From Coarse Grid to Mini-Grid to Gridless: How Much can Gridless Help Contentionless?

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Abstract: We study the benefit of gridless wavelength assignment. An efficient spectrum assignment algorithm is developed. It is found a mini-grid case with a certain grid granularity performs almost the same as the full gridless case.

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1. Introduction

The traditional optical transport networks strictly follow the ITU-T wavelength grids and spacing. Nonetheless, the standard ITU-T grids are coarse, which leads to low optical spectrum utilization. On the other hand, end-to-end traffic demands between node pairs are variable and time-dependent. The traditional optical transport networks often set up a lightpath with over-provisioned spectrum. To better utilize optical spectrum resources, recently some concepts and techniques [1] that do not need an optical transport network to strictly follow ITU-T wavelength grids, but flexibly assign wavelength spectrum for each lightpath have been proposed and investigated. An ideal situation is that we can assign wavelengths and optical spectrum in a *gridless* fashion [4]. To enable such flexibility, several key optical components and subsystems are needed, including tunable laser sources, wavelength selecting switches (WSSs) [5] with tunable central wavelength and passband, and so on. In addition, optical transmission techniques with variable bandwidth allocation on a wavelength are necessary. It has been found that CO-OFDM-based optical transmission technique [6] is promising to realize flexible wavelength and optical spectrum assignment.

In this paper, in the context of a CO-OFDM-based optical network [1][7], we evaluate how flexible wavelength and spectrum assignment can help lightpath service provisioning. Specifically, in terms of lightpath blocking probability (i.e., spectrum contention), we compare three cases, including (i) traditional coarse ITU-T wavelength grid and spacing, (ii) mini-grid, and (iii) an extreme case—gridless. Though “gridless” is the most flexible case, it is important to evaluate the mini-grid case that lies between the cases of coarse wavelength grid and gridless. This is because today most of optical components cannot really achieve fully gridless tunability. For example, a typical tunable laser (deployed in an optical transport network) can achieve a 0.01-nm tuning resolution and a WSS can have a passband with a several-GHz resolution [5]. It is interesting to find under what kind of mini-grid (correspondingly, what kind of hardware tuning resolution) the benefit of gridless can be fully exploited. Though there is much discussion on *gridless* and *contentionless* for the next-generation ROADMs [3], to the best of our knowledge this is the first study that evaluates how the wavelength grid granularity affects network service provisioning in the aspect of *contentionless*.

2. CO-OFDM-based optical transport networks

This study is based on a CO-OFDM-based optical transport network [1][7] owing to its promising features of flexible wavelength and optical spectrum assignment. Nonetheless, the study is also valid for the other types of networks that can achieve similar wavelength and spectrum assignment flexibility. The CO-OFDM-based optical networks [6] have following unique features compared to the traditional ITU-T grid-based networks. First, the coherent detection technique enables optical carrier frequency to be *gridless*. By properly tuning a local coherent detection oscillator at a receiver side, we can almost continuously demodulate an optical carrier at any frequency. Second, by changing the number of carried OFDM subcarriers and the modulation format on each of the subcarriers [6], the optical OFDM technique is flexible in allocating signal spectrum and data rate. In [7], we have described the architecture of a CO-OFDM-based optical network. The CO-OFDM transmission technique and coherent-detection-based ROADM are also briefed. Here we do not repeat the descriptions due to the page limit.

