Provisioning Schemes Accounting for ROADM Add/Drop Constraints in GMPLS-based WSON

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Abstract: Provisioning schemes exploiting the recently introduced GMPLS extensions for add/drop in WSONs are proposed to effectively handle different ROADM structures and provide a preference on the utilization of add/drop resources with limited flexibility.

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1. Introduction

Wavelength Selective Switch (WSS) technology has recently enabled the introduction of multi-degree Reconfigurable Optical Add Drop Multiplexer (ROADM) and the deployment of cost-effective dynamic Wavelength Switched Optical Networks (WSONs). In [1,2], different WSS-based ROADM structures are presented. They differ in the way add/drop functionalities are implemented, i.e. in the number of exploited WSSs. This impacts two main aspects: the node cost and the constraints imposed during Routing and Wavelength Assignment (RWA). For example, the simplest ROADM structure adopting no WSS in add/drop guarantees the lowest cost but imposes *colored (C)* and *direction-bound (D)* add/drop, i.e. tributaries at fixed wavelengths and fixed direction. More expensive ROADM structures adopting one or two WSS per add/drop (either shared or dedicated per direction) are then able to guarantee some *colorless (CL)* and/or *direction-less (DL)* add/drop, i.e. tributaries at tunable wavelength and/or configurable direction. In today's WSONs, the most common adopted solutions are typically represented by ROADM structures implementing many fixed add/drop (*C-D*) and only a limited percentage of partially flexible (*C-DL*, *CL-D*) or fully flexible add/drop (*CL-DL*). Ad-hoc WSON planning is indeed performed to determine the ROADM structures to install, thus achieving an overall adequate flexibility in RWA at the lowest possible cost.

To enable effective RWA in dynamic WSONs encompassing ROADMs with add/drop constraints, extensions to the GMPLS protocol suite have been proposed [3,4]. In particular, [4] and companion IETF documents, present routing protocol extensions to describe internal ROADM structures. They enable the advertisement of internal node connectivity limitations and specific node characteristics through the combined utilization of the connectivity matrix and resource pool concepts. In this way, the *capacity* of each ROADM structure can be announced with great detail, e.g. including the number of installed add/drop per type (C-D, CL-D, C-DL and CL-DL). Such extensions are not expected to vary frequently during network operations. In [4], the possibility to advertise also *available* ROADM resources (e.g., the availability of each specific add/drop resource) is considered. These extensions, however, might require frequent updates within the WSON. In either cases, the GMPLS routing protocol can or not be used to advertise also detailed WSON Link information (i.e., detailed wavelength availability) [4] .This provides additional information during path computation but might introduce further control plane scalability issues. Thus, provisioning schemes have to be carefully defined according to the considered WSON scenario in terms of both (i) ROADM add/drop capacity and availability and (ii) adopted control plane extensions.

In this study we first propose provisioning schemes aiming at effectively exploit the different add/drop resources. The schemes are then evaluated through simulations under different dynamic WSON scenarios, i.e. considering different ROADM structures and adopting different routing protocol extensions.

2. Provisioning schemes

A WSON with N nodes and L bi-directional links is considered. Each node is equipped with a combination of C-D, C-DL, CL-D, and CL-DL add/drops. GMPLS control plane is assumed. RSVP-TE signalling protocol gathers wavelength availability along the path within the Label Set (LS) object. Four cases of OSPF-TE are considered, in which OSPF-TE is extended [4] to advertise: 1) add/drop capacity; 2) add/drop availability; 3) add/drop capacity and detailed wavelength availability; 4) both add/drop and detailed wavelength availability. In scenario 1) and 3), each node has updated availability information related to only local adds and drops. In the scenarios 1-4), two lightpath provisioning schemes, detailed in the following, are proposed. Path computation and wavelength assignment of the proposed schemes are driven by a *preference rank* defined for add/drop selection: C-D (most preferred to be selected), C-DL, CL-D, CL-DL (less preferred). The lightpath provisioning is detailed as follows. Upon lightpath request from source s to destination d, if s has no available add, the lightpath is blocked. Otherwise, s computes a set of paths $P_{s,d}$ connecting s-d. Then, a path within $P_{s,d}$ is selected depending on the proposed scheme:

- *Transponder-intersection-based path computation scheme (TI):* it is applied to OSPF-TE scenarios 1) and 2). For each path in $P_{s,d}$, the number n of possible available colored add/drop pairs on the same wavelength is computed. In case of OSPF-TE scenario 1), remote drops are assumed as available, while in scenario 2) the distributed availability information is considered. In the calculation of n, four contributions are considered for colored adds/drops on the same wavelength w_j: n_1 given by C-D adds and drops; n_2 by C-D adds and C-DL drops; n_3 by C-DL adds and C-D drops; n_4 by C-DL adds and drops. For instance, in Fig. 1, n=1 is associated to the path *s-x-y-d*, since add on link *s-x* and drop on *y-d* are colored on w_1 (grey boxes along links *s-x* and *y-d*, respectively). n=3 is associated to the path *s-z-d*, considering the three C-D drops on link *z-d* on w_2 ,w_3 ,w_4, and two C-D adds on link *s-z* on w_2 and w_3 plus a C-DL add on w_4 (white box). n=2 is associated to the path *s-i-k-d*. Then, the path p (*s-z-d* in Fig. 1) maximizing n is selected for signaling. If n=0 for each path, the path p maximizing the number of colorless add/drop is selected for signaling.

