Performance Analysis of SMAC Protocol in Wireless Sensor Networks Using Network Simulator (Ns-2)

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Abstract. Energy effeciency of medium access control has been an active research area in wireless sensor networks since past few years. SMAC stands for Sensor-MAC protocol, which is designed on the basis of periodic listen-sleep mechanism of nodes for avoiding energy wastage because of idle listening. SMAC reduces energy consumptions because of collision, overhearing, control packet overhead and idle listening. This paper discusses the basic attribute of MAC protocols, their classification and the importance of SMAC protocol in wireless sensor networks. SMAC is developed primarily for Mote platform, and thereafter also implemented in Network Simulator-2.So without real hardware one can analyze the performance of SMAC under various application specific scenarios with NS-2.In this paper, the performance of SMAC protocol is analyzed under high and low traffic rates with different duty cycles in single hop scenario without the routing effect. The residual energy is also measured in each scenario. Since wireless sensor networks are application specific, so the behavior of SMAC is studied when the data transport performance and hence the throughput and jitter also plays an important role along with the energy effeciency. Finally it has been shown that under higher traffic loads, if the value of duty cycle is increased to optimum value, the residual energy of the node is improved with a better throughput.

Keywords: Wireless Sensor Networks, SMAC, residual energy, throughput, NS-2.

1 Introduction

Advancements in wireless information system, embedded systems and the VLSI technology has enabled the development of wireless sensor networks which consist of thousands of tiny sensor nodes deployed in Adhoc or structured preplanned manner. These [1] are low power devices equipped with one or more sensors, a processor, limited memory, a power supply, a radio, and an actuator. Since the sensor nodes have limited memory and are typically deployed in unattended locations, a transceiver is implemented for wireless communication to transfer the data to the base station.

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K. Singh, A.K. Awasthi, and R. Mishra (Eds.): QSHINE 2013, LNICST 115, pp. 42–51, 2013.

[2]Battery is the main source of power in a sensor node. Wireless sensor networks are used in range of applications such as monitoring, tracking and surveillance of borders, in industry for factory instrumentation, in metro cities to monitor traffic and road conditions, in engineering to monitor buildings structures, in environment to monitor forest, oceans etc. To serve these different applications of wireless sensor networks, the protocol stack has not been standardized yet, and the research is continued on each layer to design energy efficient protocols suitable for specific applications. The transceiver of sensor nodes consumes maximum amount of energy [2]. One solution to reduce energy consumption is to develop the energy efficient communication protocols. The[2] MAC protocol has been the research area since past few years because by designing a good MAC protocol, the energy effeciency of the nodes may be increased which is the prime concern in case of wireless sensor networks [1].

1.1 The MAC Protocol Design Issues

The MAC protocols for wireless Adhoc networks such as 802.11 DCF is not suitable for wireless sensor networks because it does not consider the nodes with limited battery[4].The good design of the MAC protocol should prevent energy wastage due to packet collisions, overhearing, excessive retransmissions, control overheads, and idle listening. It should also adapt to topology and network changes efficiently. Various MAC protocols with different objectives are proposed for wireless sensor networks. The main attribute of MAC protocol on which authors concentrated is the energy effeciency [6]. Other important attributes are scalability and adaptability to changes like network size, node density and topology. Secondary attributes are throughput, latency and per node fairness. The MAC layer defines two main criterions for designing efficient MAC protocol. First is to detect the reasons for energy waste and second is the communication pattern which the network follows since these patterns decides the behavior of traffic which the MAC protocol will handle[6]. A wide range of energy efficient MAC protocols for example [7][8][9][10] are proposed which are categorized according to channel accessing approaches ,into contention-based, TDMA-based, hybrid, and cross layer MAC protocols . In recent research [15][16][17] it is pointed out that wireless sensor networks when used in industrial control or monitoring applications then apart from energy and latency the throughput and packet delivery ratio should also be taken into consideration.

