A Centralized Scheduling Algorithm in On-Board Hybrid Optical/Electric Switching

Yi Zhang1,*, Jun Li1, Quan Zhou1, Jingling Li1, Wei Liang1 and Tao Cui1

1National Key Laboratory of Science and Technology on Space Microwave(Xi’an) 
China Academy of Space Technology, Xi’an, China

*lbzytogether@163.com

Abstract: To realize the interconnection of heterogeneous links, it’s necessary to develop the on-board hybrid optical/electric switching technology. Because of the separate scheduling strategy in on-board hybrid switch, there is conflict among different ports, and the cell loss rate is greatly reduced. In order to solve this problem, a centralized scheduling algorithm in on-board hybrid optical/electric switching is proposed. According to the parameters and characters of optical data and electric data, the proposed algorithm with the group performance idea can schedule the multi-granularity traffic by analysing the resource utilization of hybrid switch fabric, which has the principle of the highest throughput. This algorithm can increase the matching probability between input and output ports, reduce the inner congestion probability of hybrid optical/electric switch module, and improve the performance of this switch fabric. The analysis and simulation results show that the proposed algorithm has fewer parameters and simple implementation steps, which can effectively avoid congestion, and has the better performance than others in cell loss rate.

1. Introduction

The space information network is a system for acquiring, transmitting and processing spatial information in real time, and the carrier of this network is the space platform, such as GEO/MEO/LEO satellites, stratospheric balloon, and manned or unmanned aircraft, etc.

With the growing demand for spatial information, the spatial information network should not only meet the requirements of high-speed information relay and broadband high-capacity information forwarding, but also should have flexible access and global coverage capabilities. In the space information network, the laser and microwave links will coexist for a long time and have complementary advantages. This network is a heterogeneous network composed of laser-microwave hybrid link.

To realize the intercommunication of heterogeneous links and the exchange of data between heterogeneous nodes, it is necessary to develop the on-board hybrid optical/electric switching technology, which should have the capabilities of service classification, aggregation, convergence and distribution for the different links. Because of the great differences between optical switching and electrical switching[1-3], the use of separate scheduling is a relatively easy control method, but the disadvantages are also obvious: the optical switching unit and the electrical switching unit schedule and manage the services according to the status of the single unit, which can cause conflict between the optical port and the electrical port, and congestion of the hybrid switching unit. The data loss rate is greatly reduced, and the exchange performance has deteriorated.
To solve this problem, a centralized scheduling algorithm in on-board hybrid optical/electric switching is proposed. According to the characters of optical data and electric data, the algorithm with the group performance idea can schedule the multi-granularity traffic by analysing the resource utilization of hybrid switch fabric, which has the principle of the highest throughput. This algorithm can increase the matching probability between input and output ports, reduce the inner congestion probability of hybrid optical/electric switch module, and improve the performance of this switch fabric.

This paper is arranged as follows: the new algorithm is described in section II, in which the idea of the algorithm is introduced in detail; Section III introduces the implementation method of the proposed algorithm; Then the performance is analysed in section IV and the algorithm is simulated in order to show the better performance in cell loss rate in section V. At last, section VI concludes the paper.

2. The centralized scheduling algorithm in on-board hybrid optical/electric switching

2.1. Composition of onboard hybrid optical/electric switching

The module of on-board hybrid optical/electric switching is shown as figure 1, which include input/output procession unit, hybrid switching unit and hybrid scheduling unit.

![Figure 1. The module of onboard hybrid optical/electric switching](image)

In Figure 1, the hybrid scheduling unit receives state information from the input processing unit and the hybrid switching unit, and computes an internal conflict-free optimal port configuration scheme for the hybrid switching unit. The hybrid switching unit exchanges the mixed data by the matching result. Therefore, the scheduling algorithm directly affects the performance of the hybrid switch.

2.2. Typical optoelectronic hybrid scheduling algorithm

At present, most scheduling algorithms are developed for the scheduling of one single service, such as input/output serial scheduling algorithm [4][5], FC-WFQ for iSCSI Virtualization Switch [6], and so on. Multi-service scheduling algorithms are mainly focused on the switching mechanism [7], variable-length messages [8], multicast [9], such as hierarchical smooth round-robin scheduling algorithm-mFGSR, hierarchical hybrid scheduling algorithm-MSHF, and so on.

The traditional optoelectronic hybrid switch[10] adopts an independent scheduling management for different services, as shown in Figure 2. The optical service and the electrical packet scheduling algorithm operate independently. Since the scheduling unit does not focus on the traffic characteristics of various services and the resource utilization of the hybrid switching unit, conflicts of various services at the output port will occur, which results in the congestion inside the switching unit. The data loss rate is greatly increased, which affects switching performance.
2.3. The centralized scheduling algorithm

To solve the above problems, a centralized scheduling algorithm for on-board hybrid switching is proposed in this paper. Combing the parameters which include the incoming photoelectric service, the burst length and the QoS requirements of each service, and the use of resources such as the buffer and the service tag in the hybrid switching, the matching result between each input port and the output port is calculated and the data among multi-granular ports achieve aggregation and distribution. Figure 3 shows general idea of the proposed algorithm.

