A Service-Based Intelligent Time-Domain and Spectral-Domain Flow Aggregation in IP-over-EON Based on SDON

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Abstract: The rapid growth of IP traffic has contributed to wide deployment of optical devices in elastic optical network. However, the passband shape of wavelength selective switches (WSSs) that are used in reconfigurable optical add-drop multiplexer (ROADM)/optical cross connect (OXC) is not ideal, causing the narrowing of spectrum. Spectral narrowing will lead to signal impairment. Therefore, guard-bands need to be inserted between adjacent paths which will cause the waste of resources. In this paper, we propose a service-based intelligent aggregation node selection and area division (ANS-AD) algorithm. For the rationality of the aggregation node selection, the ANS-AD algorithm chooses the aggregation nodes according to historical traffic information based on big data analysis. Then the ANS-AD algorithm divides the topology into areas according to the result of the aggregation node selection. Based on the ANS-AD algorithm, we propose a time-domain and spectral-domain flow aggregation (TS-FA) algorithm. For the purpose of reducing resources' waste, the TS-FA algorithm attempts to reduce the insertion of guard-bands by time-domain and spectral-domain flow aggregation. Moreover, we design a time-domain and spectral-domain flow aggregation module on software defined optical network (SDON) architecture. Finally, a simulation is designed to evaluate the performance of the proposed algorithms and the results show that our proposed algorithms can effectively reduce the resource waste.

Keywords: IP-over-EON; time-domain; spectral-domain; flow aggregation; big data analysis; SDON

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1 Introduction

With the emerging requests for Internet applications, cloud services, big data, and more, the 5G-oriented transport network faces many technical challenges such as high capacity, low latency, network fragmentation, and intelligence [1]. IP over elastic optical networks (IP-over-EON) is a promising multilayer network architecture that can achieve efficient IP traffic accommodation at the optical layer [2].

Software defined optical network (SDON) decouples the application plane, data plane and control plane, and offers a centralized control of all networking elements via software programming through a controller [3]. The implementation of new allocation method based on SDON just needs to add the corresponding modules in the SDON controller, not affecting the current network and allocation method, which is an important solution to meet the intelligent request of the next-generation optical transport network and has a wide range of application prospects in 5G.

Now, the rapid growth of IP traffic has contributed to wide deployment of optical devices in EON [4]. However, the passband shape of wavelength selective switches (WSSs) which are used in reconfigurable optical add-drop multiplexer (ROADM)/optical cross connect (OXC) is not ideal, causing the narrowing of spectrum [5]. Spectral narrowing will lead to signal impairment. Therefore, guard-bands need to be inserted between adjacent paths. As shown in **Fig. 1**, there are five requests. Each request occupies three spectral slots and the guard-bands between adjacent requests occupies two spectral slots. The ratio

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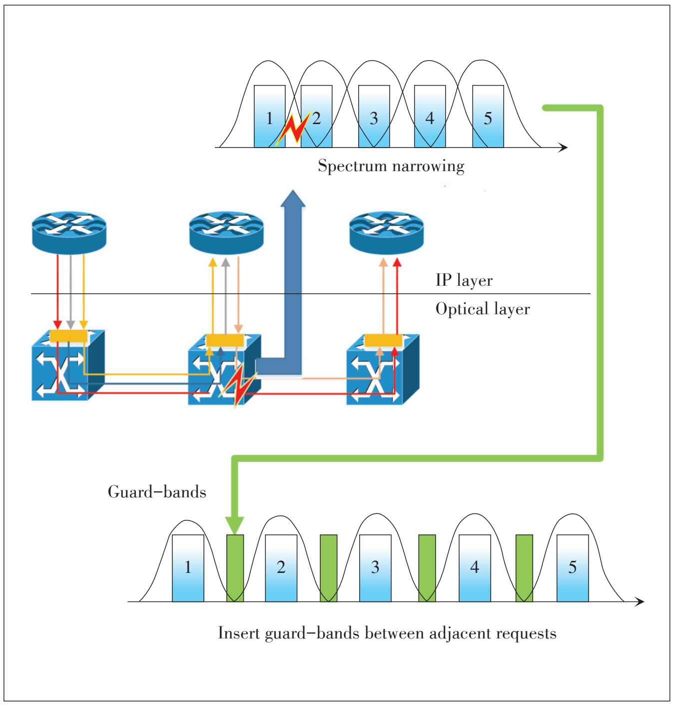


