# Sort order scheme for assigning local traffic demands to spatial channel networks

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**SUMMARY** Spatial channel networks achieve both high resource utilization and cost efficiency by hierarchizing the conventional optical layer into a wavelength division multiplexing layer and a spatial division multiplexing layer with effective spatial bypassing and spectrum grooming. This paper examines the efficiency of assignment in "Local" classified demands routed with spectral grooming. The results show that assignment in descending order of bandwidth and distance is superior in terms of core resource utilization efficiency and cost, and that the advantage in this efficiency depends on whether bandwidth or distance is assigned first, depending on the total traffic load.

***keywords:*** *Spatial channel network, Spatial division multiplexing, Wavelength multiplexing, Multicore fiber, Core selective switch*

## 1. Introduction

Spatial division multiplexing (SDM) technology [1] has been studied to meet the ever-increasing data communications demand. Recently, a spatial channel network (SCN) architecture that employs multi-core fibers (MCFs) has been proposed [2], combining ultra-high capacity with economic efficiency [3, 4]. In an SCN, the current optical layer evolves into hierarchical wavelength division multiplexing (WDM) and SDM layers, while an optical node is decoupled into a spatial cross-connect (SXC) and a conventional wavelength cross-connect (WXC) to form a hierarchical optical cross-connect (HOXC). This enables end-to-end routing of high-capacity traffic using SXCs, while low-capacity traffic can be efficiently multiplexed into the SDM layer through spectral grooming in the WDM layer WXCs as required. In other words, a reduction in total node costs can be expected by introducing low-cost spatial switching in SXCs while maintaining high spectrum utilization efficiency with appropriately placed WXCs as required. A core selective switch (CSS) is then used to enable low-cost low-loss spatial switching. A CSS is a one-input MCF and N-output MCF device where an optical signal launched into any core in the input MCF can be switched to a core that has the same core identifier of any output MCF.

We previously conducted simulations to evaluate economically SCNs and showed that high resource utilization and cost-effectiveness are achieved when the total network traffic load is above 1 Pb/s [3,4]. In this paper, we report on the impact of the ordring method on the efficiency of the assignment of small "Local" classified traffic demands that are routed with spectral grooming at the WDM layer.

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## 2. HOXC Node Architecture and Devices

The node architecture used for verification is shown in Fig. 1. A CSS in the SXC allows switching of optical signals on a spatial basis, and signals switched to the Add/Drop block are processed by the WXC on a wavelength basis. The diagram on the left shows the grooming site where spectral grooming can be performed by the wavelength selective switch (WSS) in the WXC if required. For lower cost, non-grooming sites with no frequency-grooming functionality and only wavelength multiplexer (WMUX) functionality are mixed in the network, as shown on the right. Each unit model is shown in Fig. 2. Figure 2(a) shows a line-side CSS unit, which is equipped with CSSs that select whether optical signals entering a node are spatially bypassed on a core-by-core basis or added/dropped at that node. Figure 2(b) shows the Add/Drop CSS/CPS unit, which is equipped with the same number of CSSs as the node degree and the required number of core port selectors (CPSs), so there are no contention constraints, and the configuration is highly flexible in terms of core resource assignment. Here, the CPS has an input single mode fiber (SMF) and multiple output MCFs, with the function of connecting the core of the input SMF to the core of any output MCF. Figure 2(c) shows a WMUX unit for demands connected end-to-end by a MCF splitter (SPL) and a booster erbium doped fiber amplifier (EDFA). Finally, Fig. 2(d) shows an SDM-side WSS unit and Fig. 2(e) shows a multicast switch (MCS) unit. Both are for demands routed during spectrum grooming, with the former incorporating WSSs and booster EDFAs and the

