A Load-Balanced and Heterogeneous Switch Path (LHSP) Algorithm in Space Optical-Electrical Hybrid Switching System

Jingling Li[1(✉)], Yi Zhang[1], Wei Liang[1], Tao Cui[1], Jun Li[1], and Gong Li[2]

[1] National Key Laboratory of Science and Technology on Space Microwave, CAST, Xi'an 710100, China
ljlspirit@foxmail.com

[2] Beijing Institute of Space Mechanics and Electricity, Beijing, China
13651058529@189.cn

Abstract. Currently, with both optical and packet heterogeneous paths existing in space optical-electrical hybrid switching system, the method of independently calculating the optical/packet switching path cannot comprehensively consider the availability of the system's path resources, which result in the possibility of selecting irrational switching path and making the path load of the switching system unbalanced, even may cause high path blocking probability. In this paper, the homogeneous path influence factor and the heterogeneous path influence factor are defined to quantitatively measure path weights, and based on the optical/packet integrated signaling, a load-balanced and heterogeneous switch path algorithm (LHSP) is proposed to calculate the internal heterogeneous switching path. Moreover, the load balancing degree and the path blocking probability are simulated based on Switching Structure Simulation Model in OPNET. Extensive simulation results show that the LHSP algorithm can reduce average load balancing degree by about 32% and average path blocking probability by about 51% with previous algorithm.

Keywords: Optical-electrical hybrid switching · Integrated signaling · Switching path · Load balancing

1 Introduction

The space information network needs the large capacity and strong anti-jamming capability of optical communication, and also needs the wide beam and easy access characteristics of microwave communication. The future spatial information network will be a form of optical/microwave hybrid network in a certain period of time. The switching system in this network should have the capability of optical-electrical hybrid switching, which may exist on a certain satellite node, or a number of tightly coupled spatial nodes to complete the aggregation or distribution switching function of optical-electrical services. This paper mainly focuses on the optical-electrical hybrid switching on satellite node.

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At present, there are many forms of optical networks combining with electricity. Their common feature is the integration of optical and electrical data communication at the data plane, and the unified control at the control plane. For example, POTN [1] networks based on OTN, has the unified control plane, leading PTN Ethernet and MPLS-TP packet switching and processing functions to realize the organic convergence of optical and electric. And there is no optical-electrical hybrid situation in POTN switching system. In terms of the optical protocol, the GMPLS technology based on the IP backbone network has been proposed to integrate the IP layer with the optical layer [2], the literature [3, 4] propose the RSVP-TE signaling in GMPLS protocol which can be used in the satellite networks and based on a unified control, but there is no relevant description of the optical-electrical hybrid switching system. In the research of space information network, the literature [5] proposes an optical-electrical hybrid on-board switching technology scheme, with the edge nodes packing the packet data into optical data and the core nodes switching the optical data, which doesn't have implemented an integral optical-electrical hybrid switching system in one satellite node.

In the satellite switching system, optical switching mainly includes resources such as wavelength/band, matrix switch, and time slice. Packet switching mainly includes resources such as routing table/forwarding table, bandwidth, and time slot. When the optical service needs to be switched to packet output port, or the packet service needs to be switched to the optical output port, such services need to be switched through heterogeneous switching system, which may pass through different combination paths of optical and electrical. If irrational switching paths are selected, some of the path loads may be oversaturated which may lead to path blocking of the paths. At the same time, other available paths in the switching system are idle and are not fully utilized. This situation may result in unbalance path loads and lower resource utilization. Currently, most of the load balancing-based path algorithms in satellite consider hops control [6], the load balancing of homogeneous path [7], or the effect of other constraints, for instance control link constraints [8] are introduced in the SDN network routing algorithm and energy constraints are combined [9] to calculate the paths.

In this paper, the load-balanced and heterogeneous switch path algorithm (LHSP) is proposed to build heterogeneous path source weight function, which is based on the space integrated signaling. And according to the homogeneous path influence factor and the heterogeneous path influence factor etc., the path load capacity can be quantitatively measured by the path source weight function, then the optimal hybrid switching path satisfied the load balancing could be selected with the maximum path resource weight. The simulation results based on switching model with OPNET shows that the LHSP algorithm not only can effectively distribute the optical-electrical load, but also can improve the utilization of path resources and reduce the blocking probability of the switching system.

