A Novel Algorithm of Congestion Control Based on Satellite Switching

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Abstract. One of the characteristics of satellite switching network is limited link resources. When the satellite switching network is congested, there are not enough resources to send the congestion notification message to the ground terminal. In order to solve this problem, a novel algorithm of congestion control based on satellite switching is proposed in this paper. The congestion notification messages are sent while transmitting the switching data according to the specific hiding approach, which uses the redundant information in the switching data to embed the congestion control information into the transmission data. The method can send congestion control messages to the ground terminal without any additional physical resources, and also increase the amount of information that can be transmitted by each port of the onboard switch. The performance analysis and simulation result show that the proposed algorithm can not only avoid congestion in the onboard switch, but also save link resources and improve the performance of the satellite switching network.

Keywords: Congestion control · Information hiding · Onboard switch · Data embedding

1 Introduction

Onboard satellite switching is one of the development trends of satellite communications network. With the increasing demand for satellite communication, satellite communication network needs to have the ability of large-capacity information exchange and forwarding. Onboard switching is one of the key technologies to meet the development needs of satellite communication. The satellite uses switching technology to carry out multi-beam exchange, which facilitates communication among multiple ground stations and constitutes a wireless communication network integrating space and earth. Therefore, onboard switching technology will greatly promote the development of satellite communication system [1]. One characteristic of this system is limited link resources. If the total load in the switching system exceeds the maximum throughput that the system can bear in a local time, a large amount of data will be discarded, and the system performance is greatly reduced, which means congestion.

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Increasing the internal buffer of onboard switch can only delay congestion, and the congestion problem can't be resolved. Therefore, the effective algorithm of congestion control must be taken in the satellite switching system to improve the switching performance of satellite network [1–4].

This paper adopts different congestion control strategies based on the current state of onboard buffer. In this method, the onboard switch must response its own congestion state to the ground terminal. However, when the congestion occurs, the load on the onboard switch is saturated and the congestion notification message cannot be sent to the ground terminal. In order to improve this problem, this paper proposes a novel congestion control algorithm based on specific information hiding method for onboard processing and switching system. This specific algorithm embeds congestion control messages into the switching data, and the congestion control message is sent while transmitting data in order to avoid the congestion.

This paper is arranged as follows: the composition of the satellite processing switching system is described in Sect. 1, and then introduces the novel algorithm of congestion control based on information hiding. Section 3 describes the information hiding and de-hiding algorithm proposed in this paper in detail. Finally, the new algorithm is simulated and verified with specific examples.

2 The Satellite Processing and Switching System

The satellite processing and switching system is composed of an onboard switch, ground terminals, and a ground network control center. In this system, N ground source terminals transmit data to N ground destinations through an onboard switch, and the ground network control center performs basic satellite network management functions. The satellite processing and switching system is shown below (Fig. 1):

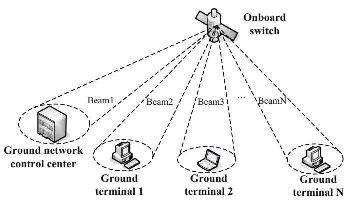

Fig. 1. The satellite processing and switching system

- Onboard switch: The onboard switch in this paper mainly refers to the packet switch, which is responsible for exchanging packet service data (including ATM data and IP data) and performing congestion control according to the onboard status.
- Ground terminal: To complete the sending and receiving of data. Each ground terminal has the function of sending and receiving cells, which can be used as a ground source and a ground destination.

- Ground network control center: Complete basic satellite network management functions (include network authentication, onboard device status supervision, network registration, etc.).

The onboard packet switching system mainly includes ATM switching and IP switching.

In the onboard ATM switching system, a connection establishment message is sent to the onboard switching by ground source before sending data. The onboard switch decides whether to agree the request according to the resources and link state of the satellite. If this request is accepted, the onboard switch sends the connection setup success message to the ground source terminal. Then the ground source terminal can send cells by the reservation rate. When the data rate sent by the ground source exceeds the reserved resources, or when the burst strength of the service is too high, the total load of the onboard switch will exceed the maximum throughput that can be supported during the local time [5].

