# Impact of Operational Mode Selection and Grooming Policies on Auxiliary Graph-Based Multi-layer Network Planning

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***Abstract*** *We propose a multi-layer path planning method that simultaneously applies a operational mode selection policy and grooming policy in auxiliary graphs. We quantitatively evaluated the impact of these two policies on multi-layer network planning performance.*

## Introduction

Digital coherent optical transmission technology undergoing continuous research and development to meet the future demands of greater capacity and full support of service diversification. In particular, the recent 400 G / 1 Tbit/s class digital coherent transceiver allows a large number of operational modes to be selected[1]. Figure 1 shows the example operational modes. By flexibly selecting the operational mode, defined by parameters such as modulation scheme, symbol rate, and number of carriers, it is possible to more effectively utilize the frequency resources of the optical path by flexibly meeting the different distance and bit rate demands.

In the field of optical networking, research on elastic optical networks using innovations in transmission technology has been considered for more than a decade, and path planning methods for multi-level modulation and new transceiver architectures have been studied[2],[3]. Most of the previous elastic optical path planning methods select either the modulation scheme with the highest modulation level that can satisfy the path demand between two geographic locations[2], or setting the number of sub-carriers in the transceiver corresponding to the bit rate demanded[4],[5]. Both of these approaches were able to uniquely select the optimal operational mode.

But on the other hand, in a multi-layer network, where lower-rate path demands in a higher layer (e.g., packet layer) are accommodated into higher-rate paths in a lower layer (e.g. optical layer) by traffic grooming, it is not always optimal to choose the operational mode with high spectral utilization efficiency unlike the case in the single-layer elastic optical network described above. This is because if the symbol rate is min-

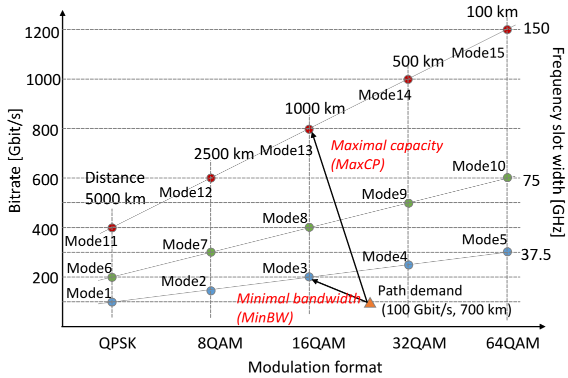


**Fig. 1:** Operational modes

imized to match the path demand, the opportunity to use later path demands to groom the optical path may be lost. To the best of our knowledge, there have been no proposals or evaluations for multi-layer path planning methods in such an environment with a large number of operational modes.

In this paper, we propose a heuristic multi-layer path planning method where path demands are accommodated in sequential order. We also quantitatively evaluate the impact of joint consideration of grooming policies operational mode selection policies on multi-layer network planning.

## Joint planning method of traffic grooming and operational mode

The proposed method combines heuristic traffic grooming based on auxiliary graphs, with a operational mode selection policy. It outputs the path, frequency, and operational mode of the new path to be set up and the path to be groomed in response to the input of optical path demands, given the network topology and operational mode candidates.

First, when an optical path demand arrives, two auxiliary graphs are created (Fig. 2). The first graph, called the assigned path graph (APG), consists of optical paths that have already been allocated and are candidates for grooming; optical paths that do not have sufficient capacity to support grooming by the new optical path demand are excluded from the assigned path graph. The second graph, called the candidate path graph (CPG), identifies the candidates for setting up new optical paths. Initially, the CPG is just a full mesh graph of all nodes.

