Module Selection Algorithm Based on WSS/SSS-Hybrid AoD Node in Dynamic Elastic Optical Networks

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Abstract. Driven by the emerging applications based on Internet, optical backbone networks need to improve their transmission capabilities while ensuring high reliability, flexibility, and scalability. Elastic optical networks and space-division multiplexing optical networks are seen as the potential solutions. In order to implement these technologies, innovative nodes are required to provide flexibility, reliability, and scalability for the optical networks. Architecture on Demand (AoD) node is a new type of elastic optical node structure proposed in the recent years and can dynamically provide a customizable structure according to the exchange and processing requirements of the network traffic. Spectrum Selector Switches (SSS) is one of the key modules but has not been widely used because of its excessive cost. To solve the problem of how to select the Wavelength Selective Switch (WSS)/SSS coexistence in the current network, we propose a pre-built algorithm for the modules in the AoD nodes. Simulation results show that the proposed algorithm performs better than the benchmarks in different network scenarios and provides a solution to the gradual upgrade of AoD nodes.

Keywords: AoD node · WSS/SSS selection · Elastic optical networks

1 Introduction

Driven by the growing of Internet traffic as well as emerging applications such as cloud computing and big data, fiber optic backbone networks need to improve its transmission capacity, reliability, flexibility, scalability and cost-efficiency. In this case, Elastic Optical Network (EON) and Spatial Division Multiplexing (SDM) optical networks have been studied extensively and became promising solutions. The appearance of optical fibers based on SDM technology and the increase in the number of basic optical fibers, which are aimed at expanding the transmission capacity, are expected to magnify and complicate the elastic optical nodes in the future optical fiber backbone networks. However, the work on flexible optical node architectures based on these

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flexible technologies is limited. This optical node that are used in SDM based EON need to provide flexibility, reliability and scalability for the entire network. Therefore, elastic optical node architectures are an interesting topic for current optical fiber backbone networks.

Among the different solutions proposed to the elastic node architectures, broadcast-and-select and spectrum-routing are common elastic optical node architectures that have sufficient flexibility to implement a completely flexible optical network [1, 2]. In these architectures, the Spectrum Selective Switch (SSS) is not only the main building module, but also the dominant module in terms of cost and power consumption. Due to the limited port number of SSSs, the cost and power consumption of these elastic optical nodes will increase significantly with the increase of the number of SSSs in large-scale networks. Another hierarchical optical switch node architecture using a small Optical X-Connect (OXC) as a subsystem module has been proposed to suppress the increasing of building modules [3], but this architecture has a negative impact on the transmission success rate. Therefore, it is necessary to consider cost, power reduction and successful transmission rate in the design of the optical node architecture.

The solution based on Architecture on Demand (AoD) [4] reduces not only the number of building modules implemented, but also exhibits remarkable flexibility [5], reliability [6] and scalability [4, 7] compared to the existing alternatives (such as MG-OXC [8], BV-ROADM [9]). However, due to the fact that key enabling devices for AoD nodes, such as SSSs that support multi-granularity service switching, are now expensive, it is not feasible to use SSS extensively across the entire network. In this paper, we propose a selection algorithm of WSS/SSS in AoD nodes to address the problem of how to choose WSS/SSS coexistence of the current network.

2 Optical Node Architecture

2.1 Traditional Optical Node Architecture

In EON or SDM, the elastic optical node will process the transmitted signal with better flexibility and finer granularity than the traditional optical network. SSS is the most important building module in EON and SDM elastic optical nodes, as Fig. 1. It is also called flexible Wavelength Selective Switch (WSS). The SSS can filter the input signals with an arbitrary width spectrum and switch them to another arbitrary port without copying the signals. The choice of SSS enables the flexible networking of EON and SDM.

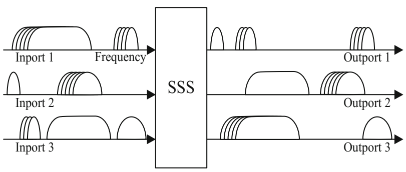


Fig. 1. The concept of SSS.