Because the onboard IP switching system doesn't establish connection in advance, the total load of the onboard switch in the local time will exceed the maximum throughput that can be supported [6, 7]. In order to improve this problem, the satellite processing and switching system must take appropriate measures for congestion control to ensure the performance and normal operation of the system [8–11].

3 A Novel Algorithm of Congestion Control Based on Satellite Switching

In this paper, a new congestion control algorithm is proposed by the characteristics of the satellite link. This algorithm adopts different measures to control the congestion according to the current state of onboard switch. Because the onboard switch sends control messages to the ground terminal, it also occupies some link resources. Therefore, this paper uses the information hiding method to embed the congestion control message into the switching data. The switching data and the congestion control information are sent to the ground terminal together.

3.1 The Type of Congestion Control Information

The onboard switch determines whether to send an alarm message to the ground source or discards the entire cell according to the congestion level. Therefore, the congestion control information of the onboard switch mainly includes the following types:

(1) Alarm message

When the onboard switch is about to be congested, the onboard switch sends a feedback message to the corresponding ground source according to the number of connections and cells in the buffer. This process is shown in Fig. 2.

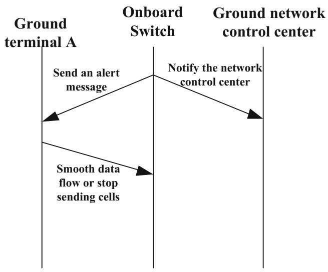

Fig. 2. Send an alert message to the ground terminal by onboard switch

When the buffer reaches the alarm threshold, the onboard switch sends an alarm message to the ground source, which has the most serious impact on the congestion of onboard switch, then send the notified message to the ground control center. The alarm message includes the onboard switching cache usage, service parameters of the connection, service type, and QoS, and the onboard switch has obtained the service parameters, such as service type, and QoS requirements of the connection while establishing the connection.

After receiving the alarm message, the ground source determines whether to smooth the data stream or stop sending the cell according to the current cache usage of the onboard switch. After this state is maintained for a period of time, the ground terminal restarts sending data.

(2) Drop notification message

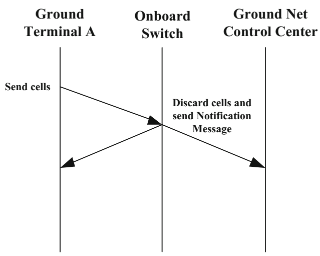

Fig. 3. After congestion, the onboard switch discards cell and sends notification cell to the ground terminal

If the onboard switch has sent the alarm message, but the congestion problem has not been resolved and the onboard ATM switch reaches the set discard threshold, the switch must choose to discard some cells. While discarding a connection, the onboard ATM switch should send a drop notification message to the connected ground source and the ground control center. This process is shown in Fig. 3. The drop notification message includes some parameters, such as service type, QoS, and so on.

3.2 The Format of Congestion Control Information

According to the Sect. 3.1, the onboard switch performs congestion control by sending different control messages to the ground terminal. The format of control information includes information type, cache status, service parameters, service type, QoS, and so on, as shown in Table 1:

Table 1. The format of control information

Information type (2bits)	Cache status (2bits)	Service type (2bits)
Service parameters (10bits)		
QoS (3bits)	Reserved (5bits)	

- Information Type: Indicates the type of the control information.
  "01" indicates an alarm message, and "10" indicates a drop notification message;
- Cache Status: Indicates the cache status of the current onboard switch. If the alarm message is sent, "01" means slowing down the sending cell rate, "10" means stopping sending the cell; if sending a drop notification message, the state is "11";
- Service Type: Indicates the type of the service.
  "00" means an unicast data; "01" means a multicast data;
  "10" means a broadcast datagram; "11" means reserved data;
- Service parameter: Indicates the connection parameter of the service;
- QoS: Indicates the QoS level of the service;
- Reserved: reserved domain.

4 Information Hiding and De-hiding Algorithm

4.1 Information Hiding Algorithm

The new congestion control algorithm proposed by this paper mainly uses the redundant information in the traffic payload to hide the control information. The redundant information here is the number that does not appear in the traffic load.