▲ **Figure 1. Spectrum narrowing may occur when adding/dropping optical paths.**

of the guard-bands bandwidth to the total bandwidth is $2 \times 4/(3 \times 5 + 2 \times 4) = 34.8\%$. When a large number of requests emerge in the network, it is inefficient to construct a light-path for each request [6], which needs to insert a lot of guard-bands and causes the waste of resources.

In order to meet the high-capacity requirements in 5G, it is necessary to save spectrum resources. An effective method is to reduce the insertion of guard-bands. In [7], the authors propose a traffic dispatching algorithm which chooses two aggregation nodes according to the topology with the largest degree. Then they make sure the requests which go through the aggregation nodes have the same routing and no guard-bands are inserted in the candidate path. When the services of a network are unevenly distributed, this method of aggregation node selection is unreasonable.

In this paper, we focus on a service-based intelligent time-domain and spectral-domain flow aggregation in IP-over-EON based on SDON. First, we propose a service-based intelligent aggregation node selection and area division (ANS-AD) algorithm based on big data analysis idea. Then, according to the result of the aggregation node selection and area division, we propose a time-domain and spectral-domain flow aggregation (TS-FA) algorithm based on SDON architecture. In order to obtain the most suitable number of aggregation nodes, we simulate the resource usage under different aggregation ratios (the number of aggregation nodes/the total number of nodes in the topology) and obtain the aggregation nodes under the minimum resource usage.

2 Service-Based Intelligent Aggregation Node Selection and Area Division Algorithm

2.1 Service-Based Intelligent Aggregation Node Selection Algorithm

With the development of big data, it has generated enormous publicity at home and abroad. Big Data Analytics (BDA) is at the heart of big data ideas and methods [8]. It refers to the analysis of a large variety of data with real content and the process of finding hidden patterns, unknown correlations and other useful information that can help decision-making.

Based on the idea of BDA, we propose a service-based intelligent aggregation node selection algorithm. The approach is to collect a huge amount of historical service information from the network and extract the path information of each service.

Suppose the set of historical services is

$$R = \{R_1, R_2, R_3 \dots R_i \dots R_M\}, \tag{1}$$

where M presents the number of historical services, while R_i is the ith service.

We represent the path node set of R_i as

$$Path_{Ri} = \{s_i, v_{i1}, v_{i2}, \dots v_{ij} \dots v_{im}, t_i\}, \tag{2}$$

where s_i is the source node of R_i, v_{ij} is the intermediate node of R_i, and t_i is the destination node of R_i.

Then we calculate the historical traffic of each node according to (3):

$$his\_tra_k = 2 \times \sum\nolimits_{j=1}^{M} num\_k\_intra + 1 \times \sum\nolimits_{j=1}^{M} num\_k\_s\,or\,d, \tag{3}$$

where if node k is the intermediate node of the jth path, $num\_k\_intra = 1$, otherwise $num\_k\_intra = 0$. If node k is the source or destination node of the jth path, $num\_k\_s\ or\ d = 1$, otherwise $num\_k\_s\ or\ d = 0$.

From (3) we can get each node's his_tra and sort the nodes in descending order of his_tra. We select the top ranked nodes as aggregation nodes. Suppose the aggregation node set is

$$V_{agg} = \{v_{1agg}, v_{2agg}, v_{3agg}, \dots, v_{iagg}, \dots, v_{kagg}\}, \tag{4}$$

where k indicates the number of aggregation nodes and v_{iagg} represents the aggregation node.

2.2 Area Division Algorithm Based on Aggregation Node Selection

After the aggregation node selection, we divide the topology into areas. The number of areas is equal to the number of aggregation nodes. The initial set of nodes for each area is represented as

$$area_1 = \{v_{1agg}\}, area_2 = \{v_{2agg}\}, \cdots, area_i = \{v_{iagg}\}, \dots,$$
$$area_k = \{v_{kagg}\}, \tag{5}$$

where $area_i$ represents the area.

