Optimization of T-MAC Protocol in WSN Based on Minimum Contention Window

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Abstract. Considering the issue of energy consumption caused by idle listening, collision retransmission and control consumption of MAC layer in wireless sensor networks, this paper introduces an improved MAC protocol based on the minimum contention window on the foundation of S-MAC and T-MAC protocol. The proposed protocol distinctively calculates the minimum contention window according to the position of the node in the network to contend channel, and adjust the size of the window by changing the window coefficient in accordance with the congestion. Combined with redefinition of the time interval 'TA' in the T-MAC protocol, listening and sleeping time is also optimized. The simulation results demonstrate that the protocol proposed in this paper ameliorates the performance under the congestion of network in terms of throughput, time delay and energy consumption to some extent, so as to satisfy the real-time transmission and decrease energy consumption. Eventually the efficiency of network transmission is improved.

Introduction

In WSN, both S-MAC and T-MAC are based on competitive mechanism of MAC protocol [1-2]. The former operates with a fixed working/sleeping time strategy among neighbor nodes [3], in which the synchronization mechanism is introduced to diminish the energy consumption caused by the collision in WSN, and it is achieved through the way that nodes get into sleeping when there are no data sending/receiving. Compared with S-MAC, the latter [4] has cut the activity time of sensor nodes through computing the active time according to the condition of communication traffic with a dynamically varied variable 'TA', which is related to both sleeping and listening time, while maintaining the period unchanged, and sends the information with a burst mode to lessen the idle intercepting time [5-7]. However, T-MAC introduced the problem of increasing control consumption and early sleep. In view of the shortcomings and deficiencies of the T-MAC protocol, an improved algorithm based on the minimum contention window is proposed to effectively advance the throughput of the network and reduce the energy consumption [8-9].

Calculation of Minimum Contention Window

Literature [10] manifests the scientific basis that the preferable network performance can be obtained by dynamically computing the size of minimum contention window according to the network conditions. In general, increasing the size of minimum contention window will significantly enhance the network throughput and reduce conflicts under the condition of congestion. The location of each node in WSN can be represented by the structure in Figure 1, to which the channel distribution [11] is associated. In this scheme, the minimum contention window of the layer is calculated according to the
transport layer in which the node is located, thus the minimum contention window of the node is calculated according to the number of child nodes and minimum contention window of the layer.

![Figure 1. Wireless sensor networks node load distribution.](image)

**Layer Minimum Contention Window**

The calculation method of layer minimum contention window is as following:

\[
CW_{\text{min}}^{i+1} = \begin{cases} 
CW_{\text{min}}^{0} \cdot (1 + N_0) & , i = 0 \\
CW_{\text{min}}^{i} \cdot (1 + N_i) & , 0 < i < M
\end{cases}
\]

(1)

Where

\[
\gamma = \log_{\gamma_{i+1}} \frac{K}{CM_{\text{min}}^{i}}
\]

\[
N = \sum_{i=1}^{M-1} N_i / \sum_{i=1}^{M-1} L_i
\]

(2)

Assuming there is a M-level tree, \(CW_{\text{min}}^{0}\) is the value of minimum contention window of the root node; \(CW_{\text{min}}^{i}\) is the value of minimum contention window of the \(i\)th layer; \(N_i\) is the sum of the sub-nodes of all the nodes in the \(i\)th layer; \(\bar{N}_i\) is the average value of the number of sub-nodes of all the nodes in the \(i\)th layer; \(\bar{N}\) is the average number of sub-nodes in the network; \(\gamma\) is an adjustment coefficient, which is a fixed value for nodes in the same layer; \(K\) is a constant given by the network state; \(L\) is the sum of all nodes in the \(i\)th layer.

**Node Minimum Contention Window**

In the transmission tree, each node receives and forwards different loads because of the different number of sub-nodes. Therefore, the minimum contention window of each node should be calculated based on the number of sub-nodes and the layer minimum contention window. Calculation method is

\[
CW_{\text{min}}^{i,n} = \begin{cases} 
(1 - D_i) \cdot \alpha^{n-\alpha_{n}} + D_i \cdot CW_{\text{min}}^{i}, & \alpha_{n} < 1 \\
CW_{\text{min}}^{i} & , \quad 0 \leq \alpha_{n} \leq 1
\end{cases}
\]

(3)

\[
D_i = \left\lfloor \frac{n}{1 + \bar{N}_{i+1}} \right\rfloor
\]

(4)

where \(\alpha_{n}\) is the sub-nodes coefficient, obtained from the ratio of the number of all sub-nodes of one node to the average number of sub-nodes in the layer; \(D_i\) is the coefficient for the layer, to ensure that the value of node minimum contention window is between this layer and the upper one.