In this chapter, the onboard ATM switch is taken as an example for specific description. Since the ATM payload has a total of 48 bytes, and each byte can be represented as a number between 0 and 255, the payload of each cell includes 48 numbers between 0 and 255, that means, at least 207 numbers which between 0–255 do not appear in the cell payload.

Assuming that the number "X" (between 0 and 255) does not appear in the cell payload of 48 bytes, then you can choose number "X" to hide information. The specific hiding principle is:

- If the binary number to be hidden is "1", then all "X − 1" digits in the payload become "X";

- If the binary number to be hidden is “0”, then all “X − 1” digits in the payload are unchanged.

There will be at least 207 different “X” in the payload of each cell. If the total number of “X − 1” appears the most in a 48-byte payload, it means that more digits can be used for hiding information, so the hiding algorithm proposed in this paper use the number “X” as the hiding location. This information hiding location is stored in the cell header.

In extreme cases, if all “X − 1” occurrences are less than 8, that is, if any “X” is selected, the hidden information in the payload is less than 8 bits. In this case, the information to be hidden can be directly stored in the cell header.

Figure 4 shows the workflow of the information hiding algorithm.

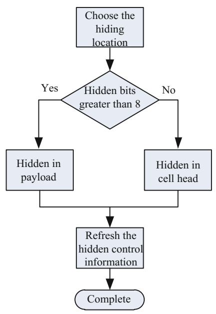

Fig. 4. The workflow of the information hiding algorithm

4.2 Information De-hiding Algorithm

The information de-hiding algorithm is the opposite process of hidden method. The workflow is shown in Fig. 5. After receiving the cell, first determine whether the cell hides the congestion information, and then find the hiding location. If the information is hidden in the header, the 8-bit hidden information is extracted directly from the hiding location field of the cell header; if the information is hidden in the payload, the hidden information is extracted in the payload by the information de-hiding algorithm. Assuming that the hidden position of the cell head is “M”, then the information de-hiding algorithm is:

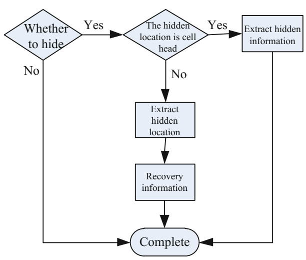

Fig. 5. The workflow of the information de-hiding algorithm.

- The byte of “M − 1” appears in the payload, and the hidden information “0” is restored. The byte remains unchanged.
- The byte of “M” appears in the payload, and the hidden information “1” is restored. The byte number becomes “M − 1”.

4.3 Hidden Control Information

In order to complete the hiding and de-hiding of control information, this paper designs a format of hidden control information, which is stored in the header of the switching cell, including identification, type and hidden location.

- ID: “1” indicates that there is hidden information in the cell, and “0” indicates that there is no hidden information in the cell;
- Type: When the flag is “1”, indicates that the information is hidden in the cell header, and “0” means that the information is hidden in the cell payload;
- Hidden position: When the flag ID and the flag Type are both “1”, means this 8 bits of hidden position are the hidden information; when the ID is “1” and the type bit is “0”, means this 8 bits are the hidden position in the payload.

In summary, the information hiding and de-hiding algorithm in this paper can hide the N-bit control information in the switching data. Taking ATM cells as an example, the algorithm can guarantee at least 8 bits of control information in each cell, that is, the worst case transmission of 3 ATM cells can transmit 24-bit congestion control information to ground terminal.

5 Algorithm Verification

This section takes the onboard ATM switching system as an example to verify the new congestion control algorithm proposed in this paper. Firstly, the feasibility of the proposed information hiding and de-hiding algorithm is verified by the enumerated method, which analyses whether the algorithm can transmit the congestion control information correctly. Then the cell loss ratios are simulated and analyzed between the algorithm of congestion control based on satellite switching and the other algorithm without congestion control strategy.

5.1 Algorithm Analysis

The congestion control algorithm proposed in this paper embeds the congestion control information into the switching data while sending cells to the ground terminal. This section mainly verifies the correctness and feasibility of the proposed information hiding algorithm by analyzing.

The implementation process of this algorithm mainly includes several steps: control information generation, information hiding, data reception and information extraction.

Suppose there is congestion in the onboard ATM switch, and an alarm message needs to be sent according to the cache condition.

