Reliable Transport Mechanism Based on Multi-queue Scheduling

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Abstract. In the Integrated Space and Onboard Network, transmission demands arrive randomly. In addition, the routing algorithm calculate the end-to-end paths the average occupied bandwidth over a period of time, causing microburst of data at the forwarding nodes. The existing queue scheduling methods usually queue the burst data and discard the amount of data which exceed the length of queues, which will cause more severe congestion with the re-transmission of discarded data. In order to solve this problem, a multi-queue scheduling method is proposed to guarantee reliable transmission without loss. Specifically, a token-based mechanism is designed to process the irregular data which has not been sent on time or has been over time in the queue. This mechanism will arrange new transmission opportunities for the data which miss them, avoiding data loss and retransmission. The simulation results show that the proposed reliable transmission mechanism can significantly decrease the network packet loss rate by about 80%, compared to existing queue scheduling methods.

Keywords: Queue scheduling algorithm · CBS (Commit Burst Size) · Multi-Queue scheduling · Space-Ground integrated network

1 Introduction

With the rapid development Integrated Space and Onboard Network (ISON), the data volume needed to be transmitted becomes more and more massive, causing huge transmission pressure for the current ISON. Specially, network congestion is inevitable due to the randomness of data arrival and inaccurate computation of route. How to deal with it will significantly affect the end-to-end delay packet loss through put, and network resource utilization.

In fact, when congestion at forwarding nodes occurs, the queue scheduling mechanism will significantly effect the performance of the network, since it can solve the shortcomings of insufficient link bandwidth and ensure that each service stream can receive works. According to their designing principles, these scheduling algorithms can be roughly divided into First-Come-First-Served, Weighted Round-Robin, and Weighted Fair scheduling [3].

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- The First-Come-First-Served (FCFS) algorithm is characterized by low cost, simple structure and easy implementation. However, FCFS cannot provide isolation technology. When a burst packet occupies a large portion of the buffer space, other packets suffer the risk of being discarded.
- The Weighted Fair Scheduling algorithm (WFQ) could serve multiple queues fairly at the same time. However, when some real-time services appear in the network, the weights cannot be changed in the WFQ algorithm, causing that the order of forwarded packets cannot be changed, which affects the quality of the real-time services.
- The weighted Round-Robin scheduling algorithm (WRR) assigns a weight to each queue. There is a counter in each queue to calculate the weight. The weight of the counter is checked before the round-robin scheduling. And if the counter weight is not 0, the corresponding packet in this queue can be forwarded automatically and then the weight of the counter will be set as zero. However, the WRR algorithm is very sensitive to packet length changes. The fairness cannot be guaranteed if the packet length changes.

As a result, the above queue scheduling algorithms do not deal with the packets that cannot be forwarded in the current time slot and have their own disadvantage. In fact, the delayed data will conflict with the current data needed to be forwarded, which affects forwarding the current data. To overcome the problem [4], a Credit-Based Flow-Control mechanism is proposed to adjust the transmission rate of delayed data in the next time slot. Next, to decrease the effects of delayed data on the data of current time slot, a Credit-Based Multi-Queue scheduling is proposed, which delays the forwarding data packets that cannot be completed in the current time slot, and adjusts the forwarding rate, it will reduce the impact on normal data. This mechanism can reduce network congestion caused by random services and reduce the PLP of delayed data packets. Finally, the performance of the scheme was verified by simulation.

2 System Model

The purpose of the time deterministic network is to realize the boundedness of end-to-end delay jitter, the determinism of forwarding delay, and the low packet loss rate and high reliability of network transmission. The forwarding scheduling strategy plans the forwarding method at each node, which is the key to realizing time deterministic network [5]. This chapter introduces the Credit-Based Flow-Control mechanism and it's system model.