2 Integrated Signaling Design in Optical-Electrical Hybrid Switching

The switching structure of the satellite optical-electrical hybrid switching system includes two types of heterogeneous switching structure: the optical switching matrix and the packet (electrical) switching matrix. Figure 1 shows an example of satellites optical-electrical heterogeneous switching structure [10], which is composed of optical switching matrix and the electrical switching matrix, with optical switching capabilities, packet switching capabilities, and optical-electrical heterogeneous switching capabilities.

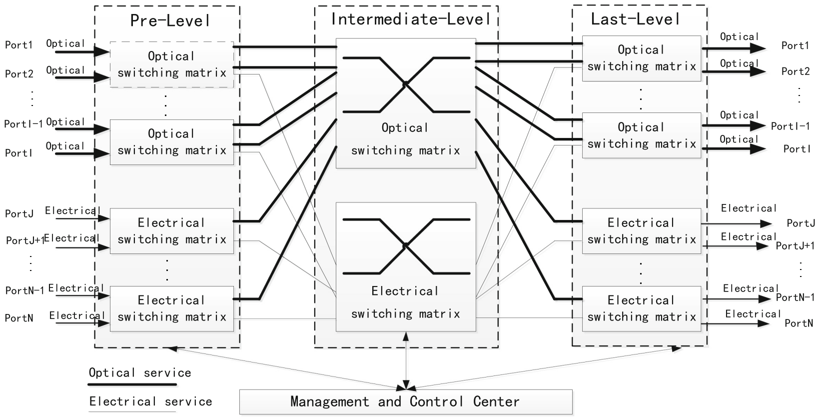


Fig. 1. An example of optical-electrical hybrid switching structure

The optical switch path must be configured before the service transmission, for the optical data is hard to cache, and the packet data can be stored and forwarded through the table. For this situation, an optical-electrical integration signaling mechanism [11] is proposed.

The switching paths inside the satellite switch are considered as a set of the combination of the optical switching path and the packet switching path, which can be expressed as: $\{P_o, P_e\}$, where P_o is the subset of optical switching paths, $P_o = \{g_1, \cdots, g_y\}, 1 \le y \le G$, G is the number of optical internal ports, and P_e is the subset packet switching paths, $P_e = \{l_1, \cdots, l_x\}, 1 \le x \le K$, K is the number of the packet internal port. When the input and output ports are heterogeneous, an integrated signaling mechanism is used for joint reservation of the optical-electrical resources.

In the integrated signaling mechanism, signaling bundling is used as shown in Fig. 2. The input service (input port) type is used as the signaling message 1, the output service (port) is used as the signaling message 2, and two types of signaling messages are used. It is nested in IP datagrams in order of priority. The signaling header must be properly modified.

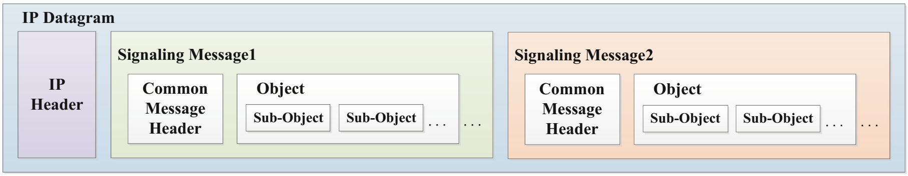


Fig. 2. The format of optical-electrical integration signaling message

After receiving the optical-electrical integrated signaling, the satellite switch determines whether to accept the signaling request according to the message request, the available path resources and network resource status of the optical/packet. And the optimal switching path is generated according to LHSP algorithm.

