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The Research and Simulation of CSMA/CA Mechanism of ZigBee Protocol

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Abstract

In order to improve the performance of star-topology ZigBee network with fewer nodes, modified the CSMA/CA channel access mechanism of ZigBee protocol, and proposed an improved channel access mechanism - Circular Queue access mechanism. Described and realized Circular Queue mechanism; showed the beacon frame format of Circular-Queued. Finally, gave the simulation results, compared and analyzed the network performance of CSMA / CA mechanism before and after the modification from network response time, throughput, packet loss rate.

Keywords: ZigBee protocol; CSMA/CA; network performance; Circular Queue

1. Introduction

ZigBee has been successfully used in industrial and life applications such as intelligent buildings, industrial control, intelligent transportation and environmental monitoring as a wireless communication technology. It solves the problem of channel access with the use of CSMA / CA mechanism.

Because of its uniformity of technology, highly scalability, the performance of CSMA / CA mechanism of ZigBee Protocol in specific environments will be affected. The efficiency of CSMA / CA mechanism is not very high when solving the conflicts that are caused by multiple devices sharing the same channel in star-topology ZigBee network with fewer nodes, and the collision rate and backoff period are still relatively high and long. In view of this situation, this paper presents a mechanism based on CSMA / CA channel access mechanism - the Circular Queue mechanism, than the CSMA / CA

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mechanism can automatically adjust and change the parameter settings to improve the performance of star-topology network with fewer nodes.

2. Circular Queue mechanism

2.1. Description, implementation of Circular Queue Access Mechanism

The research focus on reducing the risk of collision of CSMA / CA mechanism , and the main methods are as follows : controls the time of backoff period, staggers the backoff period of devices, makes the backoff periods different. The variable that controls backoff period is BE. We focusing on its beacon-enabled mode for star-topology Time Slots network and BE is initialized with constant macMinBE. The devices' BEs select the same value, As a result, after the first time backoff, the probability of the second conflict is very high. So we increased the range of BE selection to reduce the probability of choosing the same BE value by changing the original range of 0 to 3 to 0 to 5, and dynamically adjusted the initial value of macMinBE and BE according to different network addresses of each device, which may cause less conflicts. By setting variable macMinBE, dynamically adjusting macMinBE ,we achieve the dynamic adjustment of the BE value. And by senting variable ROT during the beacon frame to take into account the fairness of the node transmission in the beacon-enabled star-topology network.

Improved mechanism described as follows :

Set variable nodes_all as the total number of nodes, then set the variable ROT that transmit in the beacon frame, and edit a function abv (x,y)that takes subtraction and then absolutes .Use the network address of each node minus the coordinator node's and take the absolute value. we can get an initial sequence number for each node with this value，and than sum with a continuous increment rotation variable ROT. The node constantly adjust it's final number current_order by a series operations with the BE's range. The variable current round number, which is later to be assigned to macMinBE and BE, decides backoff period. Fig. 1

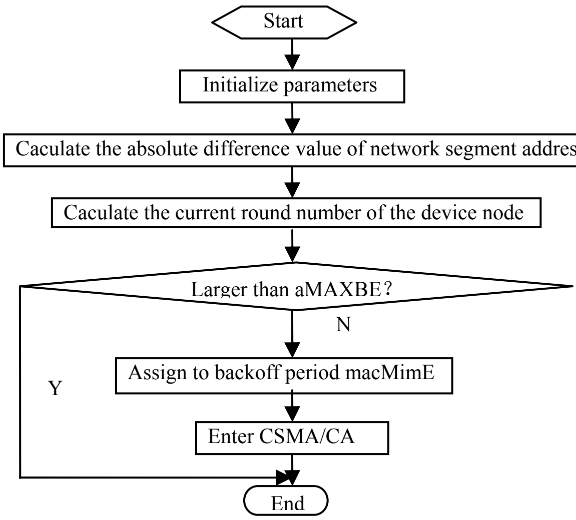

Fig. 1. flow chart of Circular Queue access mechanism based on CSMA/CA

We'll easily get the absolute value after the subtraction, and the value may be a large number. so we need to get the remainder of total numer of nodes nodes_all using the absolute value, then sum the rotation variable ROT and the reminder to get current round number. If the number is larger than the specified maximum of macMinBE, give up the value. It means that the node will not be transmitted in this round, and the CAP part in this super frame will not be transmitted because Back Period is too long. The status variable t_status will be assigned with m_INVALID_PARAMETER, meaning it's illegal parameter. If the absolute value is not larger than the maximum of macMinBE, assign it to macMinBE, then we identify the backoff period.