Assume that the non-aggregation node set is

$$V_{non\_agg} = \{ v_{1non}, v_{2non}, v_{3non} \ldots, v_{jnon} \ldots, v_{N-Knon} \}, \tag{6}$$

where N is the number of nodes in the topology, K indicates the number of aggregation nodes, and v_{jnon} represents the jth non-aggregation node.

The distance from v_{jnon} to v_{iagg} is recorded as

$$len < path_{v_{jnon}, v_{iagg}} >, \tag{7}$$

where $path_{v_{jnon}, v_{iagg}}$ is the shortest path from v_{jnon} to v_{iagg}

The minimum distance from v_{jnon} to each aggregation node is calculated as

$$\min \left\{ len < path_{v_{jnon}, v_{1agg}} >, len < path_{v_{jnon}, v_{2agg}} >, \cdots, \right.$$
$$\left. len < path_{v_{jnon}, v_{Kagg}} > \right\}. \tag{8}$$

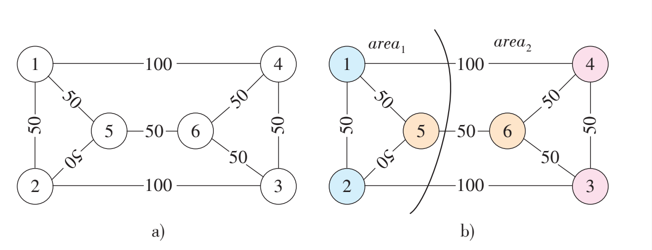
Then v_{jnon} is assigned to the same area as the aggregation node which corresponds to the minimum distance.

Until all nodes are partitioned, the area division ends. Then virtual direct links between the aggregation nodes are established. We use the shortest path algorithm to calculate the candidate path for any two aggregation nodes. For the optical links on the aggregation candidate paths, we allocate the spectral resources to the non-aggregation requests and the aggregation requests in a ratio of 2:1.

2.3 Illustrative Example

A topology is shown in **Fig. 2a**. For the convenience of explanation, we use five historical paths as shown in **Table 1** to calculate the historical traffic of each node. From (3), we calculate the his_tra of each node and get $his\_tra_1 = 2, his\_tra_2 = 3, his\_tra_3 = 1, his\_tra_4 = 1, his\_tra_5 = 5, his\_tra_6 = 4$, e.g., node 5 is the intermediate node of $Path_1$ and $Path_2$, and the source node of $Path_3$, so $his\_tra_5 = 2 \times (1 + 1) + 1 = 5$. Sort the nodes in descending order of his_tra and we get the node sorting set as $node\_sorting = \{5, 6, 2, 1, 3, 4\}$. We choose two nodes from $node\_sorting$ as aggregation nodes, then the aggregation node set is $V_{agg} = \{5, 6\}$ and the non-aggregation node set is $V_{non\_agg} = \{1, 2, 3, 4\}$.

As shown in **Fig. 2b**, we divide the topology into areas and get $area_1 = \{5, 1, 2\}, area_2 = \{6, 3, 4\}$, e.g., $len < path_{1,5} >= 50$, $len < parh_{1,6} >= 50 + 50 = 100$, $\min \{ len < path_{1,5} >, len < parh_{1,6} > \} = 50$ so node 1 and node 5 are divided into the same area. Suppose the number of the spectral slots of each optical link is 300, the first 200 spectral slots between node 5 and node 6 are used for non-aggregation requests, and the last 100 spectral slots are used for aggregation requests.



▲ Figure 2. a) Six-node topology; b) aggregation node selection and area division result.