1.2 Sensor-MAC Protocol Design

Sensor-MAC (S-MAC), is a contention based Medium Access Control protocol for Wireless Sensor Networks proposed by SCADDS project group at USC/ISI[10] which is different from traditional IEEE 802.11DCF for Adhoc networks. Implementation of the protocol is done on Rene Motes, developed at UCB as test beds. Mote uses TinyOs as an efficient event driven operating system. For SMAC, energy efficiency and self-configuration ability are the primary goals, while others attributes, like latency and fairness, are secondary. While designing the protocol, it is assumed that the major sources of energy waste are collision, overhearing, control packet overhead and idle listening (keep on listening to receive possible traffic which is not sent). In MAC protocols such as IEEE 802.11 nodes must listen to the channel to receive possible traffic which consumes 50–100% of the energy required for receiving. But [3] S-MAC tries to reduce the waste of energy from all the above sources. SMAC consists of three major components: periodic listen and sleep, collision and overhearing avoidance, and message passing. . During sleep, the node turns off its radio, and sets a timer to awake it later. Periodic listen and sleep is used to avoid idle listening. Contention mechanism [5] is same as in IEEE 802.11 to avoid collision. Overhearing is avoided by letting interfering nodes go to sleep when they hear RTS/CTS packets, So that they may not hear the long data packet and the ACK.NAV value is used for this purpose. Message passing is used to reduce control overhead in contrast with 802.11.In message passing; long messages are broken into small fragments and transmitted as a burst. Extra delay is caused because of node periodic sleeping and is further improved by the technique of adaptive listening [5]. In the second section of this paper , we have discussed the implementation of SMAC in NS-2 and in third section the simulation experiments has been carried out in NS-2.35. In fourth section the analysis of results has been done and finally section fifth concluded the paper.

2 SMAC Model and Its Implementation in NS 2.35

S-MAC is based on the Mote platform that runs TinyOs operating system. For hardware implementation, which needs real hardware as its running platform, at times it is not easy to carry out the performance analysis for the experimentation purposes and hence S-MAC has been also implemented in NS2[11][12][13], the network simulator. SMAC has been tested on the real platform but little work has been done on the NS2 for further improving the SMAC for the mission critical applications in wireless sensor networks. Besides this, [9][10][14]researchers have studied SMAC performance for energy and latency. But for mission critical applications one needs to analyze the performance of S-MAC protocol in terms of residual energy of nodes, throughput , packet delivery fraction and the impact of different duty cycles to analyze the protocol fully. Frame structure of SMAC is given in Figure 1.The listen period is further divided into two parts. SYNC periods designed for SYNC packets, which are broadcast packets and solve synchronization problems between neighboring nodes.

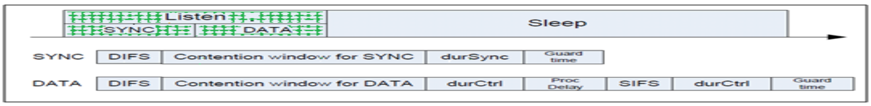

Fig. 1. Frame intervals (listen + sleep) [3]

Table 1. The default Energy Model for SMAC

Idle Power	1.0 watts
TxPower	1.0 watts
RxPower	1.0 watts
SleepPower	0.001watts
TransitionPower	0.2 watts
TransitionTime	0.005seconds

3 Simulation of SMAC Protocol in NS-2

Environment. Simulation experiment is performed by writing the TCL script in NS-2.35, installed in Cygwin environment. The results are obtained by analyzing the trace file obtained in new trace file format. The updated energy model has been used in this paper and different scenarios are considered to carry out simulation.

Topology. Five S-MAC nodes form a single hop star topology, with four sources and one central sink which is given in figure 2.The UDP agents are used at source nodes and they are attached to the CBR traffic.

Input Parameters. The packet inter-arrival time is varied from .01seconds (considered highest traffic load) to 50 seconds (lower traffic load). Duty cycle is varied from 1% to 50%. Syncflag is set to 1, S-MAC runs with periodic sleep. If it is set to 0, SMAC runs without periodic sleep. Duty cycle controls the length of sleep. Here we have set the SelfConfigFlag to 1. Packet size is set to 100Bytes. The initial Energy of nodes is set to 1000J. The simulation runs for 5000 seconds. Maximum numbers of packets are 1000. All four nodes start sending the packets after 40 seconds, which is required for synchronization of nodes.

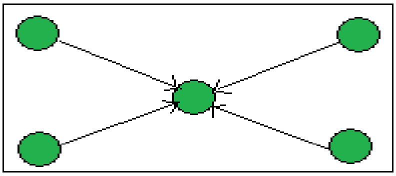

Fig. 2. Central sink node (Receiving) with four source (sending) nodes

Performance Parameters. Performance parameters which are considered in the paper are the Residual Energy and Throughput under different duty cycles and message inter arrival time.

- **Residual Energy:** In this analysis the residual energy is given by the amount of remaining energy of the node after simulation time. So the new trace file format using updated energy model gives us the residual energy after each event at each node.

- **Throughput:** We compute the throughput using the payloads received at MAC layer.

Throughput (Kbps) = Packets received at the sink node/ (T1-T2) ... (1)
T1= time when first packet sent by source nodes
T2= time when last packet received by sink node.

4 Simulation Results

The residual energy and the throughput are measured under different traffic loads with varying duty cycle.