3. Concepts of ITU-T grid, mini-grid and gridless

Fig. 1 shows three wavelength grid or spacing cases, namely (a) ITU-T standard grid, (b) mini-grid, and (c) gridless. The ITU-T grid has uniform wavelength spacing between neighboring channels. For dense wavelength division multiplexing (DWDM), typical wavelength spacing ranges from 200 GHz, 100 GHz, 50 GHz, to 25 GHz. For example, in Fig. 1(a), the wavelength spacing is 50 GHz. Under the strict ITU-T grids, the wavelengths of any lightpaths must be on the grid wavelengths. Moreover, each lightpath is allocated with fixed optical spectrum (due to fixed grids) no matter how much bandwidth is required on the lightpath. For example, in Fig. 1(a), though the bandwidth or occupied optical spectrum by the first two wavelengths is smaller than the spectrum (50 GHz) between neighboring wavelengths, the 50-GHZ spectrums are dedicated to the traffic demands on the two wavelengths. In contrast, the gridless case as shown in Fig. 1(c) is another extreme case to arbitrarily assign wavelength and optical spectrum for each lightpath. For the same first two lightpaths, we can move their central optical carriers closer as no strict ITU-T grids and wavelength spacing should be obeyed. Also, we can assign *just-enough* optical spectrum for each lightpath. It is the most spectrum-efficient if we move two neighboring optical carriers close enough to just accommodate the bandwidth required by the two lightpaths plus the required optical guard-band between two wavelengths. By comparing cases (a) and (c), it is clear to see that the latter requires less optical spectrum than the former. Thus, the gridless wavelength assignment is advantageous of more efficient optical spectrum usage.

The mini-grid case as shown in Fig. 1(b) is an intermediate case between cases (a) and (c). Rather than the most strict (coarse) or the most arbitrary, the mini-grid case requires the wavelength of each lightpath to still follow a certain set of discrete fixed frequencies. Different from the standard grids, the mini-grids have much smaller frequency granularity, also called *grid granularity*. In addition, it allows a lightpath spectrum to span multiple mini-grids when there is a high bandwidth requirement on the lightpath. As shown in Fig. 1(b), the third lightpath has a large spectrum to cross three mini-grids. It is meaningful to bring in the mini-grid (intermediate) case due to the limited tuning capability of optical components. Key components such as tunable transmitters and WSSs/WBs have limited tuning resolutions; we cannot arbitrarily or really continuously tune their wavelengths. Finally, the mini-grid case can be considered the most general case to model the other two. The ITU-T grid case can be considered a special mini-grid case with 50-GHz wavelength spacing and the gridless case can be considered a special mini-grid case with arbitrarily small wavelength spacing and an infinite number of grid frequencies.

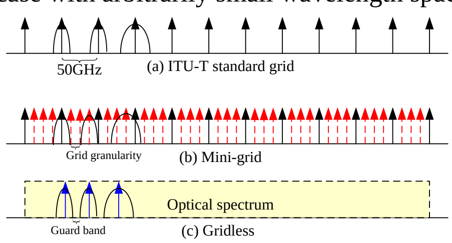

Fig. 1: Cases of ITU-T grid, mini-grid, and gridless.

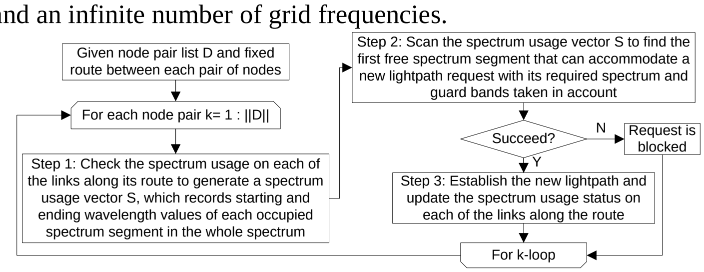

Fig. 2: Flowchart of central wavelength and optical spectrum assignments.

4. Lightpath routing and wavelength assignments

This section introduces lightpath routing and wavelength assignment algorithms for the three different grid cases. For the standard ITU-T case, there have been many lightpath routing and wavelength assignment algorithms in the literature [8]. For example, it can be fixed lightpath routing plus random wavelength assignment; it can also be adaptive lightpath routing plus first-fit wavelength assignment. Without losing generality, in this study we adopt the fixed shortest lightpath routing and first-fit wavelength assignment strategy for the standard ITU-T grid case.

