An Energy-Efficient and Low-Latency MAC Protocol Based on Adaptive Coordination Contention Window for Wireless Sensor Networks

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Abstract: Wireless sensor network (WSN) consists of massive small sensor nodes which are located in monitoring region, the target of which is to cooperatively sense, collect and process the information of objects in the coverage area, then send the information to the observer through wireless communication. It can be widely used in military applications, medical treatment, traffic, environment monitoring and so on. Medium Access Control (MAC) Protocol, which decides how to share the wireless channel, allocates the limited communication resource among nodes and a good MAC protocol can save lots of energy and reduce collision. Firstly the thesis analyzed the research background and the current situation at home and abroad, and then discussed the structural characteristics of wireless sensor networks and other content, in which indicating the energy consumption of the wireless sensor network; Then, the thesis compared and analyzed the MAC protocols of the wireless sensor Network, focusing on competition-based MAC protocol S-MAC protocol in detail. From the shortcomings of the thesis proposed a new study of the improved protocol basing on the random work sleep scheduling mechanism; Finally, the thesis simulated the improving the MAC protocol, showing that the performances of the improved protocol are better than the original in improving energy efficiency, delay, throughput and so on from the analysis of simulation results.

Keywords: Contention window, efficient, low-latency, MAC, wireless sensor networks.

1. INTRODUCTION

With the rapid development of wireless communication technology and embedded technology in recent years, sensor nodes capable of sensing, storage, processing and transmission of data, it becomes more and more convenient use and popularization. Wireless sensor networks have many applications, such as environmental monitoring, intelligent home, medical systems and robot exploration. Now more and more researchers are focusing on wireless sensor networks, they also made a lot of achievements in many aspects. Wireless sensor network MAC layer is responsible for the management of wireless channel, it avoid conflict between the nodes, distribution channel, energy and other resources play an important role. We propose an efficient MAC protocol for wireless sensor networks is very important, especially in energy efficient, node latency and throughput and other aspects can meet the practical application of the MAC protocol.

Wireless sensor nodes are generally with battery power supplies, due to environmental and cost constraints, battery with limited energy is often not replaced and charged; therefore energy efficient protocol for network longevity is more important. Mainly in waste energy of a node has the following several aspects: conflict, crosstalk, control packets consumption, idle listening and traffic flow fluctuation. At present, many researchers use periodic mechanism listen/sleep to reduce idle listening, use the classic RTS/CTS/DATA/ACK four times handshake mechanism to avoid conflicts. SMAC is a kind of MAC protocol of wireless sensor based on competition. Its main contribution to the energy saving in the following four aspects: reducing conflict, crosstalk, control packet overhead and idle listening. Compared with the previous protocol, which has achieved good results, but SMAC uses the fixed contention window, however, is not to use the flow changes. When the flow changes, its prone to transmission conflict between nodes. This paper will propose a kind of coordination of competition window dynamic adaptive based on flow queue (Contention Window, CW) MAC layer protocol, compared with the SMAC protocol, which can save an average of about 28.7% of energy.

2. RELATED WORK

Wireless MAC energy efficient protocol currently is a hot topic; researchers have proposed a lot of different solutions in study prolong the network lifetime subject. However, the existing wireless MAC protocols are mostly designed specifically for ad hoc networks, and do not apply to wireless sensor networks, such as IEEE 802.11 protocol. MAC protocol for wireless sensor networks, although many researchers now have to make a lot of work, but they still have some problems.

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SMAC [1] is a new self-configuration supports MAC protocol, which through sleep scheduling reducing idle listening energy. TMAC [2] is based on the low flow SMAC protocol, which sets a threshold TA, when exceeded the TA threshold time the incident is not activated, the node automatically end its listening state; This method is somewhat solve the SMAC early sleep problems. DSMAC [3] adds dynamic delay and duty cycle to achieve reduction energy consumption. QSMAC [4] used to adjust the duty cycle traffic ways to reduce energy consumption, the experimental results show that the throughput and reception rate than SMAC.

