무선 센서 네트워크에서 Duty Cycle의 영향

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Impact of Duty Cycle in Wireless Sensor Networks

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요 약

무선 센서 네트워크의 센서 노드는 내부 전원을 사용함으로 인해 수명이 제한적이다. 기존의 여러 MAC 프로토콜은 무선 센서 네트워크에서 에너지 절약을 위해 sleep/listen cycle을 스케줄링한다. 또한, MAC 프로토콜의 duty-cycle은 사용자의 조정에 의해 낮은 duty cycle로 변화할 수 있으며, 이는 프레임에서 sleep 시간을 결정하게 된다. 이러한 duty cycle의 크기는 MAC 프로토콜의 성능에 직접적인 영향을 미친다. 본 논문에서는 NS-2 환경에서 서로 다른 duty cycle을 갖는 TEEM과 SMAC을 시뮬레이션하고 두 개의 프로토콜의 에너지 소비와 성능 측면에서 duty cycle을 분석한다.

ABSTRACT

Wireless sensor consists of an internal power source which has limited life time. Several MAC protocols have exploited scheduled sleep/listen cycles to conserve energy in sensor networks. Duty cycle is a user-adjustable parameter in low duty cycle MAC protocols, which determines the length of the sleep period in a frame. The size of duty cycle has direct effect on the performance of MAC protocols. In this paper, we simulated TEEM (A Traffic Aware, Energy Efficient MAC) and S-MAC in NS-2 with different duty cycle values and analyze how duty-cycle effects on the performance and energy consumption of both the protocols.

키워드

Wireless Sensor Network, Medium Access Control protocol, Duty Cycle, Energy consumption

Ⅰ. Introduction

A wireless sensor network (WSN) is a self-organizing wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions at different locations. Typically, these nodes coordinate to perform a common task. These small and inexpensive devices are self-contained units consisting of a battery, radio front end, sensors, and a minimal amount of on-board computing power. Once deployed, changing batteries become difficult or even impossible, thus sensor nodes must be energy efficient.

Several MAC protocols such as S-MAC (Sensor Medium Access Control), T-MAC (Time-out Medium Access Control), DSMAC (Dynamic Sensor Medium Access Control), and TEEM (Traffic Aware, Energy Efficient) have been proposed [1][2][3][4]. Because of limited energy availability, energy efficiency is considered more important than the Quality of Service (QoS).

Either it be S-MAC or TEEM or any other low duty cycle MAC protocol, they implement concept of periodic sleep/listen cycle. The ratio of sleep period and listen period is the duty-cycle of any MAC protocol. However, duty-cycle is user - adjustable parameter in these protocols. Varying the duty-cycle has direct effect on overall performance of any low duty cycle MAC protocols.

The main objective of this paper is to investigate the effect of duty cycle on protocol performance. For this, we simulate S-MAC and TEEM in NS-2 with variable duty cycle under different traffic load.

Ⅱ. S-MAC Overview

S-MAC is a contention-based random access protocol with a fixed sleep/listen cycle [1]. It uses a coordinated sleeping mechanism, similar to the power saving mechanism of IEEE 802.11 [5]. A time frame in S-MAC is divided into two parts: a listen period and a sleep period. Sensor nodes are able to communicate with other nodes only in this listen period. By exchanging SYNC packets, all neighboring nodes can synchronize together. The two nodes can communicate with each other by the successful exchange of RTS/CTS packets (similar to IEEE 802.11). They use their normal sleep time for data packet transmission. All other nodes will simply follow their sleep schedules in order to avoid any wasteful idle listening.

In S-MAC, node's listen period is subdivided into three different phases: SYNC phase for sending/receiving SYNC packets, RTS phase for sending/receiving RTS packets, and CTS phase for transmitting a CTS packet if an RTS packet was received in the previous RTS phase. The SYNC packets are used for synchronization whereas RTS and CTS control packets are used before data communication. Successful exchange of RTS/CTS packets between two nodes implies that they should stay awake in the whole sleep period for the completion of their data communication. Again, all other nodes that are not involved in data communication can enter into sleep mode. S-MAC has the fixed timing period for listen and sleep period. The problem is that, even when nodes have no data or SYNC packet to send during some time frame, every node still has to be awake in listen time wasting their energies.