Figure 3. The centralized scheduling algorithm in on-board hybrid optical/electric switching

First, the centralized scheduling management unit collects information such as service parameters of each input port, utilization of exchange resources, and current status of the hybrid switch.

Secondly, the centralized scheduling management unit schedules the optoelectronic service from the high priority to the low priority according to the QoS requirements of different services, and allocates optical and electrical switching resources (such as electrical caches, optical tags, etc.) according to the principle of highest throughput. Considering the convergence of the optical service and the electrical packet service, one optical service may be switched to the multi-channel packet port, and the multi-channel packet service may be switched to the same optical service. Therefore, the optical switching unit and the packet switching unit resources are uniformly managed by the centralized scheduling control unit in this paper.

Then, according to the arrival of the electrical packet/optical service, the cache usage of each port, and the current state of the switch, the internal path of the exchange is calculated, then the output port of the light load is selected for various services in order to satisfying the high priority service, which can avoid conflicts between different services and reduce the data loss rate. In this algorithm, the optical service has a higher priority than the packet service. If the optical service conflicts with the electrical packet service, the optical service should be switched preferentially.

Finally, the matching scheme between each input port and the output port is calculated, and the matching result is sent to the hybrid switching unit.

Due to the constraints of the space environment, the algorithms in the on-board hybrid switch can’t be too complicated. The algorithm proposed in this paper requires fewer parameters, simple implementation steps and low complexity, which is suitable for application.
3. Specific implementation method
The main steps of the centralized scheduling algorithm in onboard hybrid optical/electric switching proposed by this paper are as follows:

Step 1, collect various types of state information according to data characteristics.

Step 2, calculate the internal path for various services.

- If the service is optical, it needs to be split into X packets and switched to the electrical output port K (optical->electrical)
  a) In the hybrid switching matrix A (i, j), if i in equation (1) exists, the corresponding input port is selected to receive optical service data, and is transferred to c); if not, it is transferred to b);

\[
A(i, K) = 0((M + 1) \leq i \leq (M + N))
\]  

(1)

b) Compare the port buffer states B1, B2, ..., BN of the electrical packet switching unit, and select the electrical input port with less buffer capacity to receive the optical service data;

c) Encapsulate optical service data into internal packet data format and send it to the corresponding electrical input port;

d) If the current status of the output port is idle, go to the third step; if the current status of the output port is busy, the data is cached, and when the output port is idle, the data is output preferentially, and the process goes to the third step.

- If Y-way electrical services need to be aggregated into optical port H (electrical->optical)
  a) In the hybrid switching matrix A (i, j), if the conditional expression referred to (2) satisfied, one of the corresponding optical input ports is selected to receive the optical data, then proceeds to c); if the condition is not met, the process proceeds to b)

\[
A(i, H) = 0(1 \leq i \leq M)
\]  

(2)

b) Buffer the electrical data. If i that satisfies Equation (2) exists, goes to c); if not, goes to b);

c) Converge electrical data into optical data;

d) Output the optical data to the optical switching unit and go to the third step;

- If the data is optical, it needs to be output from optical port J (optical->optical)
  a) In the hybrid switching matrix A (i, j), if equation (3) is established, go to step c); if equation (4) is satisfied, go to step b);

\[
A(i, J) = 0(1 \leq i \leq M)
\]  

(3)

\[
A(i, J) = 1(1 \leq i \leq M)
\]  

(4)

b) Delay the input optical data and wait, if the formula (3) is satisfied, go to step c);

c) If no other optical data is output to port J, the data is directly output and goes to the third step. If there are multiple input data to be output to port J, compare the data with other data priority of P. If the priority value of other data is higher, go to b). If the business priority value of the data is the highest, go to the third step;

- If the data is electrical, it needs to be output from electrical port J1 (electrical->electrical)
  a) In the hybrid switching matrix A (i, j), if the equation (5) is satisfied, the data is directly output to the third step; if the equation (6) is satisfied, go to the step b);

\[
A(i, J1) = 0((M + 1) \leq i \leq (M + N))
\]  

(5)

\[
A(i, J1) = 1((M + 1) \leq i \leq (M + N))
\]  

(6)

b) When multiple input data are output to port J1, and the number of services to be outputted in port J1 is the least among all the output ports, go to d); if there isn’t a port J1, then go to c);

c) Poll all electrical output ports according to the number of services to be output. When polling to output port J1 which met the condition in a), then go to d);

d) When the service priority is the highest among all competing services, the service is output to
port J1, then go to the third step; when the service priority is not the highest and the polling pointer does not point to the input port, the service is cached until the round robin pointer points to this input port, then the service is output to port J1 and go to the third step.