▼Table 1. Historical path information

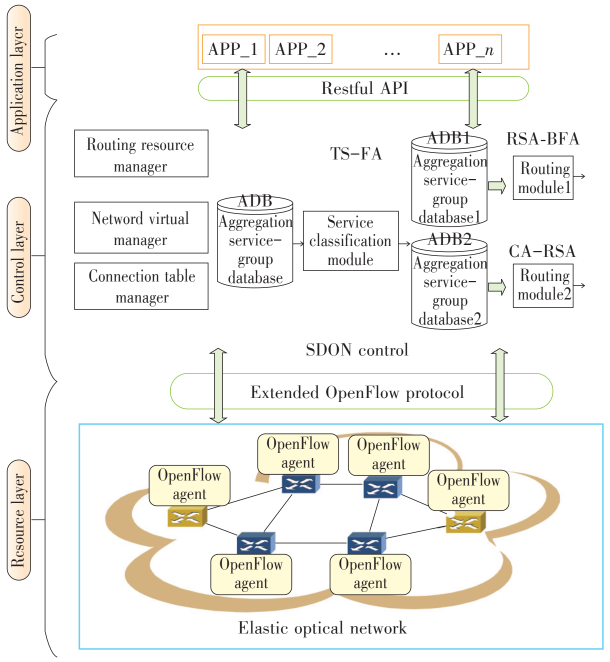
Path	Path node set
$Path_1$	{1,5,6}
$Path_2$	{2,5,6}
$Path_3$	{5,6}
$Path_4$	{1,2,3}
$Path_5$	{6,4}

3 Time-Domain and Spectral-Domain Flow Aggregation Module and Algorithm Based on SDON

3.1 Time-Domain and Spectral-Domain Flow Aggregation Module

Software defined network (SDN) is a new type of network architecture with forwarding control separation and software programming. SDON, the extension of SDN in optical network, offers a global view of network resources, enabling more optimized configuration strategy for the network [8]. SDON architecture mainly consists of resource layer, control layer, and application layer. The resource layer is composed of optical network resources, such as OXC, ROADM, and bandwidth-variable transponders (BVTs). Each optical device is logically connected with its own OpenFlow agent. The control layer is the core of the SDON architecture, responsible for programming the physical hardware at the resource layer based on the requests from the application layer. SDON controller is the logical entity that implements this function and it communicates with optical devices by the OpenFlow agent using the extended OpenFlow protocol. The application layer is composed of applications. An application can submit the network behavior requiring a request to the controller in a programmable manner via the restful application programming interface (API).

Based on the proposed ANS-AD algorithm, we design a TS-FA module on SDON architecture (**Fig. 3**). There are several submodules in the TS-FA module, including service classification module, routing and spectrum allocation (RSA-BFA) module and cross-area routing and spectrum allocation (CA-RSA) module. The implementation of these modules depends on the controller's unified management and control of traffic and the



ADB: aggregation service-group database
API: application programming interface
CA-RSA: cross-area routing and spectrum allocation
RSA-BFA: routing and spectrum allocation
SDON: software defined optical network
TS-FA: time-domain and spectral-domain flow aggregation

