An Enhanced Dynamic Multilayer Routing for Networks with Protection Requirements

Anna Urra, Eusebi Calle, Jose L. Marzo, and Pere Vila

Abstract: **This paper presents a new enhanced dynamic and multilayer protection (DMP) routing scheme that considers cooperation between packet and wavelength switching domain in order to minimize the resource consumption. The paper describes the architecture of the multilayer network scenario and compares the proposed algorithm with other routing mechanisms applying protection at the IP/multi-protocol label switching (MPLS) layer or at the optical layer. Simulation results show that DMP reduces the number of optical-electrical-optical (o-e-o) operations and makes an efficient use of the network resources compared to non-multilayer proposals.**

Index Terms: **Multilayer survivability, multi-protocol label switching (MPLS), protection mechanisms.**

I. INTRODUCTION

A single fiber failure can result in potentially huge data losses as the effects propagate up and through the network causing disruptions in the service of many applications. Thus, survivability has become a key issue to improve and satisfy the increasing requirements of reliability and quality of service (QoS) of these applications. The use of Internet protocol/multi-protocol label switching (IP/MPLS) [1] in optical core networks has been presented as a suitable choice for the next generation Internet architecture. The integration of both layers is facilitated by the development of generalized MPLS (GMPLS) [2].

Different fault recovery schemes have been adopted in the network in order to provide such survivability in both layers. These schemes are based on switching the traffic affected by the failure to a backup path. The computation of the working and backup paths is a crucial step to offer the required QoS to the traffic services. Some relevant parameters, such as resource consumption and recovery time, could be affected negatively if suitable routing algorithms are not used. According to the timing of backup path computation, recovery mechanisms are classified in protection and restoration [3]. Although restoration is flexible in terms of resource consumption, it offers low recovery time and the recovery action may not be successful because of insufficient network resources. Protection describes recovery schemes that are pre-planned for both spare capacity and backup paths achieving the shortest recovery time and providing high availability against network failures. The accuracy and performance of routing algorithms with protection in terms of resource consumption depends on the available network information. The availability of full or partial network information influences the management of the network capacity [4]. The reduction of the recovery time is another parameter to be considered for backup path selection and it is achieved by applying segment or local backup path methods instead of path protection [5].

Nowadays different QoS routing algorithms exist that consider protection mechanisms, full/partial network information and local/segment backups [4]–[8]. However, these routing schemes operate in a single switching layer: Either optical and wavelength oriented or IP/MPLS and label switched path (LSP) oriented. Thus, both optical and IP/MPLS layers independently deploy their own fault recovery methods. This results in protection duplications making fault management more difficult and poor resource utilization. Two network scenarios may be considered in order to improve network management and resources: 1) The static multilayer network scenario or 2) the dynamic multilayer network scenario. In the static multilayer network scenario [9], [10], the logical topology defined by the optical layer is given, fixed and partially protected. Some of the logical links are assumed to be already protected at the optical layer. Thereby, at the IP/MPLS layer, spare capacity is reserved to protect only those logical links that are unprotected. In the dynamic multilayer network scenario, interoperability between each IP/MPLS and optical switching domain is considered. Although effort has been devoted in developing dynamic multilayer routing schemes that consider both switching domains [11], protection is not considered amongst them. In this paper, a dynamic cooperation between wavelength and LSP domain is taken into account in order to provide protected paths cost-effectively.

II. MULTILAYER NETWORK SCENARIOS. ARCHITECTURE OVERVIEW.

In the multilayer architecture, electrical-based label switched paths (eLSPs) are routed in the optical network through optical-based LSPs (oLSPs) also known as lightpaths. For better utilization of the network resources, eLSPs should be efficiently multiplexed into oLSPs and then, these oLSPs should be demultiplexed into eLSPs at some router. This procedure of multiplexing/demultiplexing and switching eLSPs onto/from oLSPs is called traffic grooming. Traffic grooming is an important issue for next generation optical networks. Photonic multilayer routers have the technology to implement traffic grooming. Fig. 1 describes this architecture. Further details can be found in [11]. Each consists of a number of packet-switching capable (PSC) ports (p) and number of wavelengths (w). The number of PSC indicates how many oLSPs can be demultiplexed into this router, whereas the number of wavelengths corresponds to the number of wavelengths connected to the same adjacent router. Three scenarios are associated with p according to the following

Manuscript received May 15, 2007.