For fair performance comparison, we also employ the fixed shortest path routing algorithm for the other two cases in their lightpath routing. For their wavelength assignments, we need to consider two aspects, namely (i) central wavelength assignment and (ii) optical spectrum assignment for each lightpath. Such a process is different from the traditional wavelength assignment under the standard ITU-T grid case. Specifically, for the mini-grid case, two constraints should be obeyed. First, an assigned central wavelength must be one of the mini-grids; second, when assigning wavelengths and spectrum of two spectrally neighboring lightpaths, in addition to the required optical spectrums by the two lightpaths, we need to reserve a certain amount of spectrum as an optical guard-band. In contrast, under the gridless case, the constraint of "central wavelength being on one of the mini-grids" is not necessary, but we should most efficiently select a central wavelength and assign lightpath spectrum.

For the mini-grid and gridless cases, we have developed a heuristic (as shown by the flowchart in Fig. 2). Specifically, for each node pair that has been found with a fixed shortest path, Step 1 generates spectrum usage for the lightpath by merging the spectrum usage on each of the enrouted fiber links. Here no wavelength conversion is considered. Thus, the spectrum that is used on any enrouted fiber link is considered used on the lightpath, which is essentially an "OR" operation for the spectrum usage on all the enrouted fiber links. Fig. 3 shows an example of merging spectrum usage on a two-link lightpath, which is a result of an OR operation of the spectrum usage of links 1 and 2. Based on the lightpath spectrum usage status, Step 2 selects the first free spectrum segment that can accommodate the current lightpath request. The free spectrum segment should be wide enough to support the spectrums required by the lightpath and the inter-channel guard-bands. Particularly, for the mini-grid case, when selecting a suitable free spectrum segment, we also need to ensure that the assigned central wavelength must be on one of the mini-grids. If such an eligible free spectrum segment can be found, Step 3 establishes a new lightpath and updates the spectrum usage on the enrouted fiber links; otherwise, blocks the request.

5. Simulations and performance analyses

To evaluate the performance of the proposed wavelength and spectrum assignment approach, we conducted simulations under the widely-used 14-node and 21-link NSFNET network. Under the ITU-T standard grid, we assume there are 40 wavelengths with 50-GHz wavelength spacing on each fiber link, which corresponds to a total 2000-GHz continuous optical spectrum for the mini-grid and gridless cases. The shortest path routing algorithm is applied to find a route for each node pair. The first-fit wavelength assignment algorithm [8] is applied for the wavelength assignment of the standard ITU-T grid case. The algorithm shown in Fig. 2 is applied for the wavelength assignments of the mini-grid and gridless cases. The optical guard-band between neighboring optical channels is set to be 5 GHz. We consider dynamic traffic demand to assume that the service arrival on each node pair follows a Poisson distribution and the served lightpath holding time takes a negative exponential distribution. The Erlang traffic load on each node pair is assumed to be the same, ranged from 1.0 Erlang to 2.0 Erlang. A total of 10^6 lightpath arrival events are simulated. We evaluate blocking performance for the three grid cases. Specifically, we consider *lightpath blocking probability*, which is a ratio of total blocked lightpath requests over total arrived lightpath requests. We also consider *lightpath spectrum blocking percentage*, which is a ratio of total blocked spectrum over total requested spectrum.

Figs. 4 and 5 show the blocking performance in terms of blocking probability and spectrum blocking percentage, respectively. It can be found that with the decrease of wavelength spacing or grid granularity (from standard ITU-T 100 GHz to mini-grid 3 GHz to gridless), the blocking performance becomes better to show a lower blocking probability and spectrum blocking percentage. Another interesting observation is a performance saturation phenomenon—when wavelength spacing decreases to a certain level (here 3 GHz), the overall blocking performance of the mini-grid case is almost the same as that of the gridless case. It seems not necessary to *over*-enhancing the tuning resolutions of optical components, as almost no performance improvement can be exploited when tuning resolution reduces from 3 GHz to infinitely small. Such a result is very meaningful since the current optical components do not allow us to tune them in a real gridless fashion. Rather, they are subject to certain tuning resolutions, which are the limit that the proposed wavelength and spectrum assignment schemes can achieve. Viewing the fact that typical tunable lasers deployed in a network can achieve a tuning resolution at a 1-GHz level, we find an optical transport network based on today's optical components can fully achieve gridless performance.