Wise MAC and BMAC [5] use leading way to reduce idle listening time, when the low traffic in wireless sensor networks, which have achieved very good results. DMAC design goal is convergence wave communication, although the delay and energy aspects make a certain contribution, but after all, limited by its applications.

Above proposed several protocols are fixed contention window to competition medium. When traffic flow is very heavy, the smaller competition window will cause more conflict, it will waste a lot of energy; when the traffic flow is very light, a larger contention window will cause energy waste. By modifying the contention window for cluster head election, the experimental results show that modify the contention window through self-adaptation approach can be more than enough to elect the cluster head with high success rates, and the cluster head is evenly distributed, the effect is very obvious. In 2008, Navrati Saxena proposed a MAC protocol based on a modified duty cycle window, and achieved lower latency and higher throughput results [6]. From the point of view node residual energy, adjust the contention window size according to the residual energy. Through changing contention window size impact on the performance of the sensor network is very large, above mentioned studied the method of modification contention window from different way and its achieved results, this paper proposed a MAC protocol of self-adaptation contention window based on traffic flow, considering from the transmission flow of wireless sensor network, fully embodies the characteristics of the network.

Next, we will describe a MAC protocol based on modified contention window (CWQ-SMAC), then to verify the protocol through the simulation and analysis of experiments, at last summary the algorithm [7].

3. CONCEPT

3.1. CWQ-SMAC Protocol

In SMAC protocol contention window is fixed and can not self-adapt to traffic flow changes in the wireless sensor networks. Process of changing the traffic flow size, if there is no corresponding contention window self-adapt, it would waste a lot of energy. In IEEE 802.11 [8], the contention window use binary back off (Binary Exponential Back off, BEB) way. A new dynamic adaptive coordination contention window MAC protocol is based on SMAC protocol, while using the three kinds of threshold parameters to improve the performance of the binary back off mechanism [9].

3.2. The SMAC Mechanism

SMAC is a periodic listen/sleep MAC protocol for wireless sensor networks, in sleep mode; turn off all unnecessary components in order to achieve energy savings. When a node is in listening state, the node listens the channel and use CSMA [10] mode to competitive channel, and according to the obtained RTS/CTS to determine the sleep, so the SMAC can reduce the idle listening and energy saving. This periodic listen/sleep mode also determines the required time synchronization mechanism, only time synchronization in order to make better use of RTS/CTS control package information [11].

Periodic sleep leads to very high sleep delay. Because the receiving node receives a completed state must sleep to listening state to compete next channel. That is forwarded to the next hop node [12]. The delay caused by the cycle of sleep is called sleep latency (sleep delay). Adaptive listen technology can be used to reduce the sleep delay, node in the listen state listen to neighbor nodes receive packets of data. It may be speculated their next hop neighbor nodes receiving is completed, calculation time at this moment the open short time. So the receiving node in the receiver can be completed with the next hop node get in touch immediately reach a handshake packet forwarding. The information transmission technology can reduce half of the sleep delay.

However SMAC competition using a fixed window, it can not adapt to changes in network traffic. If the CW [13] is too small and relatively heavy traffic flow at this time, then it will generate a lot of unnecessary transmission collisions; similarly, when the CW is too big and the traffic flow is relatively light at this time, there would not get channel by a long time competition, and waste unnecessary energy as shown in Fig. (**1**).

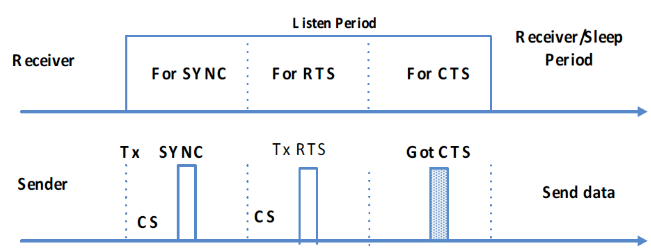

Fig. (1). DCF schematic diagram.

3.3. BEB Characteristics in IEEE 802.11

Distributed Coordination Function (DCF) [14] in IEEE 802.11 as shown in Fig. (**2**) is a basic media control mode. When transmission conflict between nodes, DCF binary back off way to dynamically adjust the contention window, that CW doubles and adopt a new back off intervals; once $CW>CW_{max}$, put the set $CW = CW_{max}$. After each successful transmission, set the $CW = CW_{min}+1$.