2.1 A Credit-Based Flow-Control Mechanism

The Credit-Based Flow-Control mechanism was proposed by the AVB working group firstly [5] in order to solve the problem of excessive business bursts occupying low-priority business bandwidth. Through priority classification, the transmission of high-priority services is guaranteed first, and the next best service is assigned a credit value to describe its accumulated transmission opportunity. The credit value will continue increases when it is not transmitted, and the credit value decreases when it is transmitted. Then, change the slope of the credit value to achieve the purpose of controlling the service transmission rate.

2.1.1 Types of Business in CBS

TSN uses the 3-bit Priority Code Point (PCP) in the virtual local area network (VLAN) tag defined in 802.1Q to distinguish different levels of data streams, which are divided into control data traffic (Control Data traffic, CDT), Class A, Class B and BE business.

2.1.2 CBS Queue Model

CDT is the highest priority type of service in the TSN network. Class A and Class B are generally audio and video services, those services has higher priority. Without CDT service, the Credit-Based Flow-Control mechanism will be the first choice. BE is a best-effort service, it does not has credit, and transmits in the gap of high-priority transmission. The queue model of CBS is shown in the figure below (Fig. 1):

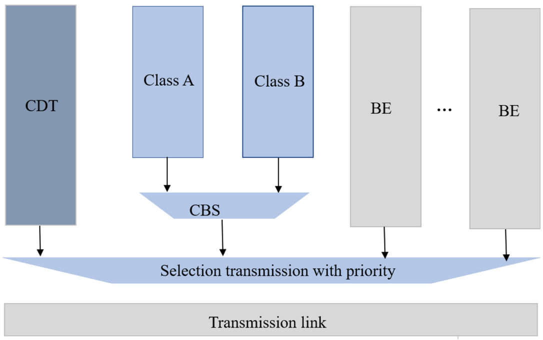

Fig.1. CBS queue scheduling

In order to control the transmission rate of Class A and Class B, the CBS algorithm gives the corresponding credit value for these two types of services to decide which service should be selected for transmission. For each level, there are two parameters used to control the increase and decrease speed of the credit value: Send slope and Idle slope. The Idle slope determines the speed of accumulating transmission opportunities when the transmission is idle. The Send slope determines the opportunities for other services to accumulate bandwidth during transmission, its size is related to the transmission rate of Class A and Class B. The calculation method is:

$$\text{idleslope} = \frac{\text{RB}}{\text{CMI}} = \text{R} \tag{1}$$

R represents the bandwidth resource allocated for this type of service, and RB is the maximum frame length of the data frame. Define the Send slope and Idle slope as S_i and I_i.CBS should meet the following conditions:

1. $S_i < 0$, $I_i > 0$;
2. $\sum_{i=0}^{N} I_i < C$,Where N represents the number of data streams, and C represents the total bandwidth of the link;
3. $S_i = I_i - C$;

Under the control of S_i and I_i, the specific sending criteria of the CBS algorithm are as follows:

1. When a certain type of data is not sent and meanwhile the queue is not empty, the credit value $Credit_i$ of this type of data rises at a slope of I_i. When the service is being transmitted, the credit value $Credit_i$ of this type of data decreases at the slope of S_i;
2. Each transmission preferentially selects the business data frame with higher priority for transmission (Class A priority is greater than Class B);
3. Data frames with $Credit_i$ less than 0 will lose transmission opportunities and cannot be transmitted;
4. When the current queue is empty, when there is no data of a certain type to be transmitted, the credit value $Credit_i$ of this type of data will be 0.

3 A Multi-queue Based on Token Mechanism

Due to the randomness of the business and the uncertainty of the network environment, which will lead to the problem of packet loss [6]. This part will propose a forwarding strategy that delayed packets that cannot be send in the current time slot will be send in the next two time slots [7]. In view of the conflict between delayed packets and normal forwarded packets, and referring to the idea of CBS, a Multi-Queue Based On Token mechanism is proposed to adjust the transmission rate of delayed services.