In the broadcast-and-select architecture, as shown on Fig. 2(a), the input signal is first copied in the splitter and then broadcasted to all output ports. On each output port, use the SSS to select the appropriate spectrum and sending the multiplexed signal through the output port. If there are many ports in a node, the replication of these splitters will seriously degrade the transmitted signal [10]. In the spectrum-routing architecture, which is shown in Fig. 2(b), the input signal is first de-multiplexed by the SSS at the input ports and not copied. These de-multiplexed signals, then, are routed to different output ports and finally multiplexed at the output ports through the SSS. Unlike broadcast-and-select architectures, the spectrum-routing architecture does not produce splitter signal degradation, but due to the number of equipped SSSs doubles at the input, the cost is much higher than broadcast-and-select architectures.

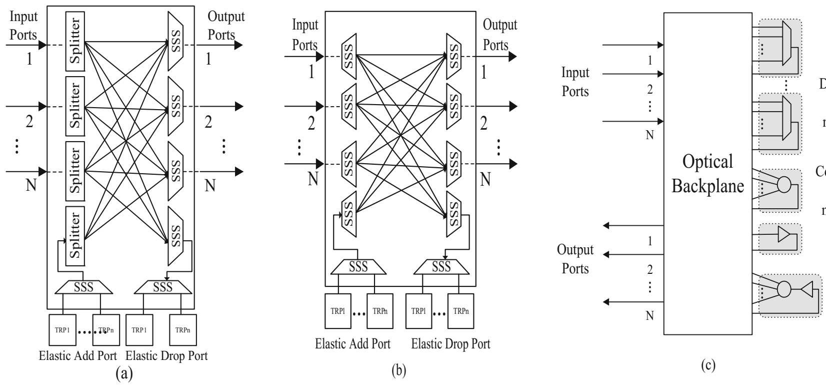


Fig. 2. (a) Broadcast-and-select architecture. (b) Spectrum-routing architecture. (c) Architecture of AoD nodes

In both architectures, the cost of elastic optical nodes will be an important issue. If the number of input/output ports of an elastic optical node is large, it is necessary to match SSSs having the same number of ports in these traditional node architectures. However, the number of SSS ports has certain limitations. In order to meet the requirements of the node architectures, the number of SSSs may increase explosively, and thus the cost of elastic optical nodes also increases dramatically.

2.2 AoD Node Architecture

The introduction to the concept of AoD is to solve the problem of insufficient flexibility in traditional optical nodes due to the hard-wired deployment of building modules. The AoD includes an optical backplane that interconnects input ports, output ports and architecture-building modules. The optical backplane can be implemented with a large port-count optical switch (e.g. 3D-MEMS) and the building modules can be either single devices for optical processing (e.g., MUX, DEMUX, WSS, SSS, amplifier, etc.) or subsystems that are composed of several devices, as shown in Fig. 2(c). AoD nodes can dynamically reconfigure the overall architecture based on the network's signals switching or processing requirements. Because these building modules are dynamically configured, they can provide additional functionalities for the nodes. Therefore, AoD nodes have greater flexibility and scalability than traditional static optical node architectures.

Reference [5] defines the flexibility of the node architecture according to the entropy of the system and compares the traditional static node architecture of AOD nodes and EON. In Reference [11], multi-granular transmission of space/frequency/time domain has been demonstrated by AoD nodes and Multi-Core Fiber (MCF). The experiment proves that the AoD node in EON based on MCF has great flexibility. The advantages of AoD node flexibility have been proved theoretically and experimentally.

Moreover, the flexibility of AoD nodes can be used to reduce the power consumption of optical nodes. Because the AoD node is dynamically constructed based on the switching request, it only needs to use a minimum amount of required building modules. The traditional optical node structure always needs to fix the maximum number of hard-wired modules without considering the request. The use of AoD nodes can reduce the number of building modules and power consumption. References [7, 12] analyze the power consumption of AoD nodes. Reference [7] analyzes the benchmark for power reduction based on the granularity of the switching request. Reference [12] shows that in the dynamic scenario, using the ILP model to find the optimal solution for AoD construction is extremely complicated, thus AoD nodes can use heuristic algorithms to build AoD nodes and eventually reduce the total power consumption of the network by more than 25%.

Although the AoD node can provide many advantages, it still has some challenges. The high flexibility and scalability of AoD nodes have a directly relationship with the number of core building modules SSSs. The number of SSSs will directly affect the cost and energy consumption of AoD nodes. Due to the high cost of SSSs, WSS is still widely used in the current network to provide network flexibility. In the following section, we will study how to choose WSS/SSS reasonably in the WSS/SSS coexistence network and propose a Pro-built algorithm to solve this problem.

