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Sleep schedule for periodic data transmissions in sensor networks*

LI Hong[1,2], HUANG Liu-sheng[1,2], XU Hong-li[1,2], XIAO Ming-jun[1,2]

(1. *Department of Computer Science and Technology, University of Science and Technology of China, Hefei* 230027, *China*;
2. *Anhui Province-MOST Co-Key Laboratory of High Performance Computing and Its Application, Hefei* 230027, *China*)

Abstract: The most recent MAC protocols for sensor networks improved S-MAC from different points of view other than periodic data transmission situation. A time-based medium access control algorithm TB-MAC was presented specifically for periodic transmission applications. Based on the traffic forecasting and the time interval during which each node needed to be active previously, TB-MAC could compute the sleep/wakeup schedule. Simulation result shows that, in comparison with S-MAC, TB-MAC has enhanced energy efficiency by at least 75%, achieving at the same time better delay capability than S-MAC.

Key words: wireless sensor networks; MAC; sleep/wakeup; sleep schedule; CSMA

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传感网中基于周期性数据传输的休眠调度研究

李 虹[1,2],黄刘生[1,2],徐宏力[1,2],肖明军[1,2]

(1.中国科学技术大学计算机科学与技术系,安徽合肥 230027;2.高性能计算及应用省部共建重点实验室,安徽合肥 230027)

研究快报

摘要:针对近年来无线传感器网络所设计的MAC协议从不同角度对S-MAC进行了改进,但均没有考虑周期性数据传输的特性这一问题,提出了基于时钟的媒介访问控制算法TB-MAC. TB-MAC根据对流量的预测和节点的历史活跃信息来计算休眠/活动周期.仿真结果表明TB-MAC比S-MAC节省了至少75%的能耗,同时获得了优于S-MAC的延迟性能.

关键词:无线传感器网络;MAC;休眠/活动;休眠调度;CSMA

Recent advancement in wireless communications and electronics has enabled the development of low-cost sensor networks[1]. The MAC algorithm is the physical basis for transmission which deals with the details about channel access and transmission process, and is thus one of the most important issues in sensor networks. IEEE 802.11 MAC protocol given in Ref.[2] is a commercial standard used in wireless traditional networks without sleep/wakeup

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Biography: LI Hong, female, born in 1982, Doctor candidate. Research field: wireless sensor networks. E-mail: lihong@mail.ustc.edu.cn

Corresponding author: HUANG Liu-sheng, Prof., E-mail: lshuang@ustc.edu.cn

schedule. It is energy costly. Ref. [3] presents B-MAC which employs an adaptive preamble sampling scheme to reduce duty cycles and minimize idle listening. Ref. [4] gives *S*-MAC with the sleep/wakeup schedule. Although it saves more power than 802.11 MAC, it does not adapt to network traffic very well since it uses a fixed duty cycle for all the sensor nodes. Ref. [5～8] improve *S*-MAC from different points of view other than periodic data transmission. As periodic transmission has a wide application in sensor networks, TB-MAC is proposed.

There is a sensor network composed of n sensor nodes, among which there are q source nodes which sense conditions around and one base station used for processing all the packets. Each source node will produce one packet per sampling interval T. Other sensor nodes are just used for relaying packets to the base.

TB-MAC is a CSMA type protocol on MAC layer. The data transmission process works like *S*-MAC[4]. It needs RTS/CTS/DATA/ACK process for one transmission. To save energy, it also uses the sleep/wakeup schedule. In TB-MAC, the listen period is the time interval for CS (carrier sense) and RTS/CTS exchange; the data period is the interval for one data packet and one ACK transmission; the active period is the sum of the listen period and the data period. Next, the computation rule of the sleep/wakeup schedule is described.

During the first whole sampling period, all the nodes keep awake without any sleep. From the second sampling period, the nodes do sleep/wakeup repetition. In the $(k-1)$-th $(k\geqslant 2)$ sampling period, when each node wants to send or relay a new packet, i. e. when it tries to do its first CS process to send a new packet, it will record the clock time, then called CStime. The CStime will be filled into the CStime field of the corresponding data packet. Each node that receives a new data packet which destines to it gets the CStime value. It chooses the minimal CStime value as the start time of the dangerous period which is the time interval during which we think that this node will receive packets. The node also needs to choose the maximum CStime value added with the length of one listen period as the end time of the dangerous period. The relationship of these periods is shown in Fig. 1 where nodes j and s are trying to send packets to node i. We call j and s the children nodes of node i. To predict the traffic through node i, we should take count of the packets i receives in $(k-1)$-th sampling period, we denote it as m_{k-1}.