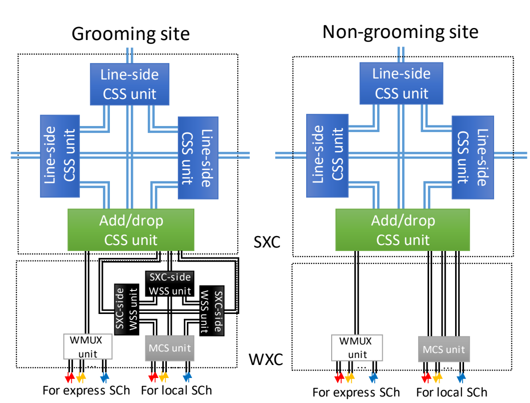


**Fig. 1** HOXC node architecture.

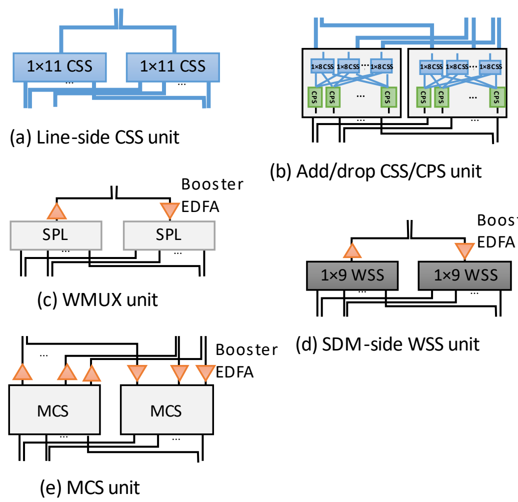


**Fig. 2** Unit models.

latter incorporating MCSs and booster EDFAs respectively.

## 3. Core and Spectrum Assignment Algorithm

We developed a heuristic algorithm [3,4] aiming to minimize the required number of cores for the most congested links in the network. The algorithm outputs the route and core- and spectrum-assignment for the media channels of the SDM and WDM layers, namely the spatial channel (SCh) and wavelength channel (WCh), respectively. At the same time, it determines the resources required to configure the network, including the number of cores required. The steps in the algorithm are described below:

(1) Select a limited number of nodes as Grooming Nodes.
(2) Calculate the k shortest paths.
(3) Using a bin-packing algorithm, a virtual frequency bin with the capacity of the C-band (96 frequency slot units (FSUs)) is filled with frequency slots with the same source/destination demand. Each demand is classified as an "Express demand," which is transmitted end-to-end over a dedicated express SCh if the filling rate of the frequency bin exceeds threshold value h. If the filling rate is less than h, the demand is classified as a "Local demand," which is transmitted over a local SCh with grooming in the WXC.
(4) Establish Express SChs and WChs to minimize the number of cores required among the k shortest paths obtained in (2) (Fig. 3(a)).
(5) Establish a local SCh so that the number of required cores is minimized among the k shortest routes obtained in (2). If there are several routes with equal number of cores required, select the SCh that reduces the total number of SChs. At the same time, WXCs are installed and WChs are established (Fig. 3(b)).

## 4. Local Demand Ordering Technique

As described in the previous section, each demand is divided into two categories: "Express demand" transmitted using an Express SCh or "Local demand" transmitted using a Local SCh. First, Express SChs are assigned to Express demands, which are connected end-to-end, so the core resource utilization efficiency does not change significantly depending on the demand ordering. On the other hand, for a Local demand, the way in which a Local SCh is established changes depending on the order of the demand to be allocated, and this has an impact on the core resource utilization efficiency. Therefore, this paper focuses on the Local demand ordering based on its bandwidth and the source-destination distance. Here, bandwidth corresponds to the number of FSUs allocated to the demand, and distance corresponds to the number of hops in the network.

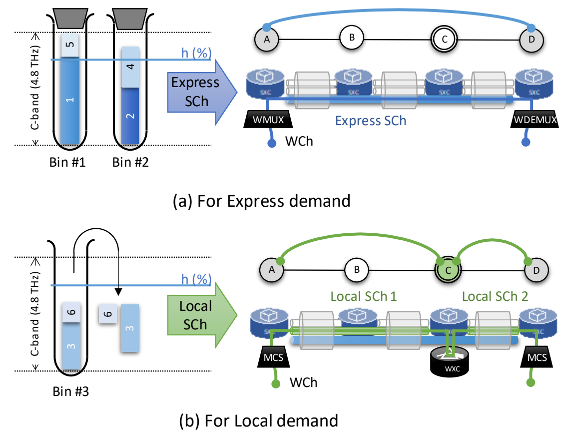


**Fig. 3** How to assign Local/Express demands.

**Table 1** Relative cost of each device.

| Device | 1x9 WSS | 1x11 CSS (2x19 CF/port) | 1x8 CSS (2x19 CF/port) | 1x4 CPS (2x19 CF/port) | WMUX (Booster EDFA) | MCS | Booster EDFA |
|---|---|---|---|---|---|---|---|
| Relative cost | 1 | 0.90 | 0.86 | 0.15 | 0.5 | 1.3 | 0.5 |

### 4.1 Ascending/Descending Order

First, we examine whether an ascending (*asc*) or descending (*desc*) ordering for the product of bandwidth and distance yields higher accommodation efficiency. Simulations were performed using network model NSF15 (15 nodes, 23 links, average node order 3.07, and maximum node order 4). The grooming nodes are set to be 40% [5] of the total nodes and frequency bin filling rate threshold h is set to 80% [3]. At this time, a static traffic model with a mixture of different bit rates is adopted, where the bit rate required by each demand is an integer multiple of the base bit rate, and the proportion of demand decreases with the bit rate [4]. Table 1 gives the relative cost of each device. For cost, it is assumed that CSSs with two bundled 19-CFs are used for each input/output port to accommodate traffic loads up to 4.8 Pb/s, supporting 38 cores per port [6, 7]. Correspondingly, the MCF ports of the 1×4 CPS are also configured with two bundled 19-CFs.