Ⅲ. TEEM Overview

TEEM is the modified version of S-MAC [4]. The working principle mention above is same for TEEM also. Unlike S-MAC, in TEEM, the listen period consists of only two parts, $SYNC_{data}$ and $SYNC_{nodata}$, and the time interval of the listen period is also shorter, compared to S-MAC. The $SYNC_{data}$ contains DATA packets, whereas the $SYNC_{nodata}$ contains SYNC packets. Both packets are used for synchronization. Each node will listen in $SYNC_{data}$, whether someone has data to transfer or not. Nodes having data will contend for medium in this period. If there is no data in this period, node having SYNC packet contend for medium in the $SYNC_{nodata}$ period and the winner sends the SYNC packet. Instead of using a separate RTS and SYNC separately, TEEM combines the RTS packet with a SYNC packet and sends it in $SYNC_{data}$ period. This combination is called $SYNC_{rts}$. Whenever a node wants to communicate with other node, it will send the $SYNC_{rts}$ packet in $SYNC_{data}$ part. If the nodes does not have $SYNC_{rts}$ packet at $SYNC_{data}$ period, then node having SYNC packet will simply send the SYNC packet in the following $SYNC_{nodata}$ period. Since the data traffic is transferred in the very first period of listen time, nodes which are not involved in current communication can go to sleep immediately. Furthermore, nodes which are involved in communication can go to sleep as soon as communication between them is over. This makes TEEM's listen period adaptive. These reasons make TEEM much more energy efficient than S-MAC.

Ⅳ. Experimental Results

The goal of this simulation is to study the effects of varying duty cycle on low duty cycle MAC protocols. For this we simulated S-MAC and TEEM with different duty cycle values under variable traffic load.

4.1. Experimentation environment

Both protocols were simulated and evaluated on NS-2 simulator (version 2.32). The simulated nodes are configured using the parameters listed in Table 1. All unmentioned parameters are default settings of NS-2.

We perform the tests on a simple topology of four-hop networks with one sources and one sink as illustrated in Fig 1. Sensor node 0 has CBR application attached to it. Data flow pass through from node 0 to node 4, via the intermediate node 1, node 2, and node 3. In our simulations, the message inter-arrival period varies from 2 to 20 seconds. 30 messages with 50 bytes each is periodically generated to be transferred to sink node.

Table 1: Node Configuration Parameters

Channel type	WirelessChannel
propagation model	TwoRayGround
Antenna model	OmniAntenna
Network interface type	WirelessPhy
Interface Queue	PriQueue
Buffer size of IFq	50
Routing protocol	NOAH
Traffic Source	CBR for UDP
Energy model	EnergyModel
Initial energy	1000 joules

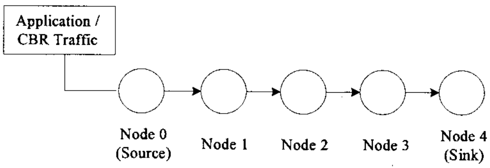

Fig 1. Node topology of NS-2 simulation.

4.2 Performance Evaluation

For performance evaluation, we measured the packet delivery ratio, energy efficiency, and average end-to-end delay of both protocols with 10%, 20%, and 30% duty cycle under variable traffic loads.

4.2.1 Result of packet delivery ratio

Packet delivery ratio (PDR) in percent of S-MAC and TEEM with 10%, 20%, and 30% duty cycle under variable traffic load is shown in Table 2. For 10% duty cycle, the PDR was less than 85% where as, at 30% it was less than 95% at message inter-arrival period of 2 secs for both protocols. Only at very low data traffic, packet delivery ratio was 100%. We can see from Table 2 that enlarging duty cycle significantly improves the packet delivery ratio. In S-MAC at 10% duty cycle, the packet delivery ratio was 100% when the message inter-arrival period was beyond 16 seconds. But at 30% duty cycle, same was achieved at message inter-arrival period of 6 seconds. This implies that increasing duty cycle increased the packet delivery ratio. The results were similar in the case of TEEM also.