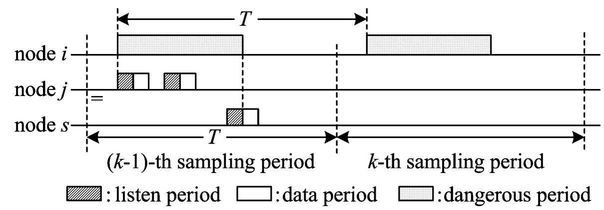

Fig. 1 Relationship between different periods

In the k-th sampling period, we can predict that the current dangerous period is the same as that of $(k-1)$-th sampling period. As Fig. 1 shows, the interval between these two close dangerous periods equals the interval of the sampling period that is T. We can also predict that in the current whole dangerous period, the node will receive m_{k-1} data packets from its children nodes. So we average the dangerous period with m_{k-1} listen periods and $(m_{k-1}-1)$ sleep periods. If the sleep period is less than the data period, then we should correct its value to the interval of the data period.

When a listen period comes, if node i has already received d packets in previous active periods, then the number of packets node i will receive in the remaining dangerous period will be $(m_{k-1}-d)$. So we need to re-average the remaining dangerous period with $(m_{k-1}-d)$ listen periods and $(m_{k-1}-d-1)$ sleep periods. For example, in Fig. 2, node i at time x has three remaining packets to receive as there are three listen periods. But it may not receive any packet in the following listen period. Then at time $(x+t1)$, see (b), it re-averages the remaining dangerous period with still three listen periods and two sleep periods. If at time $(x+t)$, node i already receives a new packet, see (a), then there will be two listen periods and one sleep period. That is, if the future traffic is heavier, then the sleep period is shorter; if the future traffic is lighter, then the sleep period is longer. If the remaining dangerous period is less than one active period, while there will still be packets to be received or to be sent, then the sleep period will be the same as the data period.

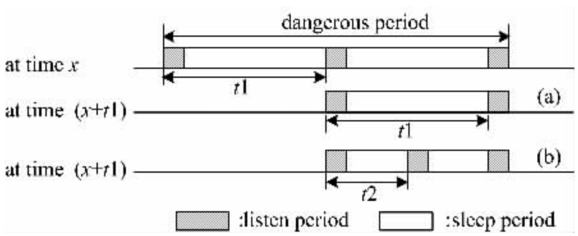

Fig. 2　Sleep/wakeup schedule of node *i*

To indicate if each node i receives all the packets, we introduce the more packet flag (Mpf). The Mpf flag is filled into the corresponding Mpf filed of any out-going data packets. The sensor node can set the Mpf flag to 0 only if it has no packet in its buffer and all its children nodes have sent the data packets with Mpf flag set to 0. The node that has Mpf flag set to 0 can go to sleep until the dangerous period of the next sampling period comes. The node that has Mpf flag set to 1 will execute the sleep/wakeup schedule as the computation rule described above.

To see the performance of TB-MAC, we first do a simple analysis. We compare 802.11 MAC, S-MAC and TB-MAC using two metrics: maximum end-to-end delay and total energy consumption in one sampling period. Chain based on topology is shown in Fig. 3, where n nodes are deployed in one line, node 0 is the source node and node n is the sink. Fig. 4 shows the converge cast topology, where $(n-1)$ source nodes from index 1 to $(n-1)$ send packets at the same time to sink node n. The notations for analysis are listed in Tab. 1, and analysis results are listed in Tab. 2. From these results, we can see that TB-MAC gets the same delay as 802.11 MAC and the same energy consumption as S-MAC in both topologies.