Although BEB provides fair competition, it still has some problems: when traffic flow frequency is great change, BEB cannot balance the node conflict and energy waste factors. In the CWQ-SMAC protocol solve the above problems by setting the way three threshold methods [15].

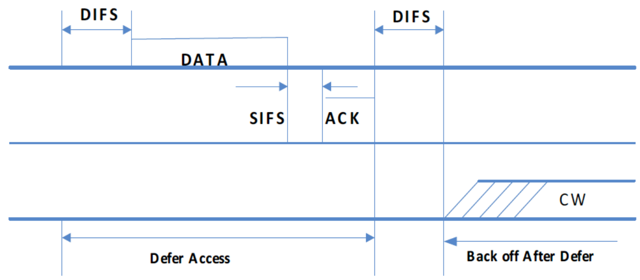

Fig. (2). DCF schematic diagram.

4. ALGORITHM

4.1. Traffic Prediction and Jitter Avoid

In SMAC protocol, synchronization between nodes is through send synchronization packet with synchronization time intervals. This paper presents an algorithm to predict traffic flow by synchronizing periodic intervals [16].

a) A synchronization cycle in network normal operation, recording five consecutive queue length, they are:

$$Q_1, Q_2, Q_3, Q_4, Q_5$$

b) Get the average queue length of the buffer

$$I = \sum_{i=1}^{4} (Q_{i+1} - Q_i) / 4 \qquad (1)$$

Because the sensor network data has regularity in general, so we can predict the flow and avoid jitter flow using the above formula [17].

4.2. Neighbor Queue Effect

As shown in Fig. (**3**), assume that node 0 only communicate with three nodes. Node 1 and node 2 is the sender node 0 data, so the node 1 and node 2 determines the node 0 traffic flow [18]. So recording node 1 and node 2 of the five contact queue length and do not need to record node 3 data. So we can get node 0 effect to neighbor nodes, the formula is as follows:

$$T = \sum_{i=1}^{4} \left(\frac{\sum_{j=1}^{n} Q_{i+1,j}}{Q_{i+1,t}} - \frac{\sum_{j=1}^{n} Q_{i,j}}{Q_{i,t}} \right) / 4 \qquad (2)$$

$Q_{i,t}$ Represents the queue length of nodes, $\sum_{j=1}^{n} Q_{i,j}$ represents all the traffic flow of a neighbor node, such as traffic node 2.

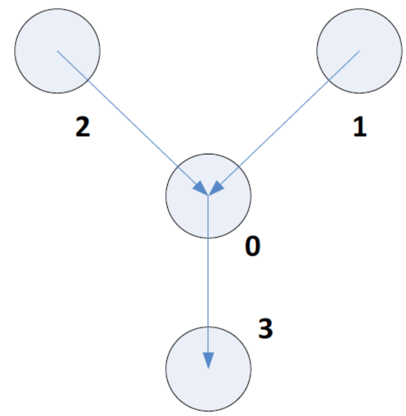

Fig. (3). Node 0 and other 3 node communication schematic diagram.

4.3. Dynamic Adaptive Coordination Contention Window Core Algorithm

In IEEE 802.11 DCF [19] change the contention window only when the conflict happens, at this time has been wasted a lot of energy. The algorithm in every time before sending synchronous package to modify the CW, and thus can avoid more conflict.

a) Assume $\alpha_1 < \alpha_2 < \alpha_3$, α_i represents maximum queue length Q_{max} proportion.

b) $\beta_{\min} \le \beta_{cur} \le \beta_{\max}$, $\beta_{cur} = 2^2 - 1$

$\beta'_{\min} \le \beta'_{cur} \le \beta'_{\max}$, $\beta'_{cur} = 2^2 - 1$

β_{cur}, β'_{cur} respectively represent the current synchronization and data contention window. Modify β_{cur} and β'_{cur} algorithm is the same, so the modified algorithm of β_{cur} is given.