3.1 Analyze the Problems in the Time-Deterministic Network Forwarding Mechanism

Due to the business arrival randomly. The traditional Internet uses a Best-Effort transmission method [8], and the node queue length is limited. When the burst service exceeds the queue length, the packets will be lost, which will affect the reliability of the network. The IEEE TSN working group proposed the queue management mechanism of CQF and CSQF, which uses a single queue to send and other queues to receive,this method will achieve time determinism [8]. In this method, the service that can be processed by a single time slot is still limited by the length of the receiving queue. When the burst service exceeds the length of the receiving queue, it will loss packet yet, which does not meet the requirements of low packet loss rate. As shown in Fig. 2.

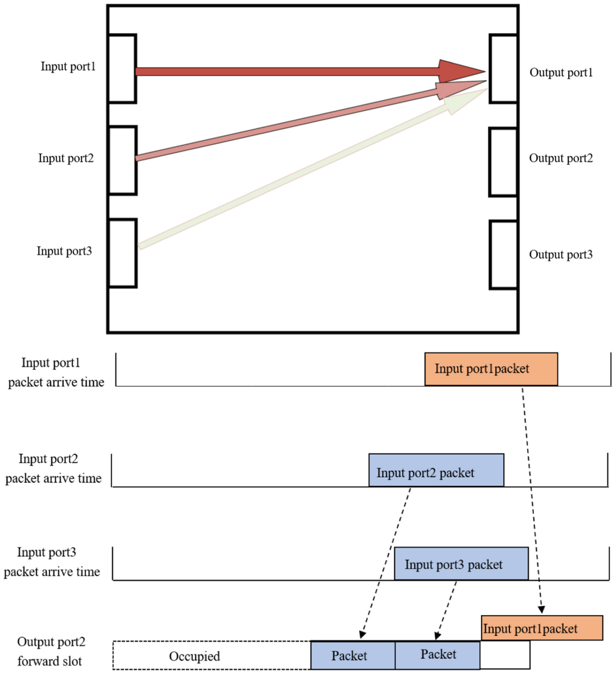

Fig.2. Failed to forward data in current time slot

3.2 A Credit-Based Multi-queue Scheduling

In order to solve the problems summarized above, a method is to delay the data packets that cannot be send in the current time slot to the next time slot, and then perform Multi-Queue joint scheduling, store the data exceeding the time slot capacity in the sending queue and participate in joint scheduling in the next time slot [9]. When the delayed transmission data packet conflicts with the normal transmission data packet, a Credit-Based Multi-Queue scheduling mechanism is proposed to adjust the transmission rate of delayed service.

3.2.1 Formulate Packet Forwarding Queue Rules

Firstly, for the data that cannot be sent in the time slot, use a reasonable queue mechanism to store the data [10]. The forwarding rule adopts the method of time slot division, and uses a multi-queue cycle method to ensure time determinism. The queue rules are as follows:

(1) Take the cyclic forwarding structure of three queues as an example. The three queues are named SQ, TQ1 and TQ2. At the same time, only the queue SQ can be opened to forward data packets, and all three queues can receive data packets. The data that exceeds the time slot resources and cannot be sent in the current time slot will be retained in the SQ, waiting for the next time slot to be scheduled.

(2) The three queues are opened periodically in turn, and the length of the open time is T, representing the current time slot and the next two time slots. The size of each queue is the maximum data that can be transmitted by the link corresponding to the outgoing port in a time slot.
(3) The data packet carries forwarding time information, according to the information carried in the header of the packet, it is determined in which time slot to forward, and enters the corresponding queue [11]. Assuming that the resources of each queue will be reserved in advance by some services, we can know the percentage of queue resources has been reserved.

