single sink node. Simulation parameters are listed in table below.

B. *Simulation Parameters*

For the same network scenario, average energy consumption and latency obtained from analytic modeling

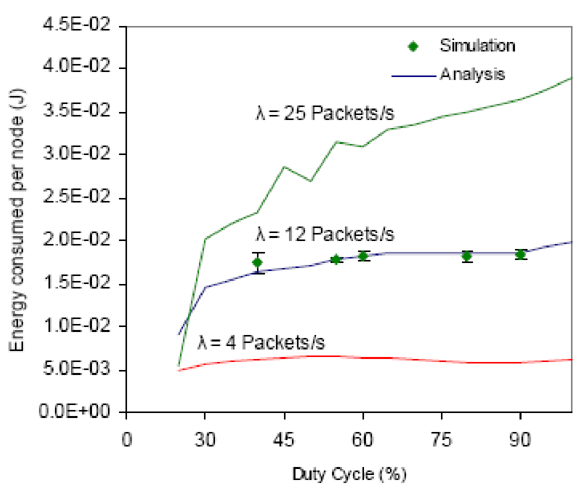

Fig.5 Energy consumption results for SMAC obtained from queuing analysis and simulation

TABLE II
DETAILS OF PARAMETERS

Channel bandwidth	20 kbps
Average packet size	50 Bytes
RTS,CTS,ACK size	30 Bytes
Reception power	13mW
Transmission Power	24.75mW
Idle Power	13mW
Sleep Power	15μW

were compared with simulation results. Fig 3 shows the results for average latency per packet at varying duty cycles. At 95% confidence intervals, it shows the simulation and analytical results are in reasonably good agreement. Other simulation data points show similar pattern, but are not included for the clarity of the figure. The figure shows that at low duty cycle, i.e., a node sleeps for a longer duration; the difference in packet latency for different arrival rates is large. This is because, at high arrival rates the demand for the channel is much higher than that at low arrival rates, therefore the performance is degraded much more at high arrival rates. As the duty cycle increases, the difference in packet latency for low and high arrival rates tends to disappear. The figure reaffirms the intuition that low duty cycle operation is appropriate for low arrival rates but can cause excessive latency at high arrival rates.

Fig 5 shows the results for average energy consumption obtained using analysis and simulation, respectively. Again the simulation results are at 95% confidence interval. The figure shows that the differences in the average energy consumption for different arrival rates increases as duty cycle increases. This is because, at low duty cycle, sleep behavior dominates energy consumption. As the duty cycle increases, packet transmission tends to dominate energy consumption. Therefore, low duty cycle operation is effective way to limit energy consumption regardless of the traffic load.

V. CONCLUSION AND FUTURE WORK

This is the first protocol to use sleep/active schedules and it offers major decrease in energy consumption and overcome of latency problem. We quantified the performance impact of sleep in a sensor MAC protocol by queuing analysis and simulation. Our results demonstrate the tradeoff between latency and energy consumption under varying duty cycles and for different packet arrival rates. As future work, we plan to study the performance impacts of sleep on the nodes that play different roles in the network such as ordinary, gateway, cluster head nodes, etc.

References

1. Mark A Perillio & Wendi B Heinemann, department of electrical and computer Engg, University of Rochester.

2. Directional MAC protocol for ad-HOC network with synchronization, By IEEE library, university of Florida.

3.”power control in distributed MAC” by V.Srinivasan & Kee Chang Chua.

4. Subah Ramakrishna, Hong Huang, Manikanden Balakrishnan Klipsch School of Electrical Engineering New Mexico State UniversityLas Cruces, USA