The next step is to select an operational mode for each edge in the CPG. In this paper, we propose two operational mode selection policies: Minimal Bandwidth (MinBW) selects the operational mode with the smallest frequency band among those that satisfy the path demand in terms of bit rate and transmission distance for the edge. This policy prioritizes frequency optimization for a given path demand over grooming for future path demands. Maximal Capacity (MaxCP) selects the operational mode with the largest path capacity among the operational modes with the bit rate that can accommodate the path demand where the transmission distance is greater than edge length. Contrary to MinBW, this policy aims to groom the future path demand as much as possible. Figure 1 shows the 15 operational modes (Mode 1-15) assumed in this paper and their modulation formats, bit rates, transmission distances, and frequency slots. For example, for a path demand of 100 Gbit/s and 700 km, MinBW selects Mode 3, while MaxCP selects Mode 13. If there is an edge with no selectable operational mode for a certain path demand, the path demand is handled by inverse multiplexing of multiple optical paths using the operational modes that can transmit that edge.

Next, we set the weights for each edge of APG and CPG. This grooming policy is based on[5]. Maximal Electric Grooming (MEG) minimizes the number of newly configured optical paths. Minimal number of Virtual Hops (MVH) is the policy that minimizes the total number of optical paths traversed, and Minimal number of Physical Hops (MPH) is the policy that minimizes the total number of hops traversed in the physical topology. The edge weights are determined by a constant term and a term proportional to the physical hop count, H. Table 1 shows the edge weights for each policy.

Finally, we make an auxiliary graph by combining APG and CPG, and find the k-shortest path with the minimum weight in the auxiliary graph. The path is decomposed into edges, and

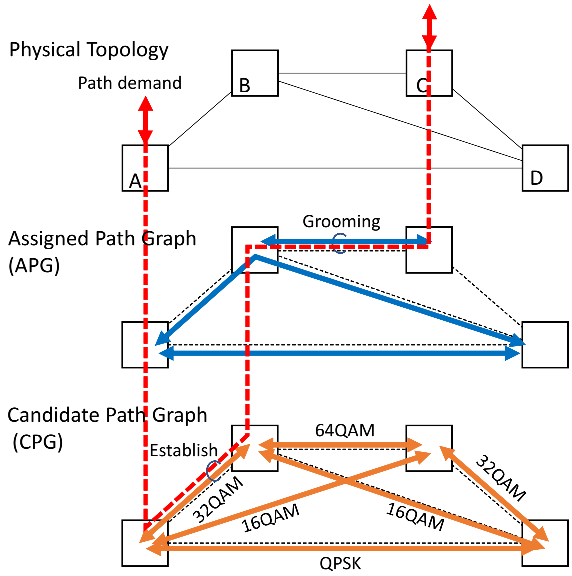


**Fig. 2:** Auxiliary graphs and path assignment example

if the edges originate from APGs, grooming is performed. If the edges originate from CPGs, the first-fit algorithm is used to select the frequency with the lowest available frequency slot number. In this way, we have achieved multi-layer path planning that takes into account both traffic grooming and operational mode selection.

**Tab. 1:** Grooming policy

| Policy | APG edge | CPG edge |
|---|---|---|
| MEG | 0.01 + 0.01 * H | 1 + 1 * H |
| MVH | 1 + 0.01 * H | 1 + 0.01 * H |
| MPH | 0.01 + 1 * H | 0.01 + 1 * H |

## Simulation results

We evaluated the impact of the grooming policy and the operational mode selection policy on the performance of multi-layer path planning for two topologies, COST266 and JPN25, where the available frequency slots for one optical fiber between the nodes are 12.5 GHz/slot * 320 slots. The path demand is distributed from 100 Gbit/s to 1200 Gbit/s in 100 Gbit/s increments with bit rates of 12:11:...:2:1. Multi-layer path planning was carried out based on the available operational modes shown in Fig. 1 and the grooming policy shown in Tab. 1. A total of six combinations of two operational mode selection policies (MinBW and MaxCP) and three grooming policies (MEG, MVH, and MPH) were compared and evaluated.