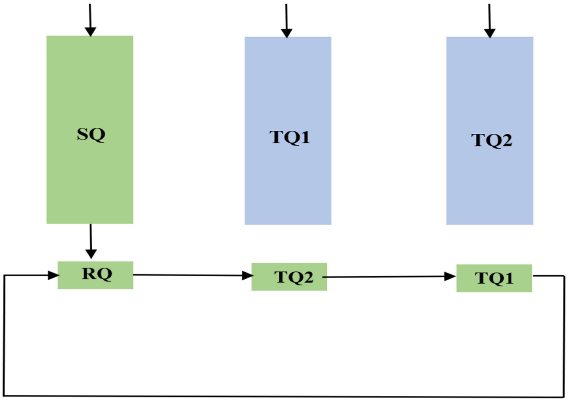

Fig. 3. Design forwarding queue

The queue diagram is shown in Fig. 3. The queue opened in the current time slot is called SQ, TQ1 is the queue opened in the next time slot, TQ2 is the queue opened with a delay of two time slots, and TQ1 and TQ2 are used to enqueue data packets that arrive early. With reference to CSQF, the three-queue structure can balance some of the effects caused by processing delay, and the number of queues can be expanded according to the size of the delay jitter. Packets arriving within 3T can enter the queue, and packets arriving early will wait in the queue until the queue is opened before completing the forwarding. SQ can also be received during transmission, so that the queue can accommodate data that exceeds its capacity, and services that exceed the current time slot resources are stored in the queue, facilitating joint scheduling in the next time slot. For the business that SQ saved when it was closed and failed to complete the forwarding, it is necessary to formulate a strategy for processing [12].

3.2.2 A Scheme of Credit-Based Multi-queue Scheduling

When transmitting delayed data, it is necessary to formulate an appropriate mechanism to adjust its transmission rate and reduce the impact on normal data. Refer to CBS for AVB service, which provides a multi-queue scheduling mechanism that can regulate the output traffic of different queues. In order to characterize the transmission opportunities accumulated by the business, credits are given to different types of business queues, adjust the transmission rate of the service by adjusting idle slop. The larger the idle slop is, the faster the service accumulates credit value will be, and more transmission opportunities can be accumulated at the same time. The smaller the idle slop is, the slower the accumulating credit value will be, and the faster the credit value will decrease to a negative value, leaving more transmission opportunities for other businesses. In accordance with this idea, this section formulates a credit-based multi-queue scheduling scheme to control the transmission rate of delayed data services.

When dealing with the problem of delayed data transmission, the data that needs to be transmitted in the current time slot can be divided into three types: normal data; delayed by one time slot; delayed by two time slots. In order to facilitate problem analysis, the total set of the three types of data is recorded as $P_{present}$, P_{1delay} and P_{2delay}.

In order to adjust the transmission rate, assign credit values to different types of data. The credit value is not set for $P_{present}$ data services, and the priority is the highest. Once the current queue has business accumulation, it will transmitted the packets directly,and the delay type data is transmitted in the gap of $P_{present}$ data service transmission. Define different credit values for type P_{1delay} and P_{2delay} data, control their sending slope by adjusting their idle slope, and make them transmit according to the bandwidth. The transmission selection of these three types of data in a time slot can be transformed into the queue model of Fig. 4.

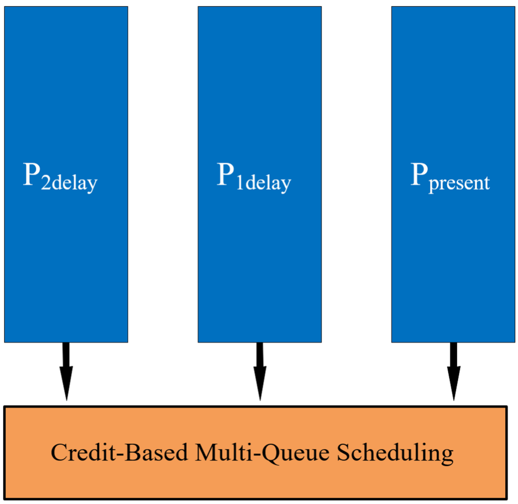

Fig. 4. Delayed data and normal data in Credit-Based Multi-Queue Scheduling

For P_{1delay} and P_{2delay} data queues, the credit values are defined as $Credit_1$ and $Credit_2$, representing their accumulated transmission opportunities. The corresponding transmission slopes of each queue are S_1 and S_2, and the idle slopes are I_1 and I_2.