- **High traffic scenarios**

Scenario 1 & Scenario2: In scenario1, the duty cycle was varied from 1% to 30% and the residual energy of sink node is observed for MIAT=.01s which is considered to be the highest traffic load. The variation is shown in Fig.3. From Table 2 and Table 3, it is seen that on duty cycle 1% and 10%, under high traffic load, no data is sent. Under highest traffic load (0.01s), if duty cycle is increased to 30%, the residual energy of the sink node becomes 0.069698 Joules and the throughput is .07kbps which is more than the 20% duty cycle (0.01 Kbps). So in mission critical applications where traffic load instantly increases, the SMAC duty cycle can configure to 30% to achieve higher throughput. This is because there is negligible difference in residual energy. Under high traffic loads if the duty cycle is increased to 50%, there is increase in throughput .44Kpbs, but it will be at the cost of residual energy. It is observed that under high traffic load, the residual energy becomes negligible at 1000s at 20% and 30% duty cycle and the throughput is also very low.

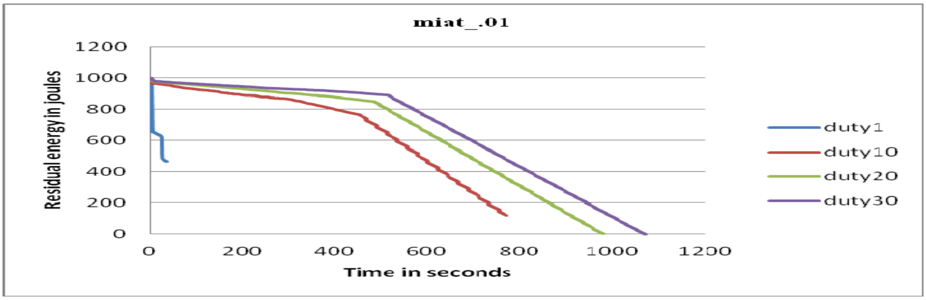

Fig. 3. Residual Energy vs Time for Message inte-arrival time .01s

In scenario2,as seen from Fig 4, varying the duty cycle from 1% to 30% the residual energy of sink node is observed for miat=1seconds which is considered to be the higher traffic rate. From Table.2, It is seen that, for miat=1s (higher traffic rate), residual energy decreases with increase in duty cycle. For 30% duty cycle, the residual energy is maximum. From Table 3, it is seen that the throughput is also increased to 1.61Kbps.So it is observed that for traffic rate 100bytes/second, the

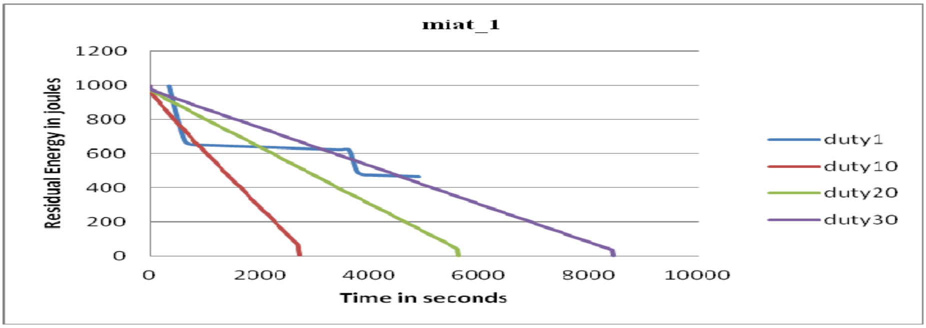

Fig. 4. Residual Energy vs Time for Message inte-arrival time 1s

SMAC can perform better when duty cycle is increased to 30% in single hop scenario. The throughput achieved is 1.61 kbps. This is the scenario where the residual energy is maximum at end of simulation.

- **Moderate traffic scenario**

Scenario 3: In Fig. 5 is shown that for miat(message inter-arrival time)=5seconds, which is considered to be the medium traffic load, varying the duty cycle from 1% to 30% ,residual energy of sink node is varied. From Table 2 and Table 4, it is seen that 20% duty cycle is best because it saves residual energy and at the same time the throughput is also same at both 20% and 30% duty cycle. The throughput achieved is .64 kbps.