*c) Specific algorithm as shown in Fig. (**4**), the following is pseudo code:*

$$\begin{aligned} & if\ Q_{cur} < \alpha_1 * Q_{\max}\ \ then \\ & \quad \beta_{cur} = \beta_{\min} \\ & if\ (Q_{cur} > \alpha_2 * Q_{\max} \parallel (I\psi - \tau T) \ge 2)\ then \\ & \quad \beta_{cur} = \beta_{cur} * 2 + 1 \\ & if\ (Q_{cur} > \alpha_3 * Q_{\max} \parallel (I\psi - \tau T) \ge 4)\ then \\ & \quad \beta_{cur} = \beta_{\max} \\ & if\ (\beta_{cur} > \beta_{\max})\ then \\ & \quad \beta_{cur} = \beta_{\max} \end{aligned} \qquad (3)$$

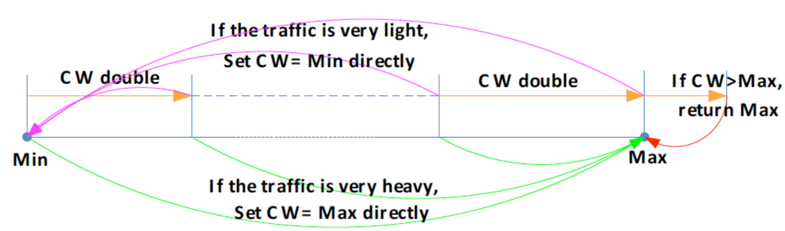

Fig. (4). Modify CW algorithm schematic diagram.

In order to adaptive CW to change the traffic flow, CWQ-SMAC must make full use node traffic flow information. Therefore, the current queue length and queue changes both as a modified window factor. When traffic flow grows rapidly, trimming βcur = βmax; when the traffic flow is heavy and reaches βcur> βmax, set βcur = βmin, rather than BEB in the βcur = βmin. Thus, this protocol can reduce conflict and avoid CW uncontrolled increases [20].

4.4. Scheduling and Synchronization Mechanism

In SMAC protocol, neighbor node time synchronization takes quite a long time to send each other SYNC package to achieve this protocol. In order for a node smoothly to receive the SYNC [21] packet, the listening state is divided into two parts: SYNC and RTS. Although SMAC has done a lot of work in scheduling, but it still can not avoid the occurrence of multiple scheduling exist in the same sensor network phenomenon. In this way, the edge node may also maintain a number of different scheduling. These nodes will energy consumption more quickly than other nodes and lead to these nodes of early death. Although SMAC protocol presents a global thought, but still need to maintain time synchronization. This paper uses a global scheduling methods, does not require time synchronization. Use from the neighbor received the N-ACK [22] Time deviation Toff to maintain scheduling. When a node receives the N-ACK, only need to adjust their Toff coincides with the neighbor nodes.

$$\begin{aligned} &\left|T_{off}\right| < \frac{1}{2}T_f \\ &If\ T_{off} > \frac{1}{2}T_f, then\ T_{off} = T_{off} - T_f \\ &If\ T_{off} < -\frac{1}{2}T_f, then\ T_{off} = T_{off} + T_f \end{aligned} \quad (4)$$

T_{off} is the clock offset nodes, T is the frame length. In order to reduce the offset error of the clock, the protocol take the average value of the clock offset of neighbor node as the new T_{off}.

$$T_{off} = \frac{1}{n}\sum T_{off}^{i} \qquad T_{off}^{i}\ is\ neighbor\ offset$$

$$\Delta T_{off} = T_{off}^{new} - T_{off}^{old}$$

ΔT_{off} is deviation for the current node offset and the previous offset

In order to cancel the time synchronization mechanism, this paper uses the delta T instead; through the delta T protocol to coordinate the clock, in order to achieve the wireless sensor nodes can communicate normally [23].

4.5. Sleep Mechanism

CWQ-SMAC still uses the listener / sleep mechanism to reduce idle listening time. It listens for sleep scheduling and leading mechanism is based on a neighbor's adjusted schedule information [24]. When B sends N-ACK to A, C can receive the N-ACK. Once C has data to send to B, then C will send the DATA packet directly after random time TR. The CWQ-SMAC protocol purpose is to minimize the lead time as shown in Fig. (**5**).