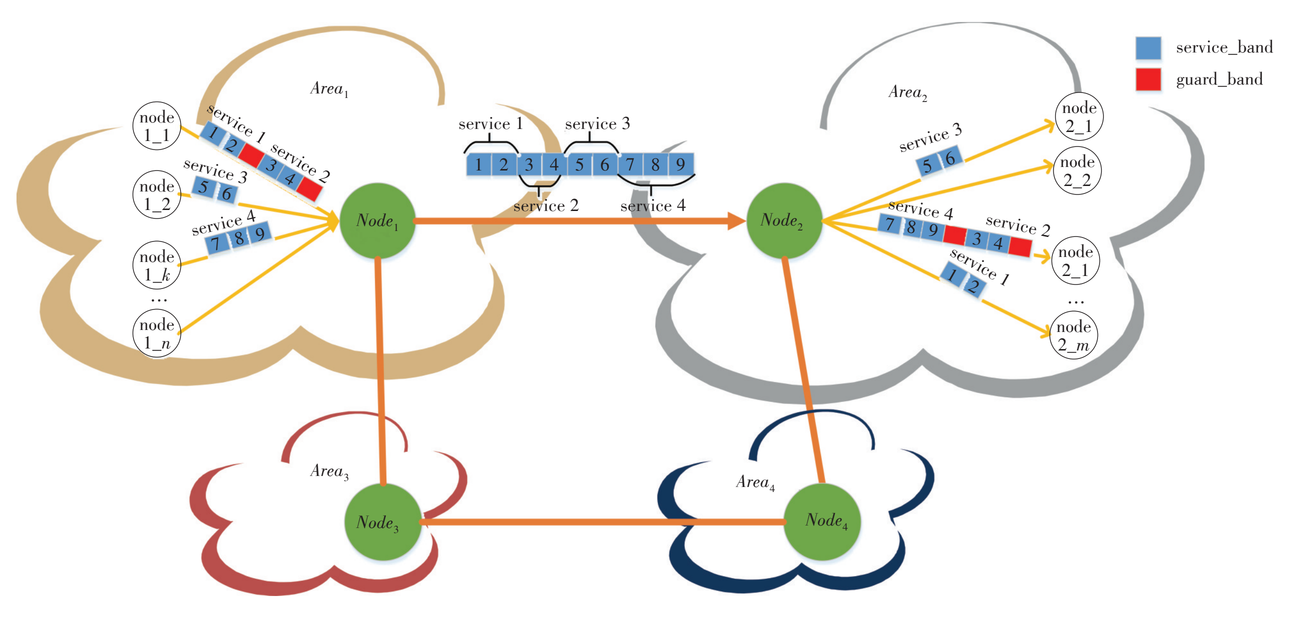
▲Figure 3. TS-FA module on SDON architecture.

flexibility of the underlying hardware [8]. The TS-FA module uses three databases to describe and store arrival requests, including aggregation service-group database (ADB), aggregation service-group database1 (ADB1), and aggregation service-group database2 (ADB2).

We set an aggregation time slot for time domain aggregation. ADB stores the arrival requests in a time slot. The service classification module classifies the requests in ADB, then stores them in the ADB1 and ADB2. The requests of the source node and destination node in the same area are stored in ADB1, the requests of the source node and destination node in different areas are stored in ADB2. The RSA-BFA module is responsible for the routing and spectrum allocation of the requests in ADB1. The CA-RSA module is responsible for the routing and spectrum allocation of the requests in ADB2.

3.2 Time-Domain and Spectral-Domain Flow Aggregation Algorithm

Based on the ANS-AD algorithm and the TS-FA module proposed above, we propose a TS-FA algorithm. The routing and spectrum allocation strategy used before flow aggregation is recorded as RSA-BFA algorithm. When the requests in a time slot arrive, classifying each request according to the request is the cross-area or same-area. Suppose a request in the time slot is $R_i(s_i,d_i,B_i)$, where s_i indicates the source node, d_i is the destination node and B_i represents the bandwidth of the request. If s_i and d_i are in the same area, $R_i(s_i,d_i,B_i)$ is a same-area request, otherwise $R_i(s_i,d_i,B_i)$ is a cross-area request. If $R_i(s_i,d_i,B_i)$ is a same-area request, it uses the RSA-BFA algorithm for routing and spectrum allocation. If it is a cross-area