Step 3, switch the services to the corresponding ports through the hybrid switching unit.

4. Performance analysis
An efficient and fair scheduling algorithm should match as many ports as possible in order to ensure the QoS requirements of various services, reduce the internal congestion probability of the switching unit, and improve the performance of the switching unit, such as data loss rate and resource utilization. Because it is difficult to compare the performance of scheduling algorithms through mathematical models, this paper first compares the matching probability of input and output ports in different scheduling algorithms, and then analyzes the performance of centralized scheduling algorithms from the aspects of QoS guarantee, data loss rate, and resource utilization in hybrid switching units.

4.1 Input/output port matching probability
First, we analyse and compare the matching probabilities of the traditional scheduling algorithms with the ports in the centralized scheduling algorithm proposed in this paper.

Definition 1: Conditional events and conditional probabilities.
Under the condition that one event occurs, another event occurs, called a conditional event; the probability that a condition event occurs is called a conditional probability. The probability of conditional event B|A is defined as

$$P(B|A) = \frac{P(A \cap B)}{P(A)} \quad P(A) \neq 0$$

Definition 2: Complete event group
Any two events in the event group are mutually exclusive and have a relationship

$$S = A_1 \cup A_2 \cup \cdots \cup A_n$$

Then, the event group is called a complete event group. The relationship of any event B is:

$$P(B) = \sum_{i=1}^{n} P(B \cap A_i) = \sum_{i=1}^{n} P(A_i) \cdot P(B|A_i) \quad P(A_i) > 0$$

(1) If the output ports of every input service are different, the number of matches obtained by the two scheduling algorithms is the same.

(2) If the output ports of multiple services are the same, assuming that the matching probability of input port is P[B], event A1 indicates that the selected output port of the input port is not matched, and event A2 indicates that the selected output port of the input port has been matched, and A1 and A2 form a complete event group.

In traditional scheduling algorithms,

$$P(B) = P(B \cap A_1) \cdot P(B|A_1)$$

When the centralized scheduling algorithm matches the input and output ports, the optical service and the electrical service are uniformly considered to avoid output port conflicts. Therefore

$$P(B) = P(B \cap A_1)$$

Because of $$P(B|A_i) < 1$$, the matching probability of the input port in the centralized scheduling algorithm is higher than the traditional scheduling algorithm.
4.2 Comparison of performance indicators

4.2.1. QoS guarantee. In a hybrid switch, the centralized scheduling unit uniformly manages optical/electrical services. According to the QoS requirements and the status of the hybrid switch, the optimal internal path is calculated for the higher priority service to meet the QoS requirements of different services.

4.2.2. Data loss rate. With the separate scheduling control mechanism in different switching unit, if the optical and electrical data are switched, it is easy to match the multiple input data to the same output port with a large amount of traffic, which causes the congestion in the output port. The proposed algorithm selects the internal path for various services with the group decision-making idea. Therefore, the proposed algorithm can effectively reduce the data loss rate and improve the performance of the hybrid switch.

4.2.3. Resource utilization of hybrid switch

When the centralized scheduling algorithm adapts the optoelectronic services, the scheduling and switch of various services are not performed separately. Instead, the parameters of the optical/electrical switch service are considered together by the centralized scheduling management unit. The input/output ports with less traffic are selected to complete the optoelectronic service adaptation, by the highest throughput rate. With this adaptation method, the utilization rate of the hybrid switching resource is improved.

In summary, the centralized scheduling algorithm has certain advantages over the existing scheduling methods. The algorithm can realize integrated scheduling of hybrid switches with fewer parameters and improve the performance of data loss rate in switching units. Therefore, it is suitable for use in on-board hybrid switching systems.

5. Simulation comparison

This section verifies the performance of the centralized scheduling algorithm in terms of data loss rate by constructing a simulation model, and compares the data loss rate of the traditional scheduling method and the centralized scheduling algorithm under different service burst lengths.

5.1 Simulation model

In the simulation, the ON/OFF model is used to simulate the arrival process of data. According to the characteristics of multi-beam onboard switching, each beam should correspond to one port of the switch. This section chooses to simulate and compare the 8-port switch.

In the ON/OFF model, it is assumed that the burst state length and the quiescent state length have geometrical distributions of the parameters \( P_b \) and \( P_e \). Therefore, the probability distribution function of the ON state can be obtained, that is, the probability that a burst lasts for \( x \) time slot is:

\[
p(x) = P_b \times (1 - P_b)^{x-1}, x = 1, 2, 3, \ldots
\] (12)

The probability distribution function of the OFF state, that is, the probability of a stationary continuous \( x \) time slot is:

\[
p(x) = P_e \times (1 - P_e)^{x}, x = 0, 1, 2, \ldots
\] (13)

Here \( x \) can be 0, indicating that one burst can follow another burst without a stationary period, that is equivalent to two different stream multiplexing, and the two bursts have different destination ports.