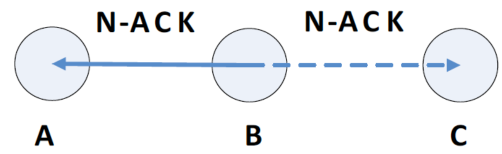

Fig. (5). N-ACK models.

Because CWQ-SMAC protocol contains additional information in the control and data packets the node scheduling information can obtain the neighbors information. Node can wake up from a sleep state until the end of the neighbors in the transmission, and then began to send leader packet. Then you can get the channel and wait for the receiver to send DATA. N-ACK note that the lead time where Tp node only needs less than Toff, because Toff is clock offset [25].

According to the above, we can get the following conclusion:

$$T_R \le T_p \le \left|T_{off}\right|$$

$$T_s = T_f - T_p - T_x$$

$$T_s = T_s^{old} + \Delta T_{off}$$

When the flow rate is very small, it can set the $T_R = 0$, in order to achieve a minimum of lead time Tp. In practice, RT is always less than the lead time Tp.

When a node receives a data packet or a control packet from a neighbor, it will modify their time offset T_{off} refer to the above formula [26]. If $\Delta T_{off} < 0$, represents the node clock slower than the other, it can put the time to adjust quickly. In other words, CWQ-SMAC can increase sleep time Ts, similarly, when $\Delta T_{off} > 0$ can also increase the length of time Ts.

5. SIMULATION RESULTS

Simulation, assume that all nodes are stationary. In this paper, the algorithm CWQ-SMAC protocol is based on the SMAC simulation, in order to justice in comparing CWQ-SMAC and SMAC didn't use the adaptive mechanism of listening [27, 28].

5.1. Network Topology

With hexagonal topology as shown in Fig. (**6**), this contains six nodes. The sender is the first 3 nodes; the recipient is after 3 nodes. Regular hexagon of side length is 166 m.

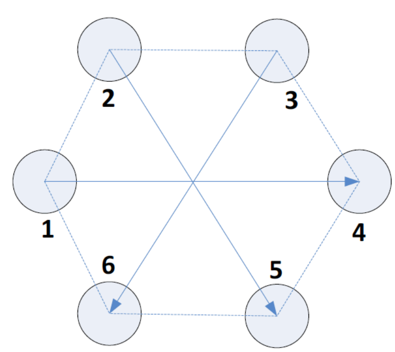

Fig. (6). Network topology.

5.2. Parameter Setting

SMAC experiment specific parameters are as follows in Table **1**.

Table 1. Simulation parameters.

Parameter	Value
NS2 version	NS2-2.29
Simulation time	1000s
Traffic	CBR
SMAC duty cycle	10%
SMAC sync CW	31
SMAC data CW	63
Simulation areas	500m×500m
Default transmit range	250m
Routing protocol	AODV
The number of nodes	6
Q_{max}	50

5.3. Experimental Results and Analysis

As shown in Fig. (**7**), the test results show that the CWQ-SMAC protocol than SMAC protocol energy saving about 28.7%. Compared with SMAC protocol, CWQ-SMAC energy consumption has remained very low, is not affected by the traffic flow fluctuation; and the relative SMAC will consume more energy in the traffic flow jitter. The experimental results show that the CWQ-SMAC can automatically adapt to traffic variation. When the Constant Bit Rate (CBR) interval is set 1.5 seconds, its performance achieves the optimal. Thus we can draw the conclusion: the algorithm in this paper is more suitable for high-speed sensor network.

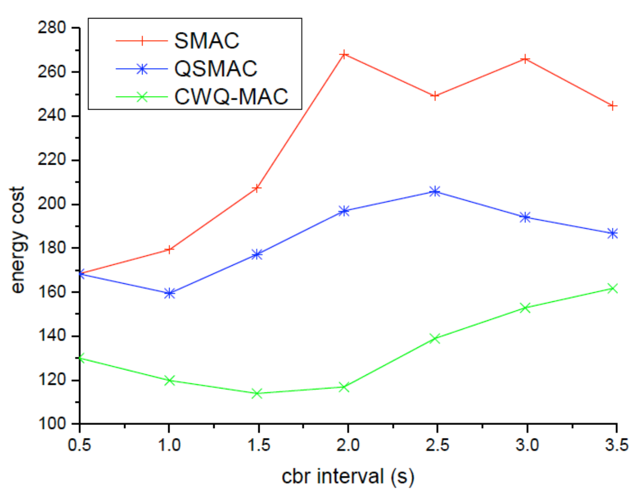

Fig. (7). Energy comparison.

However, due to the change of the CW is frequent, delay and receiving rate only equal with the performance of SMAC protocol, as shown in Fig. (**8**). From the experimental results can clearly ensure the network normal operation, the curve of the SMAC rising very fast, especially in the curve in Fig. (**9**). Although the performance of CWQ-SMAC is not better than SMAC, it can ensure the network normal state not very high and not very low. When traffic flow is very heavy, the CW will automatically set the bigger, in this way, can more quickly competition get the channel, thus the data can be transmitted in time. Due to CWQ-SMAC decreased more conflict, so CWQ-SMAC transmission and retransmission failure rate is lower than the SMAC, thus to reach the lower packet loss rate and low-latency.

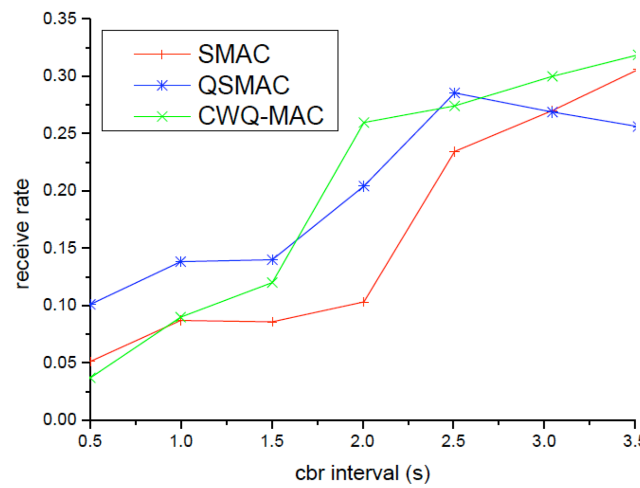

Fig. (8). Receive rate comparison.

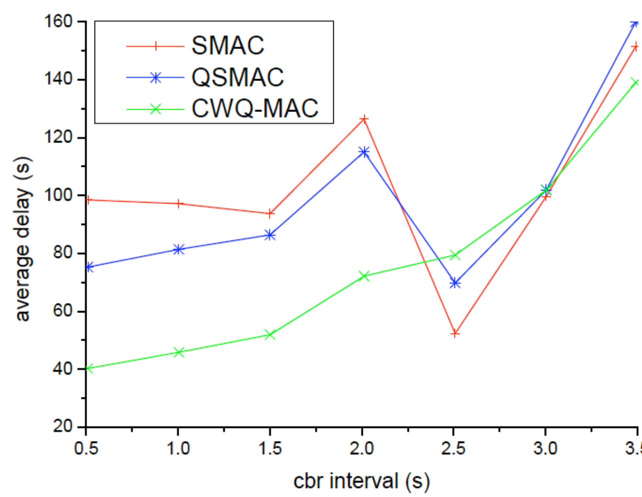

Fig. (9). Delay comparison.

CONCLUSION

In this paper, we presented CWQ-SMAC, a new energy efficient MAC protocol designed to reduce the unnecessary energy consumption. It can be reached dynamic self-adaptive traffic flow changes through the coordination of competitive window. It is obviously superior collision avoidance and sleep scheduling short leading mechanism and energy saving effect better than SMAC. In addition, data exchange scheme is used to provide both collision avoidance and reliable transmission. Simulation results show that CWQ-SMAC protocol can provide low latency and low energy consumption. It solves the conflict between energy and latency effectively.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENT

Declared none.

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Received: September 18, 2014 Revised: December 22, 2014 Accepted: December 31, 2014