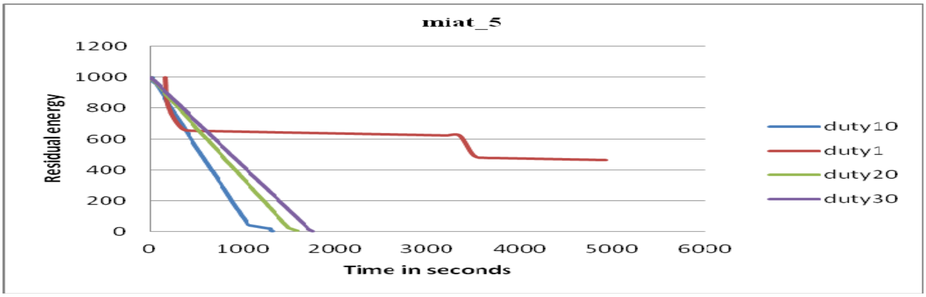

Fig. 5. Residual Energy vs Time for Message inte-arrival time 5s

- **Low traffic rate scenarios**

Scenario 4 & 5: These are the scenarios with lower traffic loads. In Fig.6 and Fig.7, varying the duty cycle from 1% to 30% the residual energy of sink node is observed for MIAT=25seconds which is considered to be the lower traffic rate. Varying the duty cycle from 1% to 30% the residual energy of sink node is observed for MIAT=50seconds which is considered to be the lower traffic rate.

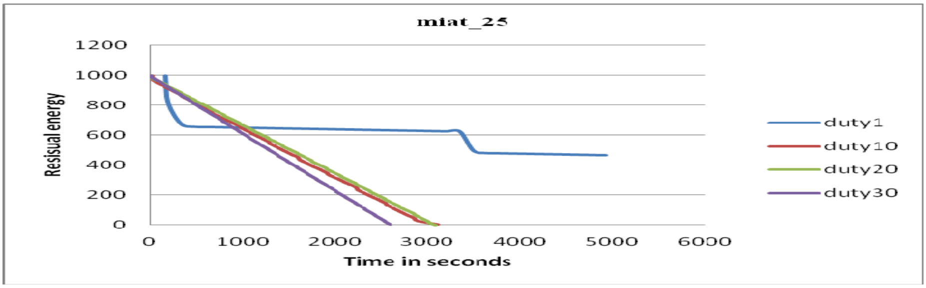

Fig. 6. Residual Energy vs Time for Message inte-arrival time 25s

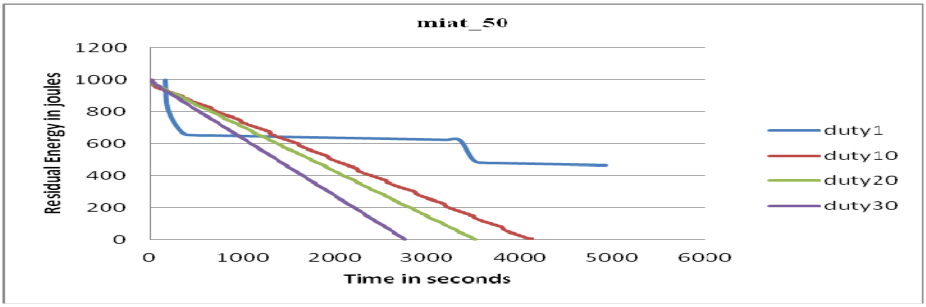

Fig. 7. Residual Energy vs Time for Message inte-arrival time 50s

As per the table 2, the graph in Fig 8 has been plotted for residual energy under different traffic loads for different duty cycles. For miat=25s and miat=50s (low traffic rate), for better results of residual energy we should keep the duty cycle low. Form Table 5,it is seen The throughput achieved is .13kbps when miat is 25s and .06kbps when miat is 50s.Since the throughput is not improved with increasing the duty cycle, hence we should keep the duty cycle low to achieve better residual energy.

Table 2. The residual energy with different duty cycles and different traffic loads

MIAT	Re.Ener	duty	Re.Ener	duty	Re.Ener	duty	Re.Ener	duty
0.01	463.6788	1	119.1136	10	2.601626	20	0.069698	30
1	463.6788	1	5.707545	10	0.694504	20	1.05225	30
5	463.6788	1	1.394872	10	7.193864	20	1.382184	30
25	463.6788	1	0.966691	10	0.148844	20	1.285791	30
50	463.6788	1	7.746957	10	1.224436	20	1.057871	30