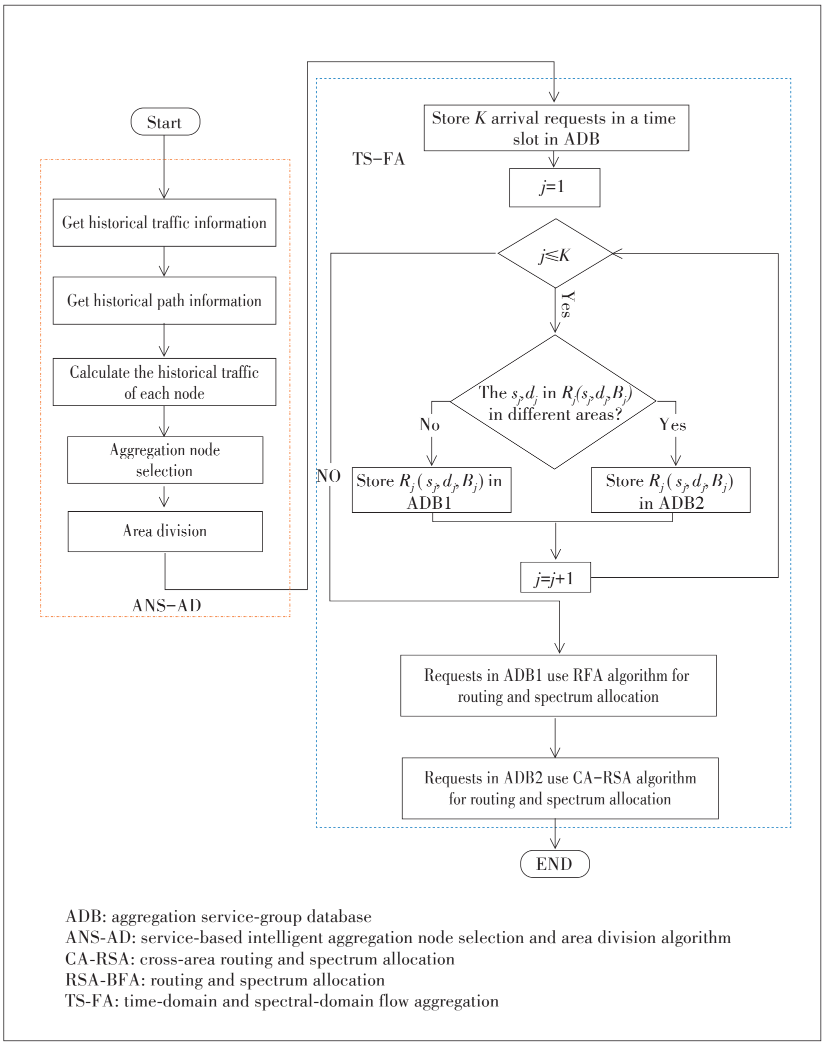


▲Figure 4. An illustrative example of the cross-area routing and spectrum allocation (CA-RSA) strategy.

request, it performs routing and spectrum allocation according to the CA-RSA strategy. We use the following example to describe the CA-RSA strategy.

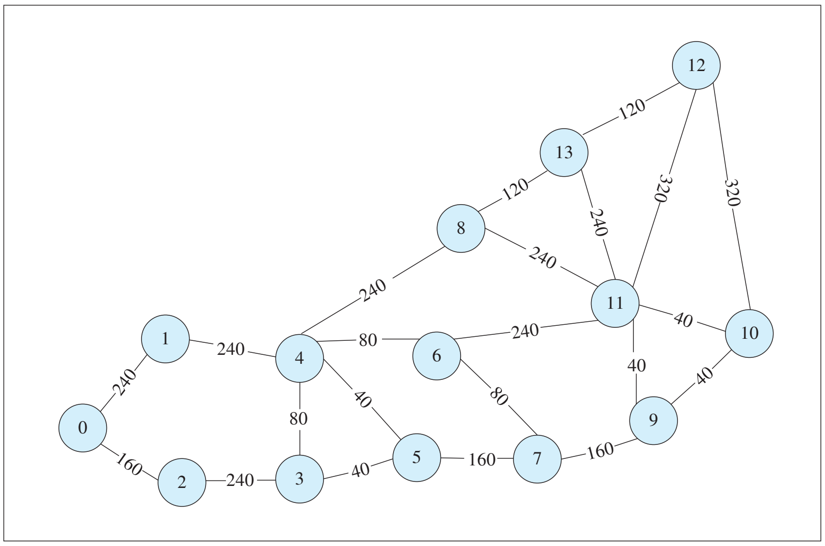
There are four requests from $area_1$ to $area_2$ in a time slot, n non-aggregation nodes in $area_1$ and m non-aggregation nodes in $area_2$ (**Fig. 4**). The aggregation node in $area_1$ is $Node_1$ and the aggregation node in $area_2$ is $Node_2$. $Node_1$ and $Node_2$ have the functions of aggregation and de-aggregation. All requests from $area_1$ to $area_2$ firstly go to $Node_1$ according to the RSA-BFA algorithm and aggregate together in $Node_1$. Then the aggregation flow is transmitted along the virtual direct link between $Node_1$ and $Node_2$. After that, the aggregation flow de-aggregates on $Node_2$ and the requests independently transmit to respective destination nodes according to the RSA-BFA algorithm with $Node_2$ as the source node. The guard-bands need to be inserted between adjacent paths in non-aggregation links. There is no need to insert guard-bands between adjacent paths in the virtual direct link. The collection of the requests in a time slot realizes the time-domain aggregation and the transmission of requests in the virtual direct link realizes the spectral-domain aggregation. **Fig. 5** shows the ANS-AD and TS-FA algorithms.