The three types of data are planned to be forwarded in the current time slot. The respective transmission resources are related to the total size of the data that needs to be transmitted. The request rate is used to characterize the bandwidth resources they need to complete the forwarding in the current time slot. The total size of the data packets of $P_{present}$, P_{1delay} and P_{2delay} are respectively defined as B_0, B_1 and B_2, Then their request rates are R_0, R_1 and R_2, which are:

$$R_0 = \frac{B_0}{T}, R_1 = \frac{B_1}{T}, R_2 = \frac{B_2}{T} \tag{2}$$

Then the total required bandwidth C_{sum} for all three types of services in the current time slot to complete the transmission is:

$$C_{sum} = R_0 + R_1 + R_2 \tag{3}$$

If the current bandwidth is C, all three types of services need to follow $C_{sum} > C$ to complete the transmission in the current time slot; if $C_{sum} \leq C$, the bandwidth resource is less than the total bandwidth required by the service, and the data in the three types of queues will inevitably be transmitted in the current time slot.

CBS stipulates that I_i and S_i satisfy $S_i = I_i - C$, and I_i is related to the reserved bandwidth of data i, so S_i can be regarded as a bandwidth resource reserved for other data. In order to limit the impact of delayed data on normal data, in the case of $C_{sum} > C$, P_{1delay} and P_{2delay} only allocate the remaining bandwidth excluding $P_{present}$ data reservation. At the same time, the transmission of $P_{present}$ data should not accumulate the credit value of delayed data. It is stipulated that I_i and S_i satisfy $S_i = I_i - (C - R_0)$. The specific queue scheduling rules are as follows:

(1) When $P_{present}$ data is being transmitted, $Credit_1$ and $Credit_2$ remain unchanged;
(2) When P_{1delay} data is transmitted, $Credit_1$ decreases with the slope of S_1, and $Credit_2$ increases with the slope of I_2; when the P_{2delay} service is transmitted, $Credit_2$ decreases with the slope of S_2, and $Credit_1$ increases with the slope of I_1;
(3) When $Credit_1$ or $Credit_2$ is less than zero, the corresponding queue is closed;
(4) When the credit values of the two types of delayed services are both 0, the P_{1delay} queue is sent first;

In the case of $C_{sum} \leq C$, bandwidth resources are sufficient. In the best case, the data in all queues can be guaranteed to be transmitted. At this time, the bandwidth resources are allocated proportionally according to the request rate of the three types of data. The credit value of the delayed data will increase when blocked by $P_{present}$ data. define as $S_i = I_i - C$. The specific transmission rules are as follows:

(1) When $P_{present}$ data is being transmitted, the credit values of $Credit_1$ and $Credit_2$ increase at the slope of I_1 and I_2;
(2) When P_{1delay} data is transmitted, $Credit_1$ decreases with the slope of S_1, and $Credit_2$ increases with the slope of I_2; when the P_{2delay} service is transmitted, $Credit_2$ decreases with the slope of S_2, and $Credit_1$ increases with the slope of I_1;
(3) When $Credit_1$ or $Credit_2$ is less than zero, the corresponding queue is closed;
(4) When the credit values of the two types of delayed services are both 0, the P_{1delay} queue is sent first;

4 Simulation

This chapter uses different time slot lengths to simulate the performance of the Credit-Based Multi-Queue scheduling and the dropped delay data scheme, and analyze the simulation results.

The design simulation scenario is shown in Fig. 5. Sent several time-determined service data packets randomly from the source node A to Router1. The data is designated to be forwarded in a certain time slot. The total amount of data sent is the ratio of the reserved bandwidth multiplied by the length of the time slot. The data packet arrives at Router1 randomly, and forwarded to Router2 through Router1. The size of the data packet is a random value in the range of 50Byte–1450Byte, the bandwidth C is 10 Gbits, and a certain amount of burst services exceeding the time slot capacity is set.