The required number of cores and total node cost are shown in Figs. 4 and 5. As a comparison to HOXC, the node architecture based on conventional technology referred to as a Stacked WXC, which comprises an SDM layer with a high WXC capacity, is also shown at the same time. The figures show that the *desc* order is superior in terms of the required number of cores and node cost, and that the difference in core resource utilization efficiency is significant at times of low traffic loads with many Local demands.

### 4.2. Bandwidth/Distance Priority

In the previous section, it was found that *desc* order is better than *asc* order for assignment. Next, we examine the impact of ordering demand starting from the highest bandwidth or longest distance on accommodation efficiency. The filling rate of the frequency bins for each traffic load is shown in Fig. 6. The frequency bin number is expressed on the horizontal axis, and the filling rate of each frequency bin is expressed on the vertical axis. Above the red line, the demand carried end-to-end is accommodated in an Express SCh, and below the red line, the demand carried by spectrum grooming with other demands is accommodated in a Local SCh. It can be seen that a certain number of Local demands are present even at high traffic loads, and that the tendency for frequency bins to become congested is different for each traffic load.

Here, examples of how it is better to assign based on the demand with the highest bandwidth and based on the demand with the longest distance are shown in Figs. 7 and 8, respectively. Assume there are multiple demands as given

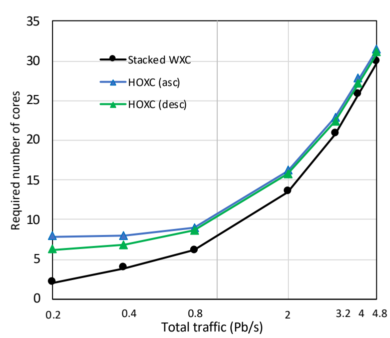


**Fig. 4** Required number of cores (Comparison of *asc* and *desc*).

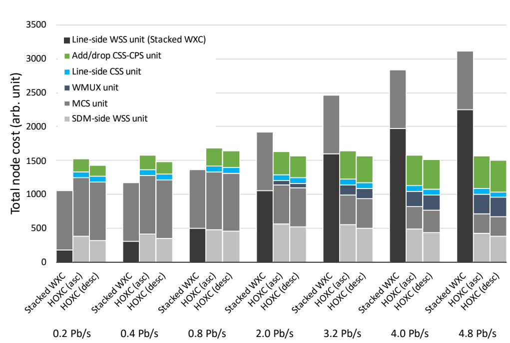


**Fig. 5** Total node cost (Comparison of *asc* and *desc*).

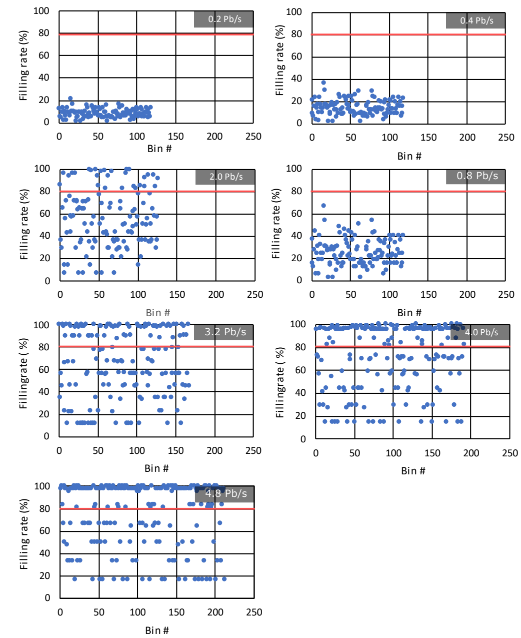


**Fig. 6** Filling rate of Bins.

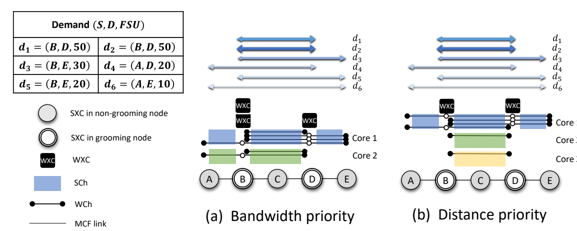


**Fig. 7** Example where bandwidth priority is superior.

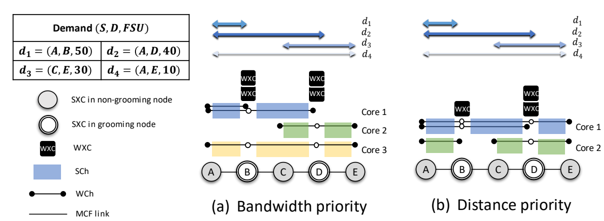


**Fig. 8** Example where distance priority is superior.

in the table. The numbers in brackets () represent (source, destination, number of FSUs required). First, in the case of Fig. 7(a), the FSUs are relatively neatly packed in each link and the number of required cores is 2. In contrast, in the case of Fig. 7(b), the demands with a narrow bandwidth are accommodated in the same core and the demands with a wide bandwidth are assigned later. This results in poor accommodation efficiency and an increase in the number of required cores to 3. Next, in Fig. 8(a), the demands with a wide bandwidth are assigned first even if the distance is short. This results in many SChs being established later to the demand with a narrow bandwidth, and the assignment is inefficient. In this case, the number of required cores is 3. In contrast, in Fig. 8(b), the multiple SChs initially established for the long-distance demands can be used for other demands, and the number of required cores is reduced to 2. Based on the above, the following predictions were made and tested.

- When there are many fine-grained local demands at low traffic loads, it may be better to assign demand with a wide bandwidth first, because prioritizing bandwidth over distance makes it easier for FSUs to cluster neatly in each link.