3 Pre-built Algorithm for AoD Node

3.1 Module Selection and AoD Construction

Our proposed Pre-built Algorithm is based on a given set of feasible requests for AoD module construction. The algorithm flow chart is shown in Fig. 3. Pre-built has five steps: one step to calculate shortest paths, three steps for switching function to switch from coarser granularity to finer granularity (that is, fiber switching, super channel, single wavelength and sub-wavelength level), the last step of AoD Module building.

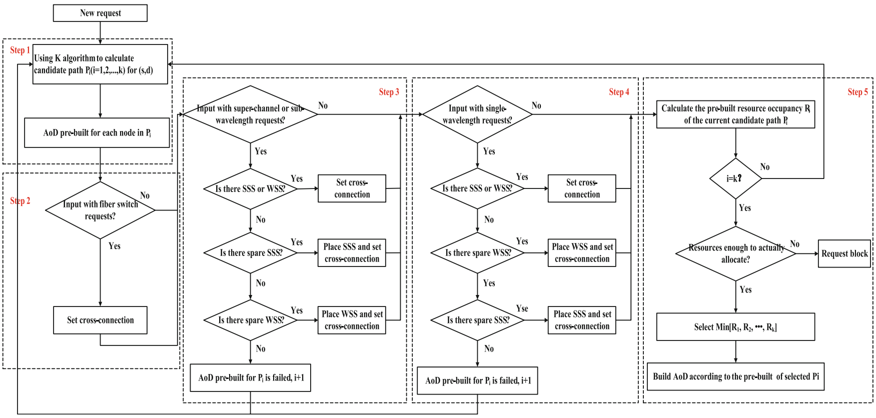


Fig. 3. The flow chart of Pre-built Algorithm.

Step 1: Calculate K alternative paths using KSP algorithm based on the source-destination node pair in a request and perform AoD pre-construction on them.
Step 2: Check if the request is a fiber switch request. If so, check the destination of all signals from each input and set the cross-connect directly if they all are the same output.
Step3: Check if the request is a super-channel or sub-wavelength request. If so, Check if there is SSS or WSS at the input port. If so, preferentially use the existing module; if not, give priority to placing SSS (due to the SSS arbitrary bandwidth switching capability), and then consider placing WSS. If SSS or WSS cannot be provided for the request at the node, the AoD pre-build on the current alternate path fails and it will return to re-build the next path.
Step 4: Check whether the request is a single-wavelength request. Similar to the third step, pre-existing modules at the port are used. The difference is that if there is no existing module, it is preferable to place the WSS, and secondly to place the SSS.
Step 5: Calculate the resource metrics R_i of the pre-built successful path. At the same time, it should satisfy all candidate paths traversed. In this case, the indexes of alternative paths are compared, and the suitable path is selected as the final AoD construction. "Ri" satisfied the following:

$$Ri = \frac{Sall + S'_{all}}{Wall} \tag{1}$$

where *Ri* represents the spectrum slots usage rate of the candidate path P_i, *Wall* is the sum of the spectrum slots in each link of the P_i, *Sall* is the sum of the spectrum slots already been occupied in each link of the P_i, S'_{all} is the sum of the spectrum slots will be occupied when pre-built in each link of the P_i.

3.2 Illustration for Pre-built Algorithm

To better to illustrate the Pre-built algorithm, we can look at the example in Fig. 4. Different businesses are shown in the table. These services include different granularity services such as fiber switching services, sub-wavelength services, single-wavelength services, and super-channel services. Taking Request 1 as an example, the service source/destination node pair is (1, 4). In this case, the K algorithm (K = 3) is first used to select a candidate path, as shown in Step 1. After that, we proceed with Step 2, which will pre-build AoD modules for this candidate path. Since this is a 100 G super-channel service, we will configure the SSS for it, and each node in the candidate path node set (1, 2, 3, 4) of the candidate path 1 will configure SSS for it. Of course, if this is a single-wavelength service (like Request 2) we will configure it as WSS. If there is already a module at the port, consider reusing the module (Request 3). In this way, the three candidate paths are pre-build in sequence, and perform the calculation in step 3, which the resources on the three alternative paths after the construction according to the pre-built algorithm is calculated. By comparison, the more available resources are in the candidate path 1, so the construction method of candidate path 1 will be used to configure the functional modules of the final AoD node. If there is no module available for use, this service will be blocked (Request 5).