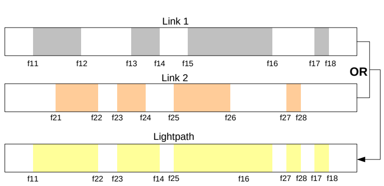

Fig. 3: Lightpath optical spectrum usage.

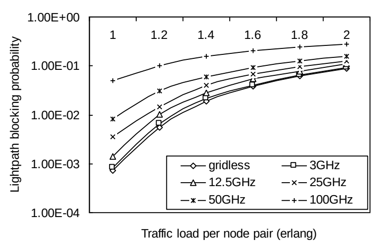

Fig. 4: Lightpath request blocking probability.

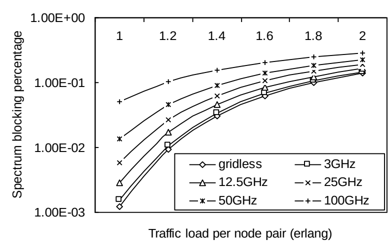

Fig. 5: Lightpath spectrum blocking percentage.

6. Conclusion

It is widely expected that gridless can help reduce spectrum contention in lightpath routing and wavelength assignment [3]. This study explores how much benefits can be achieved if an optical transport network is ideally operated under a gridless manner. Meanwhile, viewing the fact that many tunable optical components have limited tuning resolutions, we also studied the mini-grid case to find how the tuning resolution can affect the performance. A new wavelength and optical spectrum assignment algorithm was developed for the wavelength and spectrum assignments under the gridless and min-grid cases. The simulation studies indicated that the gridless and mini-grid-based wavelength and spectrum assignment perform much better than the conventional ITU-T grid case. Moreover, the mini-grid case with a certain grid granularity (e.g., 3 GHz) can achieve a performance close to that of the gridless case, which implies that to take full advantage of gridless wavelength assignment, optical components (e.g., transmitters and WSS) with certain *fine* tuning resolutions are sufficient.

[1] W. Wei, C. Wang, J. Yu, N. Cvijetic, and T. Wang, "Optical Orthogonal … Future Internet" J. Opt. Commu. Netw. vol. 1, no. July 2009.
[2] M. Jinno, *et. al*., "Spectrum-Efficient and Scalable Elastic Optical Path Network…," IEEE Com. Mag., Nov. 2009, pp. 66-73.
[3] W. Zheng, Y. Jin, W. Sun, W. Guo, and W. Hu , "On the Spectrum-Efficiency … Optical OFDM Transport Networks," *OFC/NFOEC*, 2010.
[4] OFC/NFOEC: For ROADMs, Less Is More [online]: http://www.lightreading.com/document.asp?doc_id=189733
[5] ROADMs Get Ready to Go Off-Grid [online]: http://www.lightreading.com/document.asp?doc_id=196627&site=roadm&
[6] W. Shieh, X. Yi, Y. Ma, and Q. Yang, "Coherent optical OFDM: has its time come? [Invited]," J. Opt. Netw., no. 7, pp. 234-255, 2008.
[7] G. Shen and Q. Yang, "Maximizing time-dependent spectrum sharing … in CO-OFDM optical networks," submitted to OFC/NFOEC 2011.
[8] H. Zang, J. P. Jue, and B. Mukherjee, "A Review of Routing and Wavelength Assignment…," Opti. Netw. Mag., Jan. 2000, pp. 47-60.