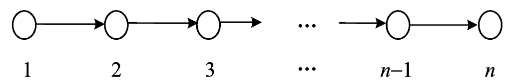

Fig. 3　Chain based topology

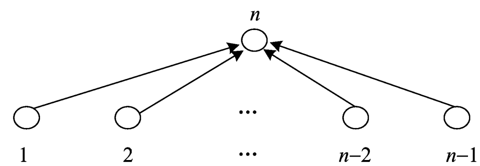

Fig. 4　Converge cast topology

Tab. 1　Notations for analysis

Notation	Explanation
T_{listen}	Time interval for CS and RTS/CTS exchange
T_{sleep}	Sleep time between two listen periods
T_{data}	Time interval for data and ACK transmission
E_{listen}	Energy consumed in CS and RTS/CTS exchange
E_{tx}	Energy consumed in data and ACK transmission
E_{remain}	Energy consumed in the total time without listen, sleep and data transmission

Tab. 2　Performance Analysis

	Chain-based / Converge cast Topology	
	Maximum end-to-end delay	Total energy consumption
802.11	$(n-1)(T_{listen}+T_{data})$	$(n-1)(E_{tx}+2E_{listen})+nE_{remain}$
S-MAC	$(n-1)(T_{listen}+T_{data}+T_{sleep})$	$(n-1)(E_{tx}+2E_{listen})$
TB-MAC	$(n-1)(T_{listen}+T_{data})$	$(n-1)(E_{tx}+2E_{listen})$

The simulation of TB-MAC uses NS2. The area is 25m * 25m with uniform distribution of 16 sensor nodes, 3 source nodes and one sink node. The duty cycle for S-MAC is set to the default value 10. Other physical simulation parameters are listed in Tab. 3. Fig. 5 compares the energy consumption of the entire network in one sampling period. Because in TB-MAC, those nodes that are not in the routing link can sleep all the time and those that are in the routing link can sleep after the transmission is done, so it gets the minimum energy consumption. In 802.11 MAC and S-MAC, the total energy is increasing with a constant when the sampling interval increases, because the active time in these two protocols is proportional to the sampling interval. But in TB-MAC, the energy is

Tab. 3 Simulation Parameters

Parameter	Value
Transmission power	0.5 Watts
Receiving power	0.3 Watts
Idle power	0.05 Watts
Transmission time for RTS/CTS/ACK	0.011 s
Transmission time for one data packet	0.043 s
Communication radius	7.5 m

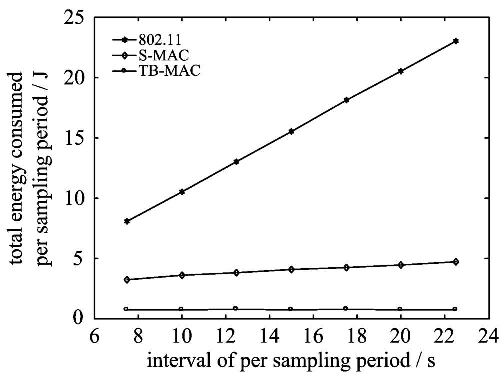

Fig. 5 Total energy consumed vs. interval of sampling period

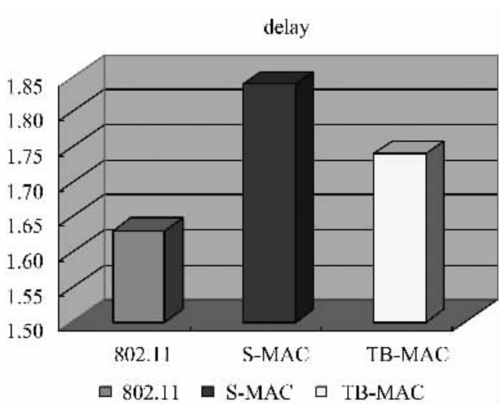

Fig. 6 Maximum end-to-end delay

only related to the data rate. When the sampling interval is 7.5 s, the TB-MAC consumes less energy than S-MAC by at least 75%. Fig. 6 compares the maximum end-to-end delay per sampling period which means that the time interval between the first packet being sent out to the last packet reaching the sink node. From the histogram, we can see that 802.11 gets the least delay and S-MAC gets the most delay, with TB-MAC being in the middle, though in a theoretical analysis , TB - MAC gets the same delay as 802.11. However, in a multi-hop situation, the average operation on a dangerous period is only a prediction and glancing which cannot fit the real situation perfectly. So the delay in TB-MAC is greater than in the analysis results.

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