- When the local demands during high traffic load are relatively few and SCh deployment is important, it may be better to prioritize distance over bandwidth for efficient core assignment. It may also be better to assign demands accordingly with longer distances first.

We performed a simulation under the same conditions as described in Section 4.1. Comparisons were also made with the results of the *desc* order of $FSUs \times hops$ presented in the previous section.

Figure 9 shows a comparison of the required number of cores when Local demands are assigned based on the demands with the largest number of required FSUs and based on the demands with the largest number of Hops. The blue plots represent the results of assignment based on the demands with the highest number of required FSUs, orange plots represent the results based on the demand with the highest number of Hops, and green plots represent the results based on the demand with the highest $FSUs \times hops$. Although the differences are not pronounced, it is confirmed that, regarding accommodation efficiency, bandwidth priority is better under low traffic conditions, while distance priority is better under medium traffic conditions. Although the differences are not pronounced, it is confirmed that, regarding accommodation efficiency, bandwidth priority is better under low traffic conditions, while distance priority is better under medium traffic conditions. This is thought to be because under low traffic conditions, there are many small demands and the FSUs tend to cluster neatly in each link. As the traffic load increases, each demand becomes larger, so the way of establishing SChs becomes more important. However, little difference is observed at high traffic loads. It is considered that at high traffic loads, there are few demands with a narrow bandwidth and long distances, so there was no difference in core resource utilization efficiency. Figure 10 shows the costs for each ordering technique. There appears to be little difference in cost between the different Local demand ordering methods, but at medium traffic loads of 0.8 Pb/s and 2.0 Pb/s, the lower cost for assigning based on demands that have the largest number of Hops is noticeable. It can be said that the effect of improved accommodation efficiency at these traffic loads can be seen in the cost. In addition, the graphs for $FSUs \times hops$ and bandwidth are almost identical. This might mean that the FSU value is dominant in the multiplication.

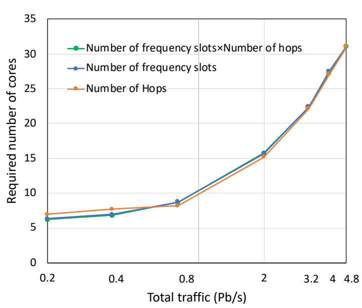


**Fig. 9** Required number of cores (Comparison of FSU and hop).

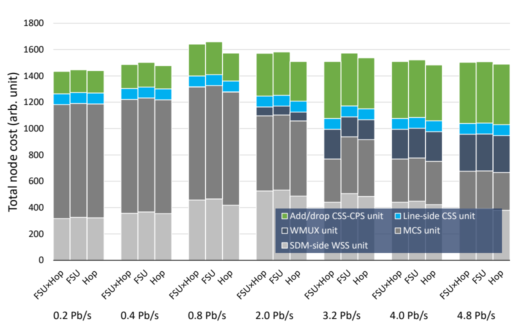


**Fig. 10** Total node cost (Comparison of FSU and hop).

## 5. Conclusion

The simulation verification results revealed the following regarding the Local demand ordering.

(1) When comparing the *desc* and asc order of the product of the number of FSUs and hops, the *desc* order is superior in both capacity efficiency and node cost.

(2) For each traffic load, the superiority of the Bandwidth priority and Distance priority varies.

We will investigate a more efficient method for ordering Local demand considering the number and size of Local demands.

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