This work was partially supported by the Spanish Research Council (TEC2006-03883/TCM) and the Generalitat de Catalunya (grant SGR-00296).

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switch architectures [12]:

- Single-hop grooming: $p = 0$. Using this type of switching architecture, the network does not offer packet switching capability at intermediate nodes. Thus, traffic from a source node is multiplexed onto a direct oLSPs to the destination node. In this case, either backup oLSPs at the optical domain or global backup eLSPs (path protection) at the IP/MPLS domain are established to protect the connections.
- Multihop partial-grooming: $0 < p < w$. In this case, some wavelengths may be demultiplexed at the intermediate nodes for switching at finer granularity. Therefore, some eLSPs will be able to perform segment/local protection.
- Multihop full-grooming: $p = w$. Every wavelength on each fiber link forms a oLSPs between adjacent node pairs. Thus, the logical topology is predetermined and exactly the same as the physical topology. All the IP/MPLS protection strategies, i.e., global, segment and local, are suitable for all eLSPs.

Note that, although the PSC ports at intermediate nodes allow performing packet segment/local protection, the number of optical-electrical-optical (o-e-o) conversions increases. Thus, the cost of o-e-o conversions must be considered during the path computation because they represent a bottleneck to network throughput and also influence the overall delay.

The granularity of the recovery strategy is also an important parameter in terms of time recovery and fault management. Diverse switching granularity levels exist into the optical IP/MPLS network scenario. Going from coarser to finer, there is fiber, wavelength (oLSPs) and eLSP switching. The level of recovery at the optical layer is bundle of oLSPs or individual oLSPs [13]. Since recovering at the optical layer recovers affected connections in-group, the recovery action is fast and easier to manage than recovering each affected eLSP individually in the IP/MPLS layer. However, the coarser is the granularity; the higher the resource consumption. The finer IP/MPLS granularity results in better resource consumption.

III. DYNAMIC MULTILAYER WITH PROTECTION (DMP) ROUTING ALGORITHM

In this section we discuss the basis of our proposed routing scheme. A tradeoff exists between the resource consumption and the cost added to the network in terms of recovery time, failure management and node technology. Better use of network resources is achieved by recovering at IP/MPLS layer due to its finer switching granularity. However, the recovery actions at optical domain are much faster and easier to manage, since the affected connections are recovered in group. Therefore, cooperation between both layers seems to be the solution in order to take advantage of each switching domain. The proposal presented in this paper is a first order approach that takes into account the dynamic multilayer network scenario. This proposal is based on the establishment of link-disjoint oLSP/eLSP pairs: The oLSPs/eLSP and the backup oLSP/eLSP. When a failure occurs at an oLSP, the traffic is switched to the respective backup oLSP. If no backup oLSP exists, the traffic is switched to the respective

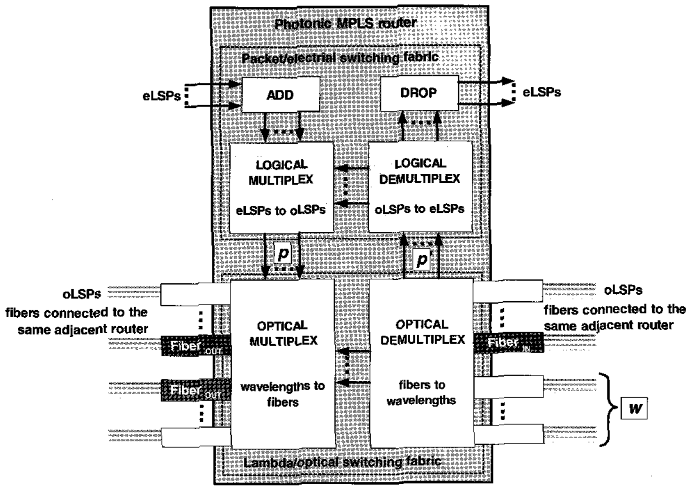


Fig. 1. Photonic multilayer node architecture.

backup eLSPs. The main objective is to take advantage of both switching domains.