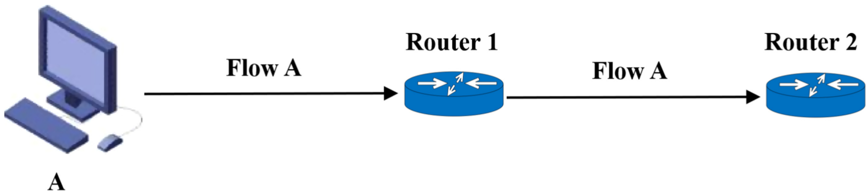

Fig. 5. Simulation scenario

The processing method for failing to send is to delay until the next time slot. The multi-queue scheduling scheme will affect the forwarding delay of service packets. In order to describe the impact of this mechanism, the definition of credit-based packet forwarding mechanism adds Average delay, the size is the difference between the average forwarding delay of all data packets under the two schemes in each experiment, and then average the difference. Change the ratio of the forwarding time slot length to the service bandwidth reservation, and then generate a certain amount of burst services that exceed the time slot resources. Perform 100 sets of experiments each time to calculate the average packet loss rate and the average increase time of the comparison experiment strategy and the multi-queue strategy Extension.

Comparative test of changing the length of the time slot:

It can be seen that the multi-queue joint scheduling mechanism can significantly reduce the packet loss rate of data packets from Fig. 6. The smaller the time slot division, the greater the packet loss rate, and the more obvious the ability of the optimized solution to reduce the packet loss rate.

It can be seen that the greater the time slot division, the greater the average delay increase caused by the optimization plan from Fig. 7. The optimization plan needs to delay forwarding the data that cannot be forwarded in the time slot, because the priority of the delayed data is lower, it is generally sent at the end of the time slot, so the larger the time slot division, the greater the increase in the average delay. When division a

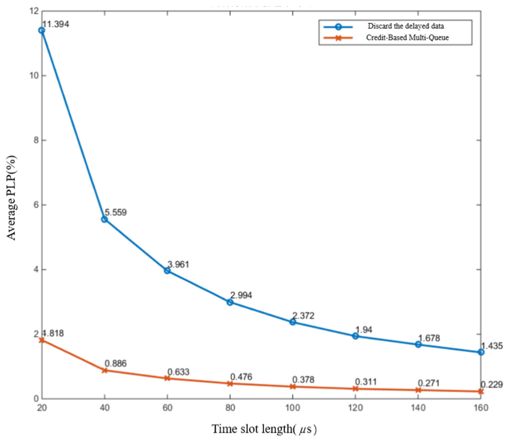

Fig. 6. Compare the packet loss rate of the two schemes under different time slot lengths

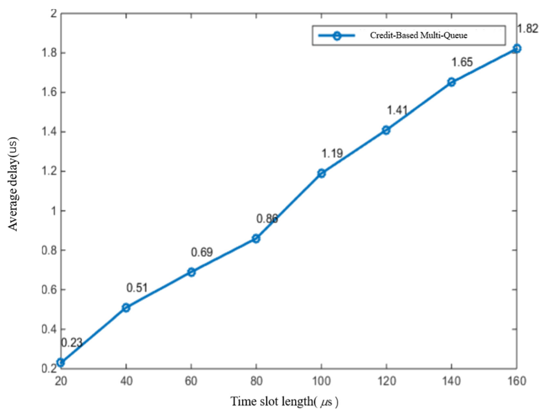

Fig. 7. Average increase delay of Multi-Queue scheduling mechanism under different time slot lengths

large time slot, the probability of packet loss will also decrease. At this time, you can consider adjusting the optimization target, it will increasing the output rate of the delayed data queue and reduce the impact of the average delay caused by the delayed data packet.

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