In the actual simulation, the parameters required by the service source are the average burst length \( M \) and the traffic volume \( L \), and it can be calculated that

\[
P_b = \frac{1}{M}, \quad P_e = \frac{L}{(M - M \times L)}
\] (14)

In the simulation, the input ports are independent, so that it is possible to generate multiple services.
of multiple input ports simultaneously to one output port, and some output ports are idle.

5.2 Simulation result
In this section, 100000 time slots are simulated. The data loss rates under the two cases of centralized scheduling algorithm and existing scheduling algorithm are simulated. Figure 4 compares the data loss rates of two algorithms under different loads and different buffer capacities.

![Data loss rate comparison](image.png)

**Figure 4.** Compare of cell loss ratio between the two scheduling algorithms

The simulation results show that the centralized scheduling algorithm proposed in this paper can significantly reduce the data loss rate of onboard hybrid switches. This is because the existing scheduling algorithm separately manages the optical service and the electrical service, and multiple services are scheduled to the same output port at the same time. Under the existing algorithm, the switching unit is congested and a large amount of data is lost. On the other hand, the centralized scheduling algorithm uses the group decision-making idea to schedule all services, which largely avoids the conflict of output ports, thus effectively reducing the data loss rate.

6. Conclusion
This paper proposes a centralized scheduling algorithm in on-board hybrid switch. According to the different characteristics of optoelectronic services, combined with the utilization of hybrid switching resources, the algorithm centrally dispatches optical and electrical services, realizes the aggregation and distribution among multi-granularity data ports, and reduces the internal congestion probability of on-board hybrid switch modules. The simulation results show that the algorithm can effectively reduce the data loss rate and improve the performance of hybrid switch. At the same time, the implementation of the algorithm requires fewer parameters and the implementation steps are simple. The low complexity of the proposed algorithm can meet the needs of spatial information network, which used laser and microwave links to carry multi-granularity service and achieve data aggregation and distribution function. Therefore, this algorithm can be used in on-board environments.

Acknowledgment
This work is supported by the Supported Foundation by National Key Lab. Of Science and Technology on Space microwave (2018SSFKLSMT-12).
References

[1] Liu Kai, Yan Jian, GaoXiaolin, etc. “Fully Distributed Fault Tolerant Scheduling for Onboard Clos-network Switching,” Journal of Electronics & Information Technology, 2016, 38(6), pp.1377-1384.

[2] Xiaoting WANG. “Novel High Performance Scheduling Algorithms for Crosspoint Buffered Crossbar Switches,” IEICE TRANSACTIONS on Information and Systems, 2015, E98-D(12), pp.2091-2104.

[3] Jihwan P. Choi, Seok-Ho Chang, Vincent W.S. Chan. “Cross-Layer Routing and Scheduling for Onboard Processing Satellites with Phased Array Antenna,” IEEE transactions on wireless communications, 2017, 16(1), pp. 180-191.

[4] Narayanan Prasanth, Kannan Balasubramanian. “Performance analysis of buffered crossbar switch scheduling algorithms,” International Journal of Information and Computer Security, 2015, 7(1), pp.49-63.

[5] Zhang Yi, Zhou Quan, Li Jun, etc. “The Simulation and Realization of Input-buffer Scheduling Algorithm in Satellite Switching System,” Space Electronic Technology, 2015, 12(1), pp.97-103.

[6] Han Yong, Yao Jianmin, Cai Shaobin, etc. “Packet Forwarding Scheduling Algorithm FC-WFQ for iSCSI Virtualization Switch,” Acta Electronica Sinica, 2013, 41(3), pp.587-592.

[7] Zhou Zhiqiang, Xu Zhanqi, Zhang Xiaolei, etc. “Survey on high performance switching architecture,” Application Research of Computers, 2015, 32(4), pp.961-966.

[8] Zhen Zheng, Lufeng Qiao, Qinghua Chen, etc. “A concurrent round-robin-based variable-length packets dispatching scheme for satellite onboard clos-network switches,” 2015 8th International Congress on Image and Signal Processing (CISP 2015), 2015, pp.1510-1514.

[9] Yang Fan, Xu Zhanqi, Li Danwu, etc. “Multicast scheduling algorithm with a dynamic weight for the input buffered Crossbar,” Journal of Xidian University (Natural Science), 2016, 43(6), pp.80-85.

[10] Liu, L., Zhang, Z., Yang, Y. “In-Order Packet Scheduling in Optical Switch With Wavelength Division Multiplexing and Electronic Buffer,” IEEE Transactions on communication, 2014, 62(6), pp.1983-1994.