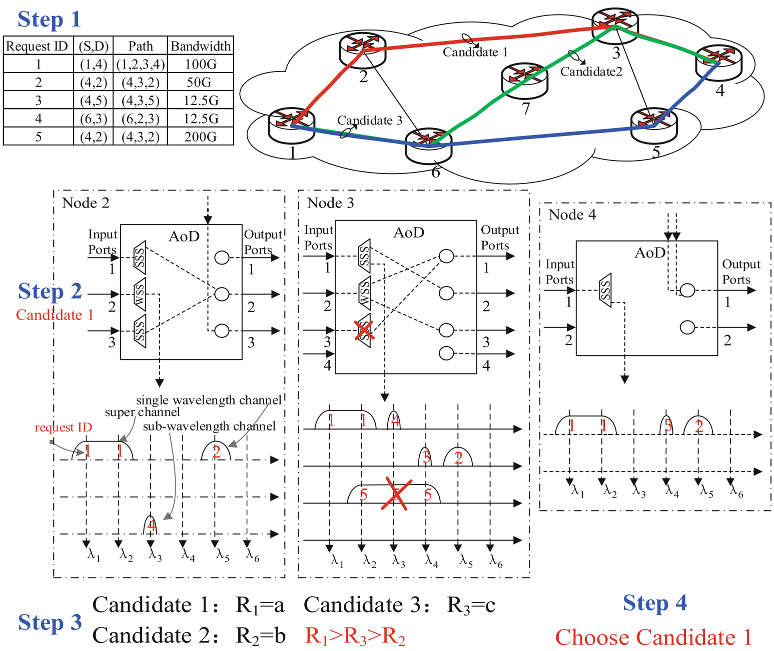


Fig. 4. Illustration for algorithm.

4 Simulations and Results

We evaluated the proposed algorithm by software simulation. The simulation uses an US network topology, which has 28 nodes and 45 links. Each bidirectional link is configured with 400 spectrum slots and each spectrum slot is 12.5 GHz. 100000 services requests following Poisson distribution are given, and their bandwidth requirements are randomly generated from 40 to 400 Gbps. For each service type, the number of spectrum slots occupation is summarized in the Table 1. Requests are processed one by one and the K is KSP is set as 3, and first-fit spectrum assignment are used for each link.

Table 1. Required spectrum for different demands

Channel	Flexible grid	Slots
40 Gbps	25 GHz	2
100 Gbps	37.5 GHz	3
200 Gbps	75 GHz	6
400 Gbps	125 GHz	10

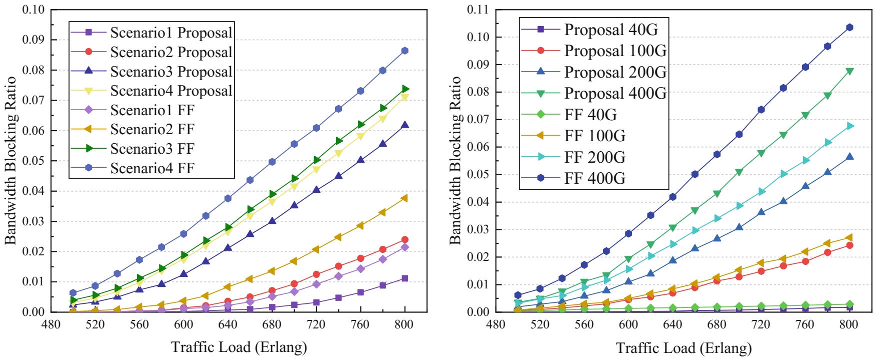
According to the demand proportions shown in Table 2, the pre-built algorithm is evaluated in four different traffic scenarios. Among them, scenarios 1 and 2 focus on small service, scenario 3 focuses on balancing services, and scenario 4 focuses on large service for testing performance of algorithms. The four scenarios follow uniform traffic models, which means that traffic is evenly distributed among all nodes in the network.

Table 2. Demands proportion in different scenarios

	40 Gbps	100 Gbps	200 Gbps	400 Gbps
Scenario 1	50%	30%	15%	5%
Scenario 2	10%	50%	30%	10%
Scenario 3	25%	25%	25%	25%
Scenario 4	0%	40%	40%	20%

Simulation results are shown in the Fig. 5. The proposed pre-built algorithm is compared with the First-Fit algorithm for the WSS or SSS modules in Fig. 5(a). In four different traffic scenarios, the proposed algorithm performs better than FF algorithm, and the two algorithms are better in scenarios 1 and 2. From Fig. 5(b), it can be further found that the traffic blocking ratio in the network increases with the traffic load, which is mainly due to the increase in the number of large-bandwidth super-channel services in the network. The increase in the occupancy of spectrum resources has led to an increase in the blocking ratio.