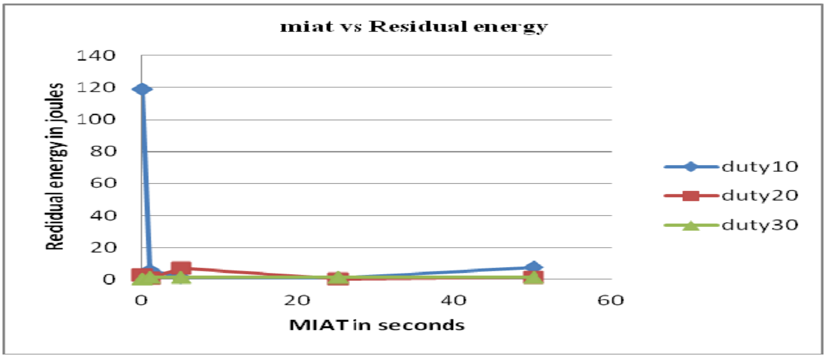

Fig. 8. Residual energy vs Message inter-arrival time

Measurement of Throughput:
Scenario1 & Scenario 2

Table 3. Throughput (MIAT=.01s & MIAT=1s)

	MIAT=.01s					MIAT=1s		
duty %	T(Kbps)	t1(start)	t2(stop)		duty %	T(Kbps)	t1(start)	t2(stop)
1%	0	40	0		1%	0	40	1037
10%	0	40	0		10%	0.42	40	1149.42
20%	0.01	40	210.95		20%	1.06	40	1062.73
30%	0.07	40	157.52		30%	1.61	40	1054.9
50%	0.44	40	111.93		50%	2.71	40	1037

Scenario3

Table 4. Throughput under different duty cycles (MIAT=5s)

	MIAT=5s		
duty %	T(Kbps)	t1(start)	t2(stop)
1%	0	0	0
10%	0.53	40	1056.28
20%	0.64	40	1505.14
30%	0.64	40	1719.69

Scenario 4 & Scenario 5

Table 5. Throughput (MIAT=25s & MIAT=50s)

	MIAT=25s					MIAT=50s		
duty %	T(Kbps)	t1(start)	t2(stop)		duty %	T(Kbps)	t1(s)	t2(s)
1%	0	40	0		1%	0	40	0
10%	0.13	40	2891.94		10%	0.06	40	4046.93
20%	0.13	40	3040.94		20%	0.06	40	3490.49
30%	0.13	40	2566.88		30%	0.06	40	2741.97

The graph has been plotted for throughput vs. duty cycle at different message inters arrival time in Fig.9. It is observed that for 50% duty cycle and message inter-arrival time=1s, the maximum throughput is achieved, but when the residual energy is also considered then the 30% duty cycle is the best choice. At 30% duty cycle, the throughput is maximum and the residual energy is almost equivalent to 20% duty cycle as seen from Fig.8.Varing duty cycle from 1% to 20% ,high throughput is not achieved which is at times the requirement for some applications in wireless sensor networks.

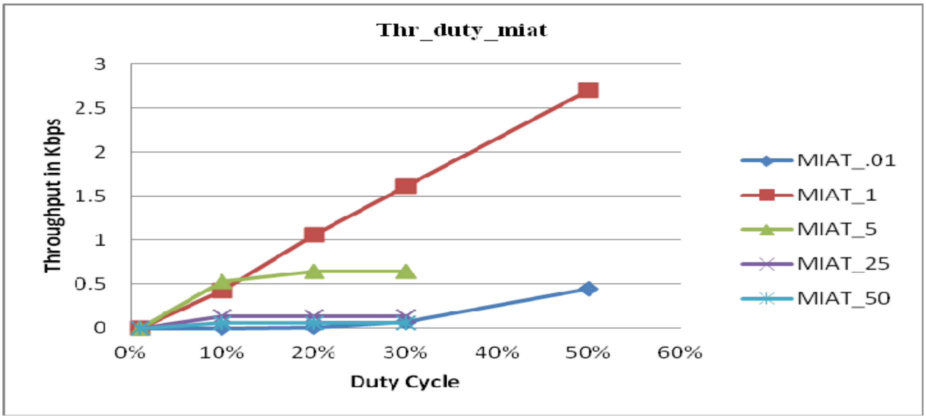

Fig. 9. The Throughput vs duty cycle at different message inter-arrival time(MIATs)

5 Conclusion

We have analyzed the S-MAC protocol in terms of throughput and residual energy. It is observed that it's not necessary that increasing the duty cycle percentage will always decrease the residual energy. At higher traffic rates, we can achieve energy effeciency (residual energy) and throughput with the proper choice of duty cycle. So [13]for mission critical application where apart from energy effeciency, the data transport performance is also important, the S-MAC protocol can be used with the proper choice of duty cycle to achieve better throughput and energy effeciency. In single hop scenario, improvement in SMAC protocol is needed when message inter-arrival time is much less (.001s). [14][15][16][17] In multihop scenario, the same analysis can further be performed and some enhancements in SMAC can be done accordingly, to improve its performance for applications where the throughput, energy effeciency and the latency all are important at higher traffic rates.

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