- *Transponder-and-continuity-intersection-based path computation scheme (TCI):* it is applied to OSPF-TE scenarios 3) and 4). For each path in $P_{s,d}$, the number n of possible colored add/drop pairs (considering contributions n_1, n_2, n_3, n_4 as in TI) with the same color w_j, such that w_j satisfies the continuity constraint on the path, is computed. For instance, in Fig. 1, n=1 is associated to the path *s-x-y-d*, given the colored add and drop on w_1 and the fact that w_1 is available in each link of *s-x-y-d*. n=0 is associated to the path *s-z-d*, given that w_2, w_3 ,w_4 do not satisfy the continuity constraint. n=2 is associated to the path *s-i-k-d* since both w_5 and w_6 satisfy continuity constraint. The path p (*s-i-k-d* in Fig. 1) maximizing n is selected for signaling. If n=0 for each path, the path p maximizing the number of wavelength satisfying continuity constraint is selected for signaling.

Signaling must account for node constraints. Both TI and TCI perform the GMPLS-based signaling as in the following. If at least one CL add is available on the outgoing link (i.e., the first link in p), LS is initialized with the set W_{L1} of available wavelengths on that link. If no CL add is available, LS is initialized with the intersection between W_{L1} and W_{add}, where W_{add} is defined as the set of wavelengths in which a C-D or C-DL add is available on the first link of p. Then, LS is propagated and updated considering the wavelength availability in each link along p. When LS reaches d, LS contains the wavelengths satisfying the continuity constraint along p, such that add is admitted at s. Wavelength selection at d, driven by the *preference rank,* accounts for add information of s. This is possible at d, given the flooded information of capacity or, according to the OSPF-TE scenario, capacity and availability of the adds in s. Thus, first-fit (FF) wavelength selection is first performed on wavelengths enabling C-D add/drop. If such a wavelength is unavailable, FF is applied to wavelengths enabling C- add/drop (C-D and C-DL adds/drops are considered). If such a wavelength is unavailable, FF is applied to wavelengths enabling CL-add/drop. Then, a drop is reserved considering the *preference rank*. If no wavelength can be reserved or drop is unavailable, the lightpath is blocked. Otherwise, RSVP-TE Resv message is sent toward s. When Resv reaches s, s selects an add considering the selected wavelength and the *preference rank*.

3. Performance evaluation

The performance evaluation of the schemes is carried out by means of a custom C++ event-driven simulator on the Pan-European network topology with N=17, L=33, W=40 [5]. Add and drop resources per node are the 30% of the total number of wavelength channels in the outgoing links. Several transponder scenarios have been considered. Here the following two are reported: A) 10 adds (and drops) are C-DL, while the others C-D; B) 10 adds (and drops) are CL-DL, while the others C-D. Lightpath requests are uniformly distributed among the *s-d* pairs. Inter-arrival and holding times of the lightpath requests are exponentially distributed with an average of $1/\lambda$ and $1/\mu$=500s, respectively. $P_{s,d}$ includes all paths within one hop from the shortest path. TI and TCI are evaluated in the presence of OSPF-TE extensions for add/drop capacity (TI-capacity and TCI-capacity) and availability (TI-availability and TCI-availability). TI and TCI are compared with a scheme in which no transponder information (*NoT*) is distributed. With NoT, path computation is random on $P_{s,d}$ and wavelength assignment assumes only drop information.