Table 2: Packet delivery ratio in %.

Interval [sec]	S-MAC duty cycle(%)			TEEM duty cycle(%)		
	10	20	30	10	20	30
2	0.84	0.90	0.93	0.81	0.86	0.95
4	0.87	0.93	0.96	0.90	0.93	0.98
6	0.91	0.96	0.98	0.92	0.96	1
8	0.93	0.98	1	0.97	0.99	1
10	0.96	1	1	0.99	1	1
12	0.97	1	1	1	1	1
14	0.98	1	1	1	1	1
16	1	1	1	1	1	1
18	1	1	1	1	1	1
20	1	1	1	1	1	1

Table 3: Average End-to-End Delay in secs.

Interval [sec]	S-MAC duty cycle(%)			TEEM duty cycle(%)		
	10	20	30	10	20	30
2	79	28	7	75	29	7
4	59	19	3	55	6	3
6	37	4	2.45	34	2.79	1.79
8	15	3.8	2.42	9	2.73	1.78
10	7	3.6	2.21	5.6	2.67	1.74
12	6.9	3.5	2.3	5.5	2.63	1.74
14	6.5	3.5	2.23	5	2.6	1.74
16	6	3.25	2.23	5	2.6	1.74
18	6	3	1.84	5	2.6	1.74
20	6	3	1.84	5	2.6	1.74

4.2.2 Result of average end-to-end delay

Table 3 shows the average end-to-end delay of S-MAC and TEEM in seconds. For both protocols, latency decreased when the duty cycle was increased. From the results of both the protocols, we found that, at high data traffic, increasing the duty cycle considerably decreased the latency. But at low data traffic, when duty cycle was increased, the improvement was poor. Further, we found that there is a minimum latency value that can be achieved for every duty cycle value. For example, in S-MAC, this minimum value was 6 secs for 10%, 3 secs for 20%, and 1.84 secs for 30% duty cycle in our experiment. However, increasing duty cycle decreased this minimum value. In S-MAC, the minimum latency value of 6 seconds was reduced to 1.84 secs when duty cycle was increased from 10% to 30%. The results were similar in case of TEEM also.

Table 4: Energy consumed in source in joules.

Interval [sec]	S-MAC duty cycle(%)			TEEM duty cycle(%)		
	10	20	30	10	20	30
2	153	93	73	49	40	43
4	155	103	90	51	45	58
6	159	110	114	54	36	79
8	164	127	134	56	73	97
10	180	138	152	73	90	116
12	187	148	165	80	100	130
14	190	160	190	85	113	155
16	200	186	208	93	130	166
18	205	200	226	98	147	184
20	210	227	236	105	153	202

4.2.3. Result of energy consumption

The energy consumption in joules at the source node for both S-MAC and TEEM are shown in Table 4. In S-MAC, at high data load, 10% duty cycle consumed more energy than 20% and 30%. Similarly, 20% duty cycle consumed more energy than 30%. This is because at high data traffic, there are lots of collision and re-transmission. But when there was low data traffic, when message inter-arrival period was greater than 14 seconds, 10% duty-cycle consumed less energy than other two. Similarly, 20% consumed less energy than 30% at low data traffic.

In case of TEEM also, the result was similar to S-MAC. However, in both protocols, rate of change of energy with time is much less in 10% than 20% and 30% which implies that in long run low duty cycle consumes less energy than large duty cycle.

V. Conclusion

In this paper, we quantified the effects of duty cycle in the performance of low duty cycle MAC protocols. We simulated S-MAC and TEEM protocols with 10%, 20%, and 30% duty cycle in NS-2 under variable traffic load. Although it seems that TEEM is better than S-MAC for all the simulation results, duty cycle has similar effect to the performance of both protocols. Our results demonstrate the tradeoff between latency and energy consumption under varying duty cycles and for different message inter-arrival periods. Large duty cycle performs well under high traffic, but duty cycle has a very less impact under low data traffic.

From our results, we conclude that adaptive duty cycle, i.e. large at high traffic and small at low traffic, would make low duty cycle MAC protocols optimal.

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