2.2. Beacon frame format of Circular Queue channel access mechanism

As the improved mechanism need to synchronize the backoff period of each device node in the network, and we can get the status of Synchronization from the information with beacon transmitted from coordinator nodes, we need to open up new parts and structures to meet the requirement of sending information for the beacon frame. This mechanism sends the rotation variable ROT by using one byte, and determines back period from the follow-up calculations of each device node.

The following table reveals the beacon frame format of Circular Queue channel access mechanism. Among them, we add "The synchronization information area" to this mechanism.

Table 1. Structure of the improved beacon frame

2 bytes	1 byte	4/10 bytes	2bytes	variable	variable	1 byte	variabl e	2 byte
Frame control field	Frame serial number	Source Addres s field	Frame characterizati on field	The distributio n area of GTS	Address description field of untreated devices	The synchronization information area	Beacon frame payloa d field	FCS
MHR（MAC layer head）			MAC frame load					MFR Check code

However you can't use this mechanism in all cases. In order to ensure that the mechanism can really effectively operate, the duration SD of each superframe time slot must accommodate all region including new entrants. If SD is smaller than the minimum time of beacon frame, this mechanism can not effectively run. We can calculate the minimum beacon frame size: (2 +1 +2 +1 +2 +10) = 18 bytes from the beacon frame format table. So the minimum time of each time slot of superframe is 18 Bytes. And MAC layer supports a maximum of 127 bytes of data, so the duration of superframe time slot must be within this range.

$$
\begin{aligned}
T_{slot} &= \frac{SD}{N} \\
&= \frac{SF_{\min} \times 2^{SO}}{N} \\
&= \frac{ST_{\min} \times N \times 2^{SO}}{N} \\
&= ST_{\min} \times 2^{SO}\, Symbols
\end{aligned}
\tag{1}
$$

T_{slot} :duration of single superframe time slot(Unit: symbols)

N :number of superframe time slot, the standard value is 16 generally

SD :total duration of superframe (Unit:symbols)

$SF_{\min}$:Minimum duration of superframe (Unit: symbols)

$ST_{\min}$: Minimum duration of superframe time slot (Unit: symbols)

Assuming that 1symbols and 1bit are the same. When SO=1, SO=2, SO=3, the capacity of superframe time slot can be calculated by the above formula:

$$T_{slot(so=1)} = 15Byte$$

$$T_{slot(so=2)} = 30Byte$$

$$T_{slot(so=3)} = 60Byte$$

No matter SO equals 2 or 3,they meet the requirements of this mechanism. In addition to a minimum of 18 bytes, there may need to transmit description field and beacon frame payload field of address of raw device .So it is better to choose 3 for simulation and testing.

3. Simulation and Analysis

We select three wireless network performance parameters: network throughput, response time and packet loss rate to make comparations of network performance between the original and the improved ZigBee CSMA / CA channel access mechanism.

3.1. Simulation of Throughput and network response time

Network throughput testing is an essential tool when analyzing problems related to network performance. Network throughput is the number of packets transmitted in unit time without packet loss. Assuming that the frame length is l bit and the unit successfully transmitted in unit time is n, then the throughput can be expressed as nl (bps) (bit / sec). Usually we can use the channel transmission rate R (bps) to normalize throughput . The normalized throughput can be set by S,

$$S = n\frac{l}{R} = nT \tag{2}$$

In the above formula, l / R is the transmission time of each frame in the channel. Ideally, frame collision does not occur, and the inter-frame gap is zero, then nl = R, the throughput S = 1. In contrast, if the number of frames successfully transmitted n = 0, then the throughput dropped to the minimum S = 0. So the range of normalized throughput is $0 \le S \le 1$.