Step 1. Generate alarm control message.

Because an alarm message needs to be sent, the information type is set as “01”. Assuming that the current cache state only requires the ground terminal to slow down the transmission rate to resolve the congestion, the bit of buffer status is set as “01”. If the cell is unicast, the connection reference value is “5”, and the QoS level is 1, then the binary control message is:
“0101000000000010100100000”.

Step 2. The generated alarm message is hidden in the switching data.

Suppose the first ATM cell to be sent is (hexadecimal):
“0241800022,0000101033334444101055556666101077771010000010103333444411010555566661010777710100000101033334444”.

Analysis of the cell load shows that:

The decimal number 17 does not appear in the payload and the account of decimal number 16 (hexadecimal is 10) appears the most (18 times) in the payload, so the number 17 is selected as the hidden bit, there is 18 digits which can be hidden in the cell.

Using the hiding algorithm introduced in 3.2, the data including control information becomes:
“2241811089,000010113333444410115555666610107777101000001010333344441010555566661010777711100000111033334444”.

In the same way, the remaining control message content is hidden into the following data.

Step 3. The switching data is sent to the corresponding ground terminal by the output address.

Step 4. After receiving the data, the ground terminal extracts the congestion control information and restores the original service data.

The received cells are:
“2241811089,00010113333444410115555666610107777101000001010333344441010555566661010777711100000111033334444”.

According to the de-hiding algorithm introduced in 3.3, the hidden information finally extracted from the cell is “010100000000001010”.

The other hidden information is then extracted from the subsequent data in the same way.

Step 5. The ground terminal slows down the transmission rate according to the requirement by the alarm control information.

The congestion control process based on information hiding is completed.

The above analysis proves that the novel algorithm proposed in this paper can correctly transmit congestion control information to the terminal without any additional physical resources.

5.2 Simulation

In this chapter, the processes including sending, buffer and switching, are simulated by Matlab. Then the performance between the proposed algorithm of congestion control and the other algorithm without congestion control strategy are compared. Because the satellite has multi-beams and every beam has one corresponding port of switch. The onboard switch we choose to simulate has eight ports.

The simulation time in this section has 100000 slots, and the cells arrive by the process of burst. Then the cell loss ratio is simulated and analyzed between the proposed algorithm of congestion control and the other algorithm without congestion control strategy. The performance of the proposed congestion control algorithm can be verified, and it will be found that whether the congestion can be controlled. If there are not any violation cells, the onboard switch doesn't drop the cells with the congestion control algorithm proposed in this paper. Consequently the cell loss ratios of the two strategies are simulated and compared when there are some violation cells.

Figure 6 compares cell loss ratio between the algorithm of congestion control based on satellite switching and the other algorithm without congestion control strategy, for which the payload is from 0.55 to 0.95 and the burst length is 16. In this figure, the cell loss ratios of some different probabilities for violation cells are also compared.

The figure shows that the proposed algorithm has the smaller cell loss ratio than the other algorithm. The conclusion is found from the simulation that the proposed algorithm in this paper, which combines the open-loop and close-loop based on the current state of onboard buffer, can reduce cell loss ratio of onboard switching obviously.

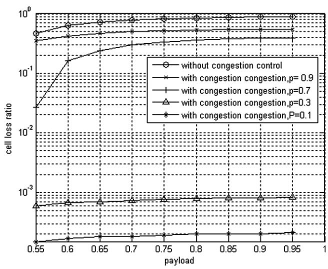

Fig. 6. Cell loss ratio between the algorithm of congestion control based on satellite switching (different probabilities for violation cell) and the other algorithm without congestion control strategy

6 Conclusion

Because satellite network has the character of limited resources, congestion control is an important issue which needs to be solved in satellite processing and switching system. If the onboard switch is congested, it will greatly reduce the performance of the system. The congestion control algorithm based on information hiding is proposed to embed congestion control messages into the switching data, and the congestion control message is sent while transmitting data in order to achieve the purpose of congestion control. This algorithm not only saves link resources, but also improves the performance of the onboard processing and switching system. Consequently, the novel algorithm can be considered to adopt in the onboard switch for which the resource are limited.

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