On the Benefits of Differentiating the Filter Configurations in Flexi-grid Optical Networks

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Abstract *An effective strategy exploiting differentiated filter configurations in flexi-grid optical networks is proposed and evaluated. Results show that 15% throughput improvements can be achieved with respect to traditional flexi-grid approaches*

Introduction

Flexi-grid technology has been recently introduced to increase the overall spectrum efficiency[1]. However, the optical filters enabling flexi-grid present non-ideal shapes[2]. This induces detrimental filtering cascade effects on traversed optical signals, thus limiting the overall transmission performance[3]. To avoid these filtering effects, a larger amount of spectrum resources is then typically reserved[4]. This way, the transmitted signals can avoid the transition region of the filters and they can safely operate on filter flat central regions. However, this typically implies a less efficient spectrum utilization.

In [3], a strategy called *super-filter* (*SF*) has been introduced to improve spectrum efficiency by compacting spectrum-contiguous lightpaths.

In this study, a further strategy is considered, called *differentiated filter* (*DF*). Moreover, the effective combination of these two strategies, named *differentiated & super filter* strategy (*DSF*), is here introduced. DSF is then implemented through an effective routing and spectrum assignment heuristic.

The benefits of all these strategies are finally evaluated, showing remarkable improvements in the overall spectrum efficiency with respect to traditional flexi-grid configuration approaches.

Traditional filter configuration

In the traditional flexi-grid approach, the frequency slot is typically configured by assigning unique bandwidth value to all traversed optical nodes (i.e., filters) along the entire connection. For example, the GMPLS parameters *n* (central frequency) and *m* (slot width, expressed as number of 12.5 GHz frequency slices) are typically configured with the same value through all traversed nodes. Fig. 1 illustrates an example of connection transmission through a cascade of three nodes. First, it is assumed that *m* slices are assigned to the connection (Fig. 1a). It is also assumed that after *NF*=2 nodes, acceptable quality of transmission (QoT) is experienced. However, after the third traversed node, excessive detrimental filtering effects are experienced, preventing the actual setup along the nodes with such tight filtering. Thus, larger bandwidth should be computed and configured in order to avoid the filter transition bands and thus limiting detrimental filtering cascade effects. Fig. 1b shows the frequency slot configured, in all the three nodes, with one additional slice (*m+1)* reserved to all nodes. In this case, adequate QoT is achieved, at the expenses of more reserved spectrum in all traversed nodes.

Differentiated filters and super-filters

Fig. 1c shows the differentiated filter (DF) configuration strategy. In DF, different values of filter width (i.e., *m*) can be configured along the path in the nodes traversed by the same connection.

In particular, the first nodes are configured with *m* slices, while *m*+1 slices are applied only to the last node. This way, the maximum number *NF* of acceptable tight filters is not exceeded. Thus, no additional detrimental filtering effects are introduced by the third node, and in particular by its (broader) filter, which is traversed by the lightpath in its flat region.

Fig. 2 reports the concept of super filter introduced in[3]. Signals can limit detrimental filtering cascade effects by sharing the central region of the filters with other spectrum-contiguous signals, also originated by different source-destination pairs. This way, the minimum amount of *m* slices per signal can be successfully allocated to the central lightpaths. Thus, the central lightpaths traverse a cascade of filters in their flat region, without experiencing significant transmission degradation.

Joint differentiated and super filter strategy

The overall filter strategy, called DSF, combines the benefits of the DF technique (which considers a single lightpath) with the SF technique (which considers multiple lightpaths). The objective is to take advantage of both the

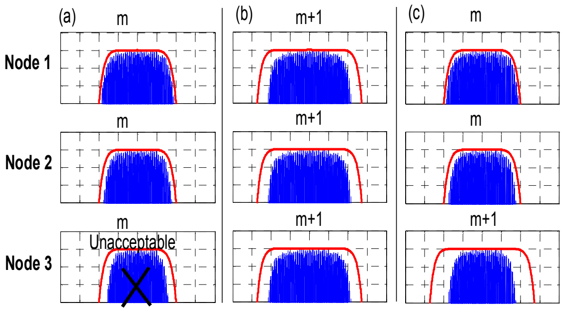

Fig. 1: Filter cascade with: (a) minimum reserved spectrum (m slices) but unacceptable filtering effects; (b) acceptable filtering effects but larger spectrum; (c) differentiated filter configuration (spectrum saving and acceptable filtering)

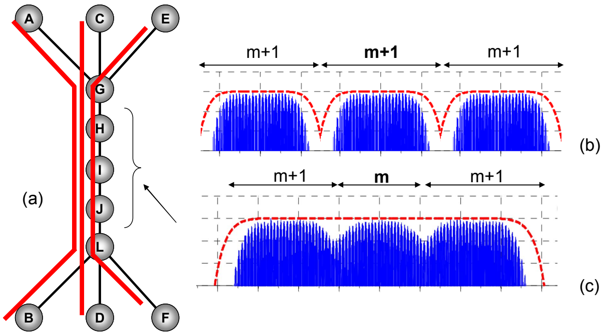

Fig. 2: (a) reference scenario with multiple lightpaths. (b) independent spectrum reservation; (c) super-filter configuration (spectrum saving and acceptable filtering effects on the central C-D signal) [3]

differentiated filter and super-filter capabilities to minimize the overall spectrum resources by accounting for the maximum number *NF* of tight filters that each lightpath can safely traverse.

In the following, the offline routing and spectrum allocation problem is formally stated:

Given: *a*) a network topology *G*(*N*, *E*), where *N* is the set of optical nodes and *E* the set of links; *b*) an optical spectrum divided into frequency slices of a given width; *c*) a set *D* of demands to be served; *d*) Max number of tight filters (*maxTFilters*) that can be used in each lightpath.

Find: the route and spectrum allocation for each demand *d* in *D*.

Objective: maximize the number of demands served.

To solve the above problem, we implemented a random heuristic algorithm derived from [5]; which provides a good trade-off between complexity and optimality; the pseudo-code is depicted in Table 1. It maximizes the number of demands that are eventually served. For every demand in *D*, its *k* shortest paths are computed. In addition, for each path its spectrum assignment is calculated depending on the strategy used (traditional, DF or DSF). Resources related to the path and spectrum allocations computed for each demand *d* in *D*, are allocated in *G*(*N*,*E*), so subsequent computations consider those resources in use. *MaxIter* iterations on the randomly sorted set *D* are done and the best solution is eventually returned.

Table. 1: Algorithm pseudo-code

```
IN: G, D, k, maxIter, maxTFilters, DF, DSF
OUT: Sol
Sol ← ∅
for i = 1..maxIter do
    tempSol ← ∅
    randomSort(D)
    for each d ∈ D do
        bestSlices ← ∞; bestLightpath ← ∅
        kLPs ← KSP(N, E, d, k)
        for each lightpath ∈ kLPs do
            tempSlices ← SA(lightpath,
                              maxTFilters, DF, DSF)
            if tempSlices ≠ 0 then
                if bestSlices > tempSlices then
                    bestSlices ← tempSlices
                    bestLightpath ← lightpath
        if bestLightpath ≠ ∅ then
            allocate(bestLightpath)
            tempSol ← tempSol U {bestLightpath}
    if |tempSol| > |Sol| then
        Sol ← tempSol
    resetAllocations(tempSol)
return Sol
```

Numerical Results

The performance of the three considered filter configuration strategies were compared on the 30-node and 56-link Telefonica national network topology (Fig. 3). Different values of the offered load were created by increasing the number of connections to serve. Source/destination pairs were randomly chosen with equal probability (uniform distribution) among all nodes.

In the evaluation, the bitrate of each connection was set to 100 Gb/s, the optical spectrum width was set to 4 THz and the spectrum granularity was fixed to 12.5 GHz. The maximum number *NF* of acceptable tight filters was fixed to 4. Regarding the spectrum assignment, lightpaths could allocate a slot of 2 or 3 slices independently at each of hop (linear regime is assumed), depending on the filtering strategy used [3].

Each problem instance was solved using the heuristic presented in Table 1. To that end, a 2.4 GHz Quad-Core machine with 8 GB RAM memory running Linux was used. Finally, note that each point in the results is the average of 10 runs and that all approaches were executed using identical input data.