3 LHSP Algorithm

3.1 Network Symbol Definition

In an optical-electrical switching system, the paths from input port to output port are called switching paths, where the passing optical or packet path is called sub-path. The topology of the on-board optical-electrical switching can be expressed as $S(M, N, G, K)$, where M represents the number of optical external ports, N represents the number of packet external ports, G represents the number of optical sub-paths, and K represents the number of packet sub-paths. For the given input and output ports, the number of sub-paths included in a switching path is the same, but the number of path conversion (optical sub-path converse to packet sub-path or packet sub-path converse to optical sub-path) times in a switching path is not necessarily the same. The switch service requests obey uniform distribution, and only one service request arrives at the same time. To facilitate the algorithm description, the following related symbols are defined:

$T(l, w)$: The optical-electrical switching structure resources status information table, which labels currently available resources for all sub-paths;
$R_{(x,y)}$: The signaling request from input port X to output port Y;
$P_{(x,y)}$: The set of all switching path combinations from input port X to output port Y in the optical-electrical switching system;
$H_{(x,y)}$: The number of path conversion (optical sub-path converse to packet sub-path or packet sub-path converse to optical sub-path) times in a switch path. If the number of path conversion is zero, $H_{(x,y)}$ equal to 0.01, that is, the switching path without path conversion is preferentially selected.

Example: Take an optical-electrical hybrid switching path $\{O_{11}, E_{12}E_{13}E_{14}E_{15}, E_{21}E_{32}E_{43}E_{54}\}$ of Fig. 1 as an example: where an optical service needs to be transmitted to four packet paths, and the switching path takes a total of nine sub-paths and one path conversion.

3.2 Algorithm Description

If the optical-electrical integrated signaling message containing the input and output port information are accepted by the optical-electrical switching system, the optical-electrical heterogeneous switching path based on load balancing needs to be calculated. The algorithm steps proposed in this paper are as follows:

(1) Firstly, initialize the optical-electrical heterogeneous switching system to record the resources usage of each sub-path in each switching structure, and establish a resource status information table $T(l,w)$. When the new switching path request is received, or the existing switch path is removed, the corresponding path resource information of the table $T(l,w)$ will be updated;
(2) When $R_{(x,y)}$ arrived, calculate the set $P_{(x,y)}$ which combining all the sub-paths in the switching system according to the service input port x and the output port y;
(3) Calculate the number of path conversions $H_{(x,y)}$ of each switching path in the set $P_{(x,y)}$, which should be avoided as much as possible, because it would bring extra resource overhead and complexity of the system;
(4) Measure the impact of choosing different homogeneous sub-paths (such as optical path set or packet path set) on the load balancing of the switching system through the homogeneous path influence factor ω;
(5) Measure the impact of different heterogeneous sub-paths on the load balancing of the switching system through the heterogeneous path influence factor υ_α;
(6) Construct the optical-electrical heterogeneous path weight function $Cp(x,y) = \frac{1}{H_{(x,y)}} \cdot \sum_{k=1}^{K} \sum_{l=1}^{L} Lw_l \cdot \omega_l \cdot \upsilon_{\alpha_k}$ to calculate the path weight $Cp(x,y)$ of all switching paths in the set $P_{(x,y)}$, where $H_{(x,y)}$ is the number of path conversion; Lw_l is the available resource value of any one of the sub-paths; ω_l is homogeneous path influence factor and υ_{α_k} is heterogeneous path influence factor;
(7) Arrange the path weights $Cp(x,y)$ of the switching paths in the set $P_{(x,y)}$ in ascending order, and select the switching path with the largest $Cp(x,y)$ value;
(8) Determine whether the selected switching path for all sub-path available resource value Lw_l is not less than the service request resource minimum Lw_{min}, if not less than Lw_{min}, go to the next step, if less than the value, go to step (10);
(9) Select the switching path of the previous step, at the same time, reserve corresponding optical switching and packet switching resources according to the signaling request message, and update the path resource status information in $T(l,w)$;
(10) Delete the path of the maximum resource weight obtained in step (8) from the set $P_{(x,y)}$, and then determine whether the set $P_{(x,y)}$ is empty, if it is not empty, go to step (8), if it is empty, the service request fails this time.

3.3 Key Factors Generation Method

The homogeneous path influence factor ω and the heterogeneous path influence factor υ_α are the key factors of the path weight function, and the calculation method is as follows:

1. Method for calculating the homogeneous path influence factor ω.
   (1) Query the available resources Lw included in each sub-path are through table $T(l, w)$;
   (2) Calculate the percentage of the available resource value Lw of each sub-path in packet/optical path set to the total number of available resource values of the same type of sub-paths in each switching path, and sort the percentage in ascending order;
   (3) Allocate the percentage of the previous step to each sub-path in reverse order, that is, allocate the maximum percentage to the sub-path with the smallest resource, and allocate the smallest percentage to the sub-path with the largest resource, and obtain the homogeneous path influence factor ω, which satisfies the constraint condition $\sum_{l=1}^{L} \omega_l = 1$, where L is the number of sub-paths in the path set of this type.
   By this method, the sub-paths can be balanced as much as possible to avoid causing hot sub-paths.
2. Method for calculating the heterogeneous path influence factor υ_α.
   (1) Calculate the greatest common divisor of the two types (optical path bandwidth and packet path bandwidth) of maximum path bandwidth values, and define the divisor to be the minimum granularity bandwidth α, which is the minimum unit to measure the bandwidth of the heterogeneous path;
   (2) Calculate the quotient of two types path bandwidth values and the minimum granularity bandwidth α respectively, and divide the quotient of optical/packet path bandwidth by the sum of them to obtain the ratio of the path bandwidth of the two types path;
   (3) Multiply the total available resources of the optical path with its corresponding path bandwidth ratio to obtain the optical path granularity ratio $Tw_{\alpha o}$; and multiply the total available resources of the packet path with its corresponding path bandwidth ratio to obtain the packet path granularity ratio $Tw_{\alpha e}$;
   (4) Calculate the percentage of ratio $Tw_{\alpha o}/Tw_{\alpha e}$, respectively, to their total;
   (5) Assign the percentage obtained from the previous step to the optical path and the packet path in reverse order, that is, the larger percentage is allocated to the path type with a smaller granularity ratio, and a smaller percentage is allocated to the path type with a larger granularity ratio. In this case, the percentage value assigned to the path is the heterogeneous path influence factor υ_α, which satisfies the constraint condition $\sum_{k=1}^{K} \upsilon_{\alpha k} = 1$, where K is the number of paths type, and here $K = 2$.

By calculating the heterogeneous path influence factor, it can be said that the impact of different types of paths on the load balancing of the overall switching system is converted into specific values related to the available resources of the heterogeneous paths, which is beneficial to the trade-off comparison between different switching paths.

4 Performance Evaluation

The optical-electrical switching structure shown in Fig. 1 has be simulated in OPNET. The front stage and the rear stage each contain two 2 $\times$ 2 optical switching matrices and two 8 $\times$ 8 packet switching matrices, and the intermediate stage contains one 4 $\times$ 4 optical switching matric and one 16 $\times$ 16 packet switching matric, as shown in Fig. 3.

In the incremental service mode, that is, when a service connection is established, it will occupy the path resources and will not be released. In this paper, the load balancing degree (LBD) of switching system based on LHSP algorithm and traditional load balance path selection algorithm [12] are compared.

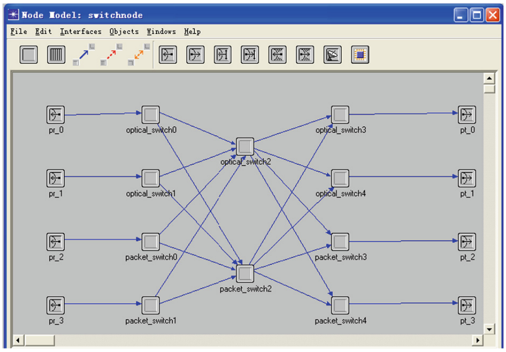
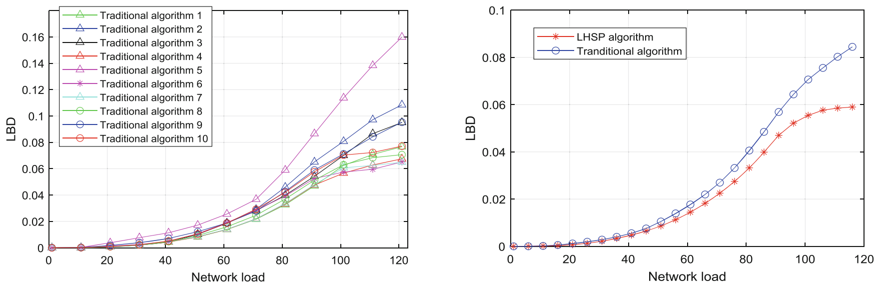


Fig. 3. Switching structure simulation model in OPNET

The LBD can indicate the balance degree of the path load through the statistical variance of the path resources, which is defined as $\mathrm{LBD} = \sum_{l \in L} (w(l) - w)^2 / (|L| - 1)$, Where L is the path set of the switching system, $|L|$ is the total number of paths in switching system, $w(l)$ is the number of available resources in the current path, and $w = \sum_{l \in L} w(l)/|L|$ is the average number of used resources in each path. A smaller LBD indicates better network load balancing, which means to distribute service more effectively on all paths. In order to compare the LBD of optical-electrical switching networks under different service load conditions, a total of 0-120 service requests are sent. The simulation results are shown in Fig. 4.