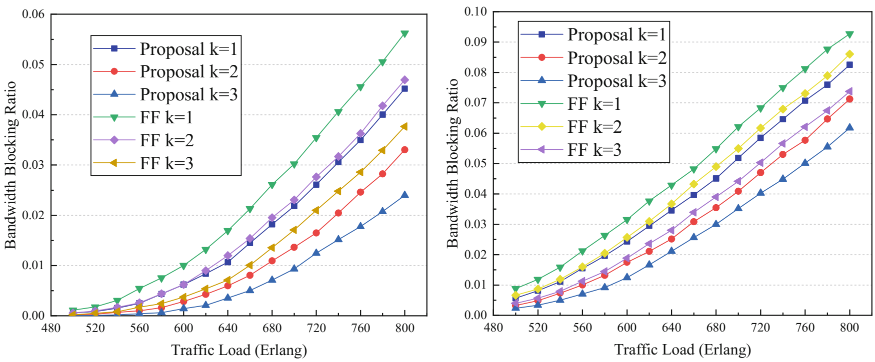
Figure 6(a), (b) show the effect of k-values on the effects of the proposed algorithm and the FF algorithm in the K-shortest routing algorithm respectively in different scenarios. From the result point of view, the pre-built algorithm works best when k = 3.



(a) BBR under different scenarios (b) BBR of different service under scenario3

Fig. 5. Simulation results with two algorithms under different scenarios.

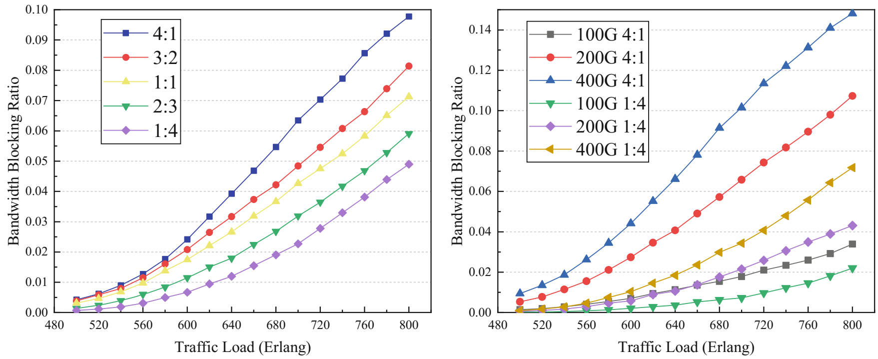
This is because the algorithm compares the resource conditions of the candidate paths in advance and selects the optimal situation to construct the AoD module. At the same time, it can be inferred that when k increases, the algorithm performs better.



(a) BBR of different k value under scenario2 (b) BBR of different k value under scenario3

Fig. 6. BBR of different k values under different scenarios.

Figure 7(a), (b) show the impact of the number of WSS and SSS on the blocking ratios in the AoD node under the fourth traffic scenario. From Fig. 7(a), it is easy to find that the blocking ratio of the network decreases with the increase of the number of SSSs in the nodes. This is because the SSS can provide more flexibility and allow more large-bandwidth super-channel services to be configured successfully. Figure 7(b) shows the blocking ratio of different services under different module proportions. This further reflects the direct impact on the number of SSSs on super-channel services. At the same time, it also indicates that in the WSS/SSS coexistence networks, we can upgrade the AoD node in a gradual upgrade manner under the premise of ensuring certain flexibility. This also provides a solution to the construction and upgrade of AoD nodes.



(a) BBR under different proportions of WSS and SSS (b) BBR of different service

Fig. 7. BBR under different proportions of WSS and SSS.

5 Conclusion

This paper studied how to select the building modules in the current WSS/SSS coexistence optical network. Based on AoD nodes architecture, we proposed a WSS/SSS selection algorithm to build AoD modules in dynamic networks and compared their performance under different traffic scenarios. In different traffic scenarios, we can see that the proposed algorithm performs better in small service scenarios, and the number of WSS and SSS plays an important role in large service scenarios. This provides a solution to the gradual upgrade of AoD nodes. In the future work, we will continue to try to explore the factors that more influence on the construction of AoD nodes under such scenario.

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