The introduction of the TS-FA solution requires adding the aggregation combiners/separators in aggregation nodes. The core of the network with ROADMs is kept unchanged thus offering a time-domain and spectral-domain flow aggregation of the requests. Moreover, the combination of time domain and spectral domain offers the finest possible granularity and thus flexibility in resource management. This ideally matches the requirement of high capacity [9].



ADB: aggregation service-group database
ANS-AD: service-based intelligent aggregation node selection and area division algorithm
CA-RSA: cross-area routing and spectrum allocation
RSA-BFA: routing and spectrum allocation
TS-FA: time-domain and spectral-domain flow aggregation

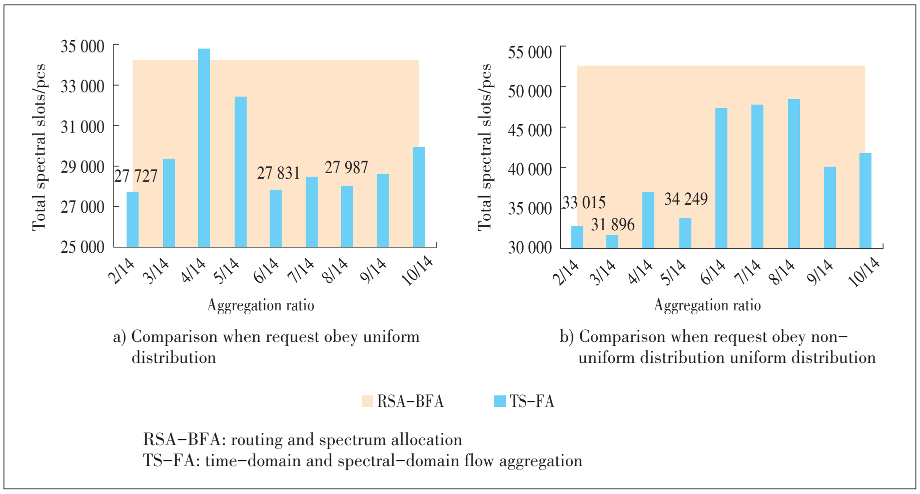
▲**Figure 5. The ANS-AD and TS-FA algorithms.**



▲**Figure 6. 14-node Japan topology.**

4 Performance Evaluation

In this section, we design a simulation to evaluate the performance of the ANS-AD algorithm and the TS-FA algorithm on the Japan topology (14 nodes and 22 links) as shown in **Fig. 6**. We set 750 spectral slots on each optical link. The bandwidth of each spectral slot is 12.5 G. The routing algorithm before flow aggregation is the shortest path algorithm and the spectrum allocation algorithm is First-Fit. The routing and spectrum allocation strategy used before flow aggregation is recorded as the RSA-BFA algorithm. Each request has a uniform distribution of spectral slots from 1 to 10. We generate 100 000 historical services for aggregation node selection. Then we generate arrival requests of twenty time slots for time-domain and spectral-domain flow aggregation and the number of requests in each time slot is uniformly distributed from 40 to 60. The service distribution for time-domain and spectral-domain flow aggregation is the same as the aggregation node selection and area division.