Let $G_P = (V, E_P)$ and $G_L = (V, E_L)$ represent the physical topology and the logical topology, respectively, where V is the set of photonic MPLS routers; E_P and E_L are the set of network physical links and existing oLSPs, respectively. Each router has p input and output PSC ports, where $PSCi(u)$ input ports and $PCSo(u)$ output ports of node u are not assigned to any oLSP yet. Each physical link has w wavelengths. When an eLSP is requested, the proposed routing scheme considers both physical links and oLSPs, i.e., $E_P \cup E_L$. In order to univocally identify the physical links and existing oLSPs that connect node pair (i, j) the 3-tuple (i, j, k) is used. Thus, the link (i, j, k) is a physical link if $k = 0$, otherwise $(k > 0)$ it is an oLSP. Note that for $k > 0$, k is basically used to identify each of the multiple existing oLSPs between node pair (i, j). Each (i, j, k) oLSP has an associated R_{ijk} residual capacity; S_{ijk}^{uv} total capacity reserved to protect the physical link $(u, v, 0)$; and T_{ijk} the total shared capacity allocated in link (i, j, k). The eLSP requests are defined by (s, d, b) where (s, d) is the source and destination node pair, and b specifies the amount of capacity required for this request. For each request, a working eLSP (WP) has to be set-up. A backup eLSP (BP) must be also set-up, whenever the WP has, at least, one unprotected oLSP. If there are not sufficient resources in the network, for either the WP or the BP, the request is rejected.

In the proposed scheme, a new procedure to compute the WP is presented. In this procedure the following cost parameters are taken into account:

- The residual capacity of the link candidates, R_{ijk}.
- The maximum number of hops, H, i.e., maximum number of oLSPs that the WP may traverse.
- The free packet switching ports of each router, $PCSi$ and $PSCo$.

Note that the residual capacity of the physical links with free wavelengths is the capacity of the wavelength. The proposed procedure, called dynamic multilayer with protection (DMP) algorithm (Alg. 1), computes the min-hop WP based on a variation of the Dijkstra algorithm. In this case, the number of hops coin-

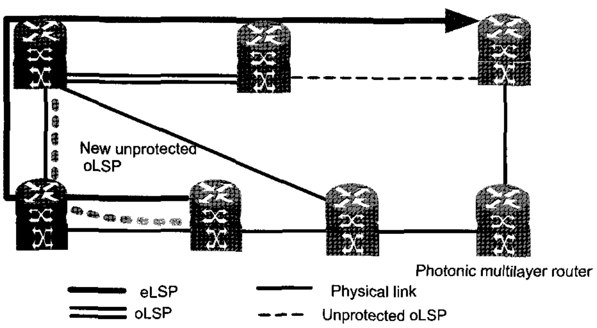


Fig. 2. Multilayer network topology.

Algorithm 1 Dynamic multilayer with protection routing

for all $v \in V$ **do**
  $Cost(v) = \infty$
  $Pred(v) = s$
  $WPlast(v) = s$
$Cost(s) = 0$
$Q \leftarrow s$
while $(d \notin Q$ **and** $Q \neq \oslash)$ **do**
  $u \leftarrow min\_cost(Q)$
  $Q = Q - \{u\}$
  for all $v \in adjacency(u, G)$ **do**
    for all $(u, v, k) \in E$ **do**
      if $(R_{ijk} \geq b)$ **and** $((k = WPlast(u) = 0)$
      or $(Cost(u) + 1 < Cost(v) < H))$ **then**
        if $(PSCi(v) > 0$ **and** $WPLast(u) > 0$
        and $k = 0)$ **or** $(PSCo(v) > 0$ **and** $k > 0$
        and $WPlast(u) = 0)$ **or** $(WPlast(u) > 0$
        and $k > 0)$ **or** $(k = WPlast(u) = 0)$ **then**
          $Pred(v) = u$
          $WPlast(v) = k$
          $Q \leftarrow v$
          if not $(k = WPlast(u) = 0)$ **then**
            $Cost(v) = Cost(u) + 1$

cides with the number of oLSPs. Thus, the consecutive sequence of physical links, that constitutes an oLSP, is only considered as one hop. The DMP procedure uses the network graph composed by oLSPs and physical links, i.e., $G = (V, E_P \cup E_L)$. This procedure ends when it reaches the destination node or there is no feasible path between source and destination nodes. If a feasible path exists then the procedure may return:

- A sequence of existing protected oLSPs.
- A sequence of physical links. In this case, a new unprotected oLSP is set up between source and destination node.
- A sequence of physical links, protected and unprotected oLSPs. In this case, new unprotected oLSPs are setup for each consecutive sequence of physical links as shown in Fig. 2.

In the DMP algorithm (Alg. 1), $Cost(v)$ is a vector containing the path cost from s to v; $Pred(v)$ contains the v's predecessor node; and $WPlast(v)$ contains the identifier k of link (u, v). Q represents the list of adjacent vertices which are not visited yet. Function $min\_cost(Q)$ returns the element $u \in Q$ with the lowest $Cost(u)$; and $adjacency(u)$ is the adjacency list of vertex u in graph G.

Table 1. Proposed algorithms.

Routing Alg.	Working path	Backup path	Protection domain
DM1	DMP	DMP	Multilayer
O1	Oki 1[1]	BL[2]	Optical
O2	Oki 2[1]	BL[2]	Optical
M1	Widest shortest path	Full information routing	IP/MPLS[3]

Once the WP is known, the BP is computed. Three different procedures could be applied depending on the WP characteristics:

Step 1. If the WP is a sequence of existing protected oLSPs, the computation of the BP is not required.

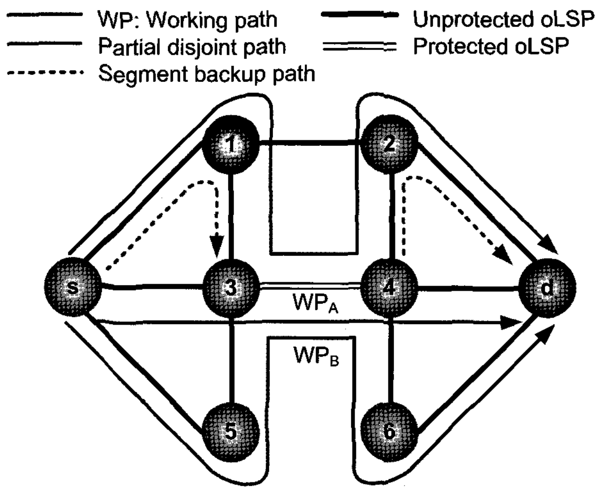
Step 2. If the WP is a new unprotected oLSP and an available and shareable backup oLSP exists, this is used to protect the oLSP. Otherwise, a new backup oLSP is set-up applying DMP algorithm (Alg. 1) with $G = (V, E_P)$. If the procedure fails to find a backup oLSP, go to Step 3.

Step 3. If the WP is a combination of protected and unprotected oLSPs, then a variation of the Partial Disjoint Path (PDP) algorithm [9] is used to compute the BP. The variations are the ones included to the Dijkstra algorithm in order to consider the packet switching ports in the DMP algorithm. The PDP may overlap with the protected oLSPs of the WP, since they are already protected, and the nodes of the WP. When the PDP overlaps with the WP, more than one segment backup paths are established (see Fig. 3(a). The main advantage of using PDP is that no extra resources are necessary in the IP/MPLS layer against failure of protected oLSPs in the optical layer as shown in Fig. 3. This is because the BP capacity is only used to protect the unprotected oLSP. Thus, the BP is shared by multiple WPs which are traversing the same protected oLSPs. In Fig. 3(b), both WPs are sharing the same backup path.