For COST266 and JPN25, the sequentially generated path demands are accommodated sequentially, and the number of path demands before blocking occurs for the first time is shown in Figure 3. These figures are presented in the form

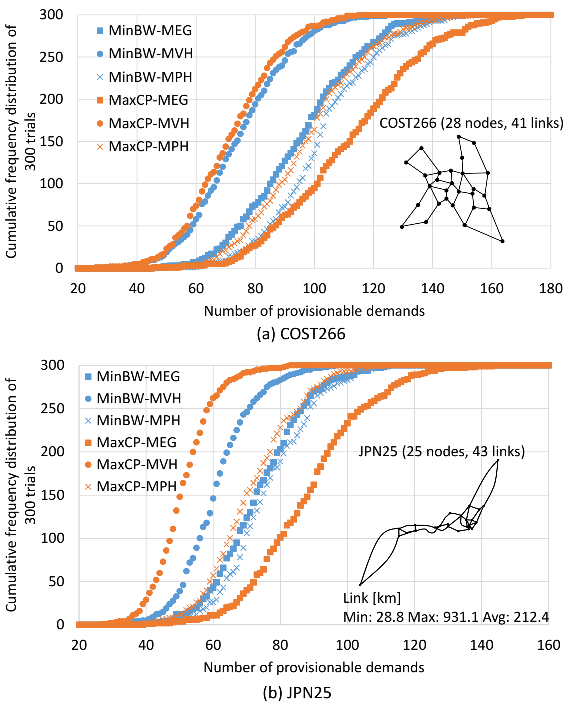


**Fig. 3:** Cumulative frequency distribution for the number of provisionable paths

of cumulative distributions for 300 trials. Table 2 also shows for COST266 the information that represents the characteristics of the multi-layer paths configured for path demand in each policy.

The number of paths that can be accommodated is roughly the same for both topologies, with MaxCP-MEG being able to accommodate the largest number of paths. This is due to the fact that the operational mode selection policy of MaxCP, which prioritizes high-capacity and short-distance operational modes, fits well with the grooming policy of MEG, and more paths can be accommodated by maximizing the grooming opportunities. This is because MaxCP's operational mode selection policy is well matched with MEG's grooming policy. This is supported by the fact that the number of optical paths groomed per MaxCP-MEG path demand is the largest in Tab. 2, which results in a smaller number of newly configured paths. On the other hand, for MVH and MPH, it can be seen that MinBW, which chooses the operational mode that uses as few frequencies as possible with as little grooming as possible, is able to accommodate greater path demand. Table 2 shows that MVH has the smallest number of newly configured optical paths and MPH has the smallest number of physical hops traversed. These policies are likely to be more effective under conditions of delay and grooming constraints.

Finally, the distribution of the operational

**Tab. 2:** Averaged multi-layer path properties per demand (COST 266)

| Policy | Established paths | Grooming paths | Physical hops |
|---|---|---|---|
| MinBV-MEG | 2.84 | 0.73 | 5.65 |
| MinBV-MVH | 2.74 | 0.05 | 5.76 |
| MinBV-MPH | 3.13 | 0.09 | 5.13 |
| MaxCP-MEG | 2.39 | 1.47 | 5.25 |
| MaxCP-MVH | 2.26 | 0.15 | 5.06 |
| MaxCP-MPH | 2.83 | 0.28 | 4.44 |

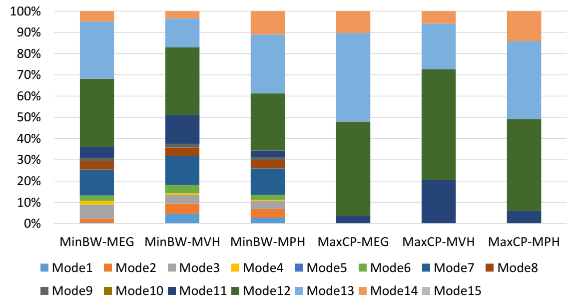


**Fig. 4:** Operational mode usage distribution (COST 266). Mode numbers follow the nomenclature of Fig. 1

modes used in each policy is shown in Fig. 4. In both policies, Modes 13 and 14, which are suitable for metro and long-haul distances, are used mostly frequently. It can also be seen that MinBW policy uses modes with small bandwidth, while MaxCP policy uses only the modes with the highest capacity at each transmission distance.

## Conclusions

We proposed a multi-layer path planning method that integrates an operational mode selection policy and a grooming policy with many operational modes in the optical layer. In terms of the number of paths that can be accommodated, we confirmed that the policy of allowing more paths to be groomed in the larger capacity operational mode is most effective.

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