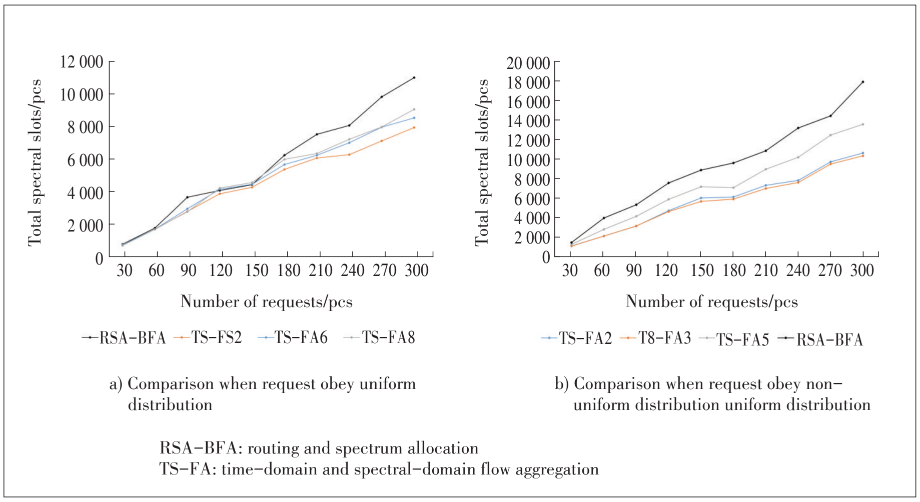


a) Comparison when request obey uniform distribution

b) Comparison when request obey non−uniform distribution uniform distribution

RSA−BFA: routing and spectrum allocation
TS−FA: time−domain and spectral−domain flow aggregation

▲ **Figure 7. Comparison of resource usage between TS−FA and RSA−BFA under different aggregation ratio.**



a) Comparison when request obey uniform distribution

b) Comparison when request obey non−uniform distribution uniform distribution

RSA−BFA: routing and spectrum allocation
TS−FA: time−domain and spectral−domain flow aggregation

▲ **Figure 8. Comparison of resource usage under different number of requests.**

We generate two service distributions to simulate the ANS-AD algorithm and the TS-FA algorithm. Then we calculate the total resource usage of the requests in 20 time slots under different aggregation ratio. Moreover, we compare the resource usage by the TS-FA algorithm with the RSA-BFA algorithm. The results are shown in **Fig. 7**. When the source node and the destination node of each request obey uniform distribution from 0 to *node_num*, where *node_num* refers to the number of nodes in the topology (**Fig. 7a**). It can be seen from Fig. 7a that the TS-FA algorithm uses less resources than the RSA-BFA algorithm except the aggregation ratio 4/14. We compare the TS-FA algorithm when the aggregation ratio is 2/14, 6/14, and 8/14 with the RSA-BFA algorithm by resource usage under different number of requests (**Fig. 8a**). The results show that the TS-FA algorithm obtains lower resource usage than the RSA-BFA algorithm. When the aggregation ratio is 2/14, the TS-FA algorithm uses the least resources.

When the source node of each request obeys uniform distribution from 0 to *node_num*/2 and the destination node of each request obeys uniform distribution from (*node_num*) /2 + 1 to *node_num*, the results are shown in **Fig. 7b**. It can be seen that the TS-FA algorithm uses less resources than the RSA-BFA algorithm under any aggregation ratios. We compare the TS-FA algorithm when the aggregation ratio is 2/14, 3/14, 5/14 with the RSA-BFA algorithm by resource usage under different number of requests as shown in **Fig. 8b**. The results show that the TS-FA algorithm obtains lower resource usage than the RSA-BFA algorithm. When the aggregation ratio is 3/14, the TS-FA algorithm uses the least resources.

From Fig. 7, we can also see that in the first service distribution when the aggregation ratio is 4/14, the TS-FA algorithm uses more resources than the RSA-BFA algorithm. The reason for this result is that some cross-area requests have to take more hops in the case of aggregation. At this service distribution and aggregation ratio, the bandwidth saved by aggregation is lower than the wasted bandwidth by more hops.

5 Conclusions

In this paper, we propose a service-based intelligent ANS-AD algorithm. Then, a TS-FA module and algorithm based on SDON are detailed. The algorithms attempt to reduce bandwidth waste and increase network capacity. The simulation results show that under different service distribution, the ANS-AD algorithm and TS-FA algorithm can effectively reduce the resource waste. Our proposed algorithms provide some ideas for service-based network deployment.

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