The traditional algorithm is based on the input port to select the optimal optical switching path and the corresponding packet switching path, which does not consider the impact of the optical switching path on the selection of the packet switching path. Therefore, as shown in Fig. 4(a), after ten calculations, the LBD obtained by the traditional algorithm is random and not the optimal result. The LBD values obtained by the traditional algorithm are averaged as shown in Fig. 4(b), it can be seen that the LHSP algorithm can effectively reduce the LBD, which can be reduced by about 32% When the network load reaches 120. When the network load is larger, the LHSP algorithm can more effectively enhance the network load balancing capability and improve the utilization of switching path resources.

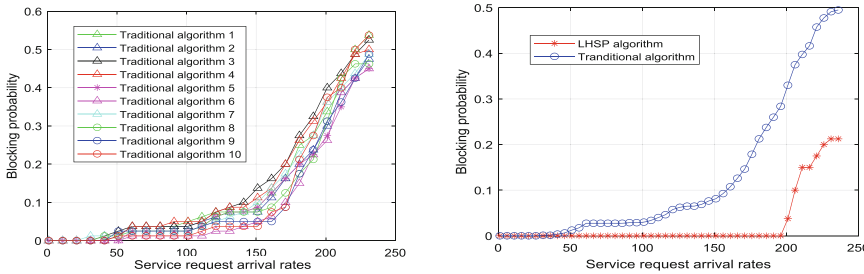


(a) LBD under ten times of Traditional Algorithms （b）The LBD of Traditional Algorithm Means and LHSP Algorithm

Fig. 4. LBD under different network loads

In the dynamic service model, the blocking probability of the LHSP algorithm and the traditional load balancing algorithm [12] in the case of different service request arrival rates are compared. As shown in Fig. 5(a), the same for ten calculations, the blocking probability obtained by the traditional algorithm is random and not the optimal result. The blocking probability values obtained by the traditional algorithm are averaged as shown in Fig. 5(b), the LHSP algorithm can effectively reduce the Blocking probability, which can be reduced by about 51% when the service request arrival rate reaches 240. When the service request arrival rate is larger, the LHSP algorithm can more effective reduce the blocking probability.

As shown in Fig. 5, when the blocking probability starts to be greater than zero, the corresponding service request arrival rate of LHSP algorithm is larger than that of traditional algorithm, which can be explained by the fact that the LHSP algorithm comprehensively considers the available resources of both the optical path and the packet path. So, the path is balanced to avoid bottleneck paths and delay path congestion. The traditional load balancing algorithm only considers the resources of the homogeneous path, which cannot comprehensively balance the overall path resources of the optical-electrical hybrid switching system.



(a) Blocking probability under ten times of Traditional Algorithms（b）The Blocking probability of Traditional Algorithm Means and LHSP Algorithm

Fig. 5. Blocking probability under Different Service request arrival rates

5 Conclusion

In this paper, a load-balanced path calculate method for optical-electrical heterogeneous switch is proposed, which can be applied to the space optical-electrical hybrid switching system. Optical switching resources and packet-switching resources are compared quantitatively, and a weight function of the switching path resources is built to comprehensively consider the current optical/electrical available switching resources and generate a switching path that satisfies the load balancing of the switching network.

In the mode of adding services, with simulation model of OPNET, the network load balancing degree and blocking probability of the LHSP algorithm and the traditional path algorithm are compared through multiple simulations, and the simulation results show that the LHSP algorithm proposed in the paper can not only improve the path load capacity, but also reduce the path blocking probability of the switching system, and ultimately improve the overall switching performance of the optical-electrical hybrid switching system. In the following work, the LHSP algorithm is further optimized by adding characterization of optical and packet heterogeneous resources.

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