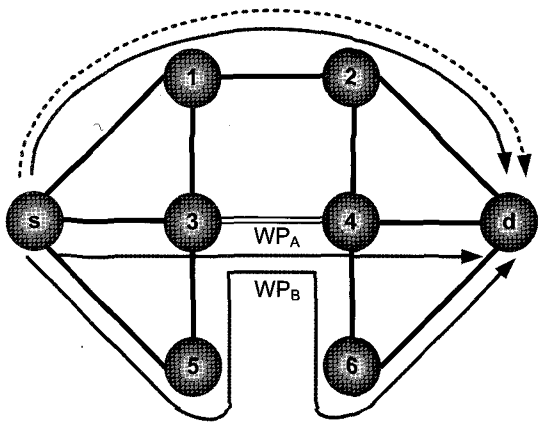
IV. PERFORMANCE EVALUATION

In this section the proposed algorithm DMP is compared with other routing algorithms that offer protection at different network layers. Table 1 summarizes the proposed algorithms.

1) Based on Oki's policies [11]. The routing policy 1 (Oki 1) tries to allocate the eLSPs to an existing direct oLSP. If a direct oLSP is not available then a sequence of existing oLSPs with two or more hops that connects the source and destination nodes are selected. Otherwise, a new one-hop direct oLSP is established. The routing policy 2 (Oki 2) first tries to allocate the eLSPs to an existing oLSP. If the oLSP is not available then a new one-hop direct oLSP is established and selected as the new eLSP. Otherwise, a sequence of existing oLSPs with two or more hops is selected.
2) Whenever a new oLSP is created, then a backup oLSP (BL) is also created.
3) Multihop full grooming. Widest shortest path (WSP) and shared backups using full information routing (FIR).



(a)



(b)

Fig. 3. IP/MPLS protection when the partial disjoint path: (a) Overlaps protected oLSPs, and (b) does not overlap the protected oLSPs.

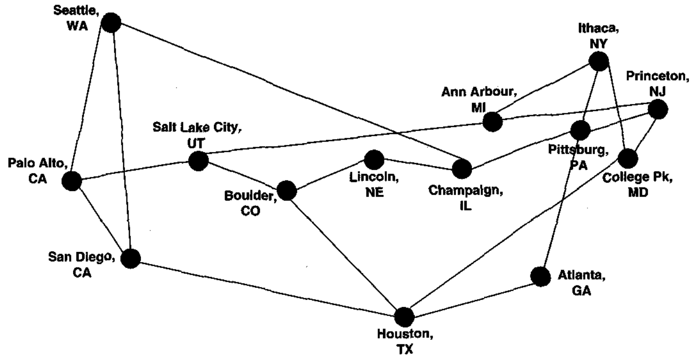


Fig. 4. NSF network topology.

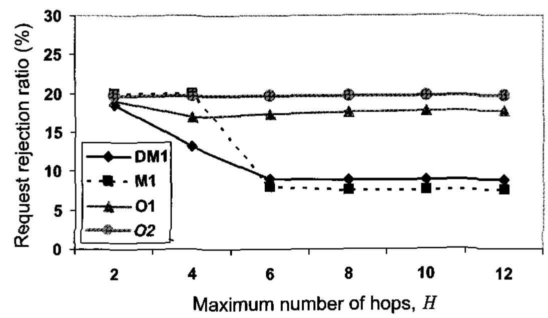


Fig. 5. Maximum number of hops.

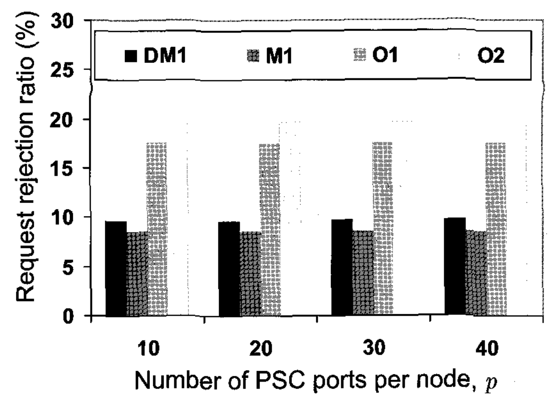


Fig. 6. Number of PSC ports.

A discrete-event simulation-based platform has been implemented in Java to model and evaluate the algorithms in distributed mesh topologies. The network topology adopted in this work is the NSFNET topology described in Fig. 4. NSFNET topology consists of 14 nodes and 21 physical links. Each physical link is bi-directional, with