**Optimized T-MAC Protocol**

**Algorithm of Contention Window**

In T-MAC protocol, BEB algorithm is applied to calculate back-off time of each node. In the view of deficiency of it, the advanced idea is proposed on the basis of the last transmission of the node to optimize the contention window in this section. Approach of enlarging the contention window is adopted when data transmission is uncompleted at the last time or there is no ACK acknowledgment.
received, which can be considered leading to the collision in channel because of narrow window and fewer intercepting times. Otherwise, if the transmission is completed, it can be considered that the contention window is excessively wide, so that it is unnecessary for the node to intercepting the channel for multiple times and the contention window may be lessened appropriately. The algorithm is

Node transmission at the last time

\[
\begin{align*}
\text{fail} & : \quad CW = CW_o \times 2 \\
\text{successful} & : \quad CW = CW_o \times A
\end{align*}
\]

In the formula above, \( CW \) is the size of contention window after the information successfully transmitted or reconstructed after the collision; \( CW_o \) is the size of the original contention window; \( A \) is the coefficient to minimize the window rapidly, configured as following:

\[
A = \begin{cases} 
1, & CW_{\text{min}} < CW_o < \frac{1}{8} CW_{\text{max}} \\ 
\frac{1}{2}, & \frac{1}{8} CW_{\text{max}} < CW_o < \frac{1}{4} CW_{\text{max}} \\ 
\frac{1}{2^2}, & CW_o > \frac{1}{4} CW_{\text{max}} 
\end{cases}
\]

As can be seen from the formula above, the algorithm applies the coefficient to alter the optimal contention window size according to the condition of network congestion. This mechanism overcoming the shortcoming that the window is above extensive or narrow, resulting in the energy consumption. Through keeping dynamic changes and coordinating with real-time network transmission, network bandwidth and channel resources can be made full use.

**Improved T-MAC Protocol**

In T-MAC protocol, variable 'TA' is introduced as a buffer between listening and sleeping time. The value is constrained as \( TA > C + R + T \). For the general network, the optimal value of 'TA' is

\[
TA = 1.5(C + R + T)
\]

Based on the minimum contention window obtained above, this section presents an improved model in terms of 'TA'

\[
TA = 1.5(\text{slot time} \times CW_{\text{min}} + \text{core-function} + \text{SIFS})
\]

In the formula above, the competition interval \( C \) is the product of the slot time and the minimum contention window. Time for sending the RTS packet is determined by the core function in the simulation tool. The short-time interval \( T \) is equal to the short-frame interval SIFS. This formula provides a further energy saving mechanism for the T-MAC protocol through supplementing the reduction time of the listening period to the sleeping period. Dynamic listening/sleeping time for T-MAC protocol and the improved one have been compared in figure 2.

![Figure 2. Dynamic listening/sleeping time chart.](image)
Simulation and Results Analysis

For the sake of analyzing the improvement of the network performance brought by the proposed algorithm under different network conditions, this paper utilizes the tool OPNET to establish the simulation model and simulate the network performance in terms of three network indicators of throughput, energy consumption and time delay towards the original protocol and proposed one.

The experimental nodes are deployed in a rectangular area of 100m x 100m. The node has single hop communication and the communication radius is 50m. There are 20 sensors in the whole network and each of it is of same setting. The data frame payload is 1000 bytes and the frame interval is 20 μs. According to the experiment results in reference [12], the simulation parameters are configured as shown in Tab.1. After establishing WSN parameter model above, one of the nodes is randomly selected to compare the performance between original T-MAC with the improved one in this article.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACK</td>
<td>112[bits]</td>
<td>( CW_{\text{min}} )</td>
<td>32[slots]</td>
</tr>
<tr>
<td>CTS</td>
<td>112[bits]</td>
<td>( CW_{\text{max}} )</td>
<td>1024[slots]</td>
</tr>
<tr>
<td>RTS</td>
<td>160[bits]</td>
<td>Channel Rate</td>
<td>1M[bps]</td>
</tr>
<tr>
<td>SIFS</td>
<td>10[ μs ]</td>
<td>Time slot Length</td>
<td>20[ μs ]</td>
</tr>
<tr>
<td>DIFS</td>
<td>50[ μs ]</td>
<td>The Maximum Number of Retransmissions</td>
<td>7[times]</td>
</tr>
</tbody>
</table>

Figure 3, Figure 4 and Figure 5 respectively show the characteristics of network throughput, energy consumption and time delay towards the original T-MAC protocol against improved one with the node traffic at different transmission rates. From the simulation results, it can be seen that the proposed algorithm presents higher throughput than the original protocol, and the advantage is more obvious with the increase of sending rate. The idle listening and repeated retransmissions are overcome in this paper reducing the number of collisions and retransmissions effectively, which is benefited from adjustment mechanism and definition of variable 'TA' with the flexibly adjusted listening time. Attributing to less waiting time in buffer, time delay is rather short compared the original protocol. The analysis results show that the algorithm appears apparent advantages in conserving energy and improving the efficiency of network transmission.

Figure 3. Network throughput simulation results.  Figure 4. Node energy consumption simulation results.
Summary
In view of the shortcomings and deficiencies of T-MAC, this paper proposes an optimization model based on the minimum contention window in accordance with the characteristics of limited resources and dynamic network topology in WSN. The calculating method of the minimum contention window of the node is proposed according to the layer and sub-nodes of the network structure. Furthermore, contention window is optimized theoretically, so that it can dynamically adapt to the requirement of network transmission under the condition of congestion. Additionally, variable 'TA' in T-MAC protocol is relocated. Finally, experiment is implemented on the simulation tool to demonstrate the practicability of the conception in this paper. Simulation results show that this scheme achieves a better performance than the original T-MAC protocol in terms of throughput, energy consumption and time delay. Furthermore, energy consumption caused by conflicting retransmissions and idle intercepting is economized; therefore the network performance has been improved.

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References