Plots in Fig 4 show the blocking probability as a function of the offered load for the three filter configurations strategies. Note that offered loads were limited to those unleashing blocking

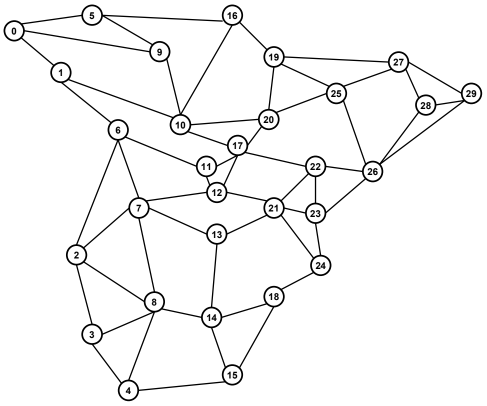

Fig. 3: Telefonica network topology

probability in the meaningful range [0%-10%].

As illustrated, when the DF strategy is applied more connections can be served in comparison to the traditional one. Noticeably, due to the fact that fewer resources are allocated for the same number lightpaths, there is more room for new connections. In addition, a gain of 5% can be appreciated at 1% of blocking probability.

Furthermore, it can be observed that the DSF strategy outperforms both, the traditional and the DF ones. The DSF strategy allows increasing remarkably the amount of connections conveyed. In fact, the gain achieved using this strategy is 10% compared to the DS one, when both unleash blocking probability of 1%.

Additionally, when focusing on the traditional strategy, the gain increases to 15%. The rationale behind that is that the DSF strategy exploits the synergy between the DF and the SF strategies.

By combining both of them, first, different segments of a lightpath can allocate the minimum number of slices applying the SF strategy. Then, those segments can be linked together using the minimum number of slices thanks to the DF strategy, thus optimizing the use of resources.

To get insight into the performance of the different strategies, let us focus on those demands whose shortest path is longer than 4 hops, i.e., longer than the maximum *NF* value of acceptable tight filters. Fig. 5 plots the blocking probability of these lightpaths versus the offered load for the three filter configurations strategies under study.

Again, the DSF strategy shows significantly better performance than that of the traditional one. In fact, comparing the offered load at 1% of blocking probability a gain as high as 22% is attained.

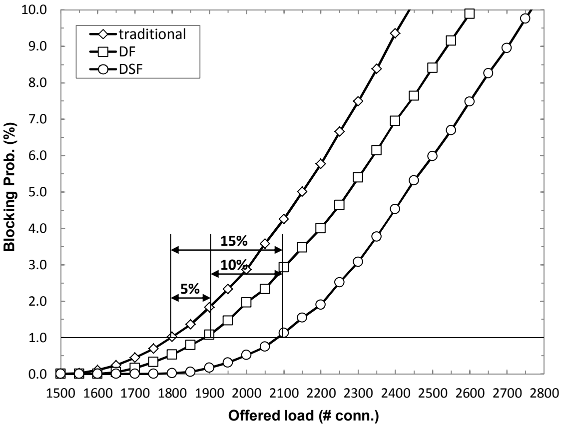

Fig. 4: Blocking probability versus offered load

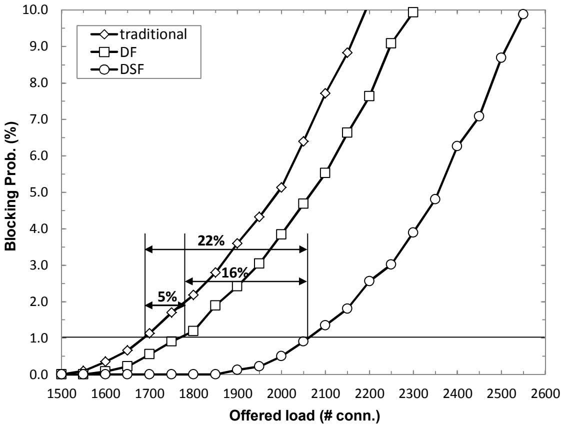

Fig. 5: Long lightpaths blocking probability vs. load

Conclusions

This study proposed an effective filtering configuration strategy enabling both single and multiple lightpaths to efficiently differentiate the filter configuration along the traversed optical nodes. A new heuristic is designed and applied to demonstrate that the proposed strategy can provide significant improvements in network throughput with respect to traditional flexi-grid approaches where each lightpath is configured with a common bandwidth value along its traversed nodes.

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