Figs. 2 and 3 show the blocking probability versus network load in the scenarios A and B. The proposed TI and TCI experience lower blocking than NoT in both A and B. Indeed, with NoT, flexible adds and drops (e.g., CL-DL in scenario B) are quickly exhausted since the routing does not account for add/drop information. On the contrary, routing of TI and TCI aims at mostly using C-D transponders and using the others (e.g., CL-DL) if strictly necessary. An high blocking reduction is obtained with TCI with respect to TI for two reasons. First, the main blocking experienced by TI is due to the lack of wavelengths satisfying continuity constraint. This blocking contribution is particularly dominant when colorless add is not available at s, so that LS is initialized only with the intersection between W_{L1} and W_{add}. Differently from TI, TCI performs routing also considering wavelength availability information in each link, thus increasing the probability to find a path with wavelengths satisfying the continuity constraint. Second, wavelength information is strictly related to add/drop information. For instance, if d has a C-D drop on w_i on a link j, and w_i on j is used by a lightpath traversing d, s is aware that this drop cannot be used, so s considers this information during path computation. By comparing TI-capacity with TI-availability and TCI-capacity with TCI-availability, a limited benefit is obtained with the distribution of add/drop availability with respect to capacity information. Indeed, LS is initialized with just the wavelengths of available adds on that path. For this reason *d* cannot select a wavelength which does not enable an add at *s*. Moreover, given the advertised add capacity information, *d* is also able to select a wavelength related to a less flexible add, thus saving CL-DL and C-DL adds. In terms of control plane load, given h_p the number of hops traversed by a new established path *p*, the following OSPF-TE LSA Updates (U_p) are advertised. In case of NoT, U_p=0 Updates are generated. In case of TI-capacity, capacity information are refreshed but no updates are triggered upon lightpath establishment (U_p=0). Thus, NoT and TI-capacity present similar control plane load given by RSVP-TE packets. In TI-availability, $U_p=2$ to account for add and drop availability updates. In TCI-capacity, $U_p=h_p$ to account for wavelength availability changes. In TCI-availability, $U_p=2+h_p$. The resulting control plane loads at 300 Erlang are 5 pck/s for NoT and TI-capacity, 120 pck/s for TI-availability, 174 pck/s for TCI-capacity and 298.8 pck/s for TCI-availability. Finally, to show the benefits of the *preference rank*, the wavelength assignment of TI- and TCI-capacity is replaced with a simple FF (*TI-capacity FF* and *TCI-capacity FF*). Fig. 4 shows the resulting performance. Again, saving flexible add/drop permits to strongly reduce blocking, e.g. TCI-capacity experiences lower blocking than TCI-capacity FF.

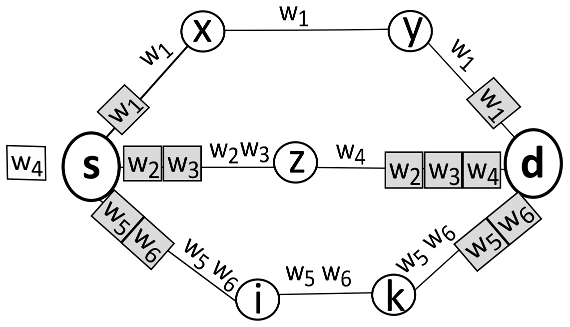

Fig. 1. Illustrative example.

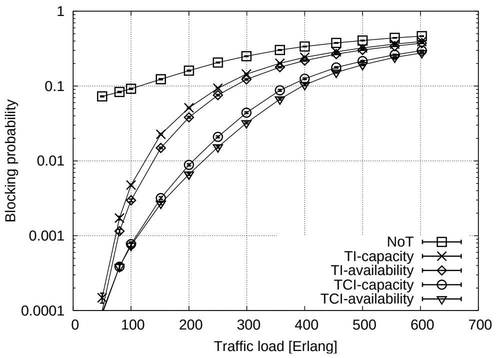

Fig. 2. Blocking probability vs. offered network load in scenario A) (C-D and C-DL transponders).

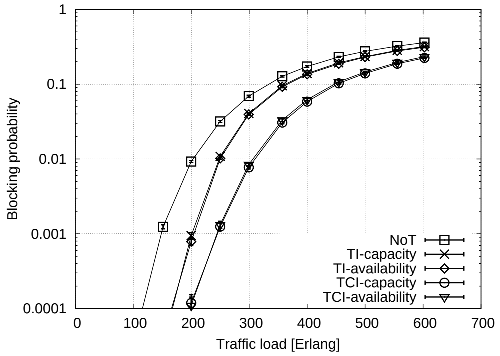

Fig. 3. Blocking probability vs. offered network load in scenario B) (C-D and CL-DL transponders).

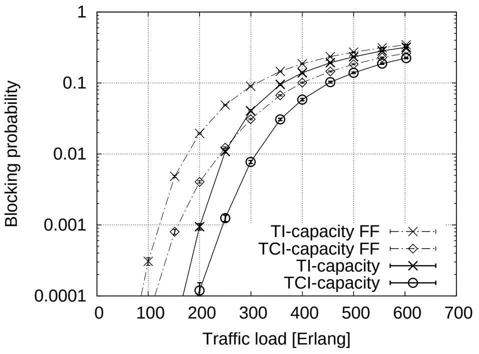

Fig. 4. Blocking probability vs. offered network load in B), if WA is FF or based on the *preference rank.*

4. Conclusion

In this study, the recently introduced GMPLS extensions for WSON are applied in the context of realistic ROADM structures including add/drop resources with limited flexibility on tunability and directionality. Provisioning schemes are proposed and evaluated through simulations showing the great improvement in blocking probability achieved by the saving of flexible add/drop resources. Results also show the benefits obtained by considering the advertisement of add/drop capacity together with link wavelength availability information and the limited improvement achieved by also considering add/drop availability information.

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References

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