Fig. 2.(a) is the throughput curve of the original CSMA / CA mechanism, Fig. 2.(b) is the throughput curve of new mechanism. Fig. 2.(c) is the comparison between the two curves.

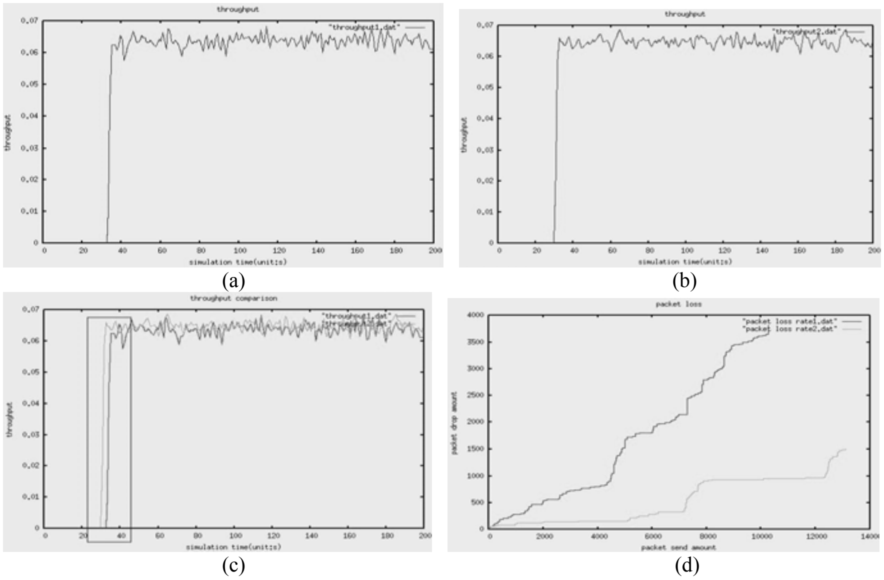

Fig. 2.(a) Simulated throughput curve of the original CSMA / CA mechanism; (b) Simulated throughput curve of the improved CSMA / CA mechanism; (c) comparation of the two simulated throughput; (d) comparation of the two simulated packet loss rate

Fig. 2.(c) shows the reaction time when the network start up. From the blue box we can see that the new mechanism starts massive data transmitting faster than the original mechanism. The new mechanism starts to transmit data at 30.60 seconds, while the original starts at 33.30 seconds by observing the data.

In the simulation time of 200 seconds, the green line is the improved the mechanism, the red line is the original CSMA / CA mechanism. The normalized average throughput of the original is 0.0530 in 200 seconds, while the Circular Queue channel access mechanism is 0.0550.The throughput increases 3.77% compared to the original .With the new mechanism, we reduces the probability of collision while transmitting between devices by assigning different Back time to different devices. The system's overall performance has been improved to some extent.

3.2. Simulation of packet loss rate

Packet loss rate (Loss Tolerance) is the ratio of the number of lost packets with the number of data packets sent, usually tested in the range of throughput. Packet loss rate is determined by packet length and packet transmission frequency. The packet length Used in this test is 117 bytes, and the sending rate is 250kbps.

From Fig. 2.(d), the red line is the curve of the number of packet loss of the original CSMA / CA mechanism when sending data in the simulation environment, while the green line is the improved in the same environment. We can see that the number of packet loss of the improved Mechanism is less than the old. The packet loss rate of the original mechanism is 37.12% in the simulation environment, and packet loss rate of Circular Queue channel access mechanism is 11.45%, with 25.67% less. The data shows the difference of backoff time reduces the number of collisions between devices, which improves the performance at packet loss rate and transmission efficiency.

4. Summary

Based on the simulation of CSMA / CA mechanism and Circular Queue Channel access mechanism and the analysis and comparation of simulation results, this paper proves that the Circular Queue channel access mechanism are better at reducing the probability of choosing the same backoff period by changing the range of BE and macMinBE, transmitting the variable priority in beacon frame, and using different network addresses of different devices. As a result, we reduced the collision rate, improved the efficiency of information transmission. And improved performances in network throughput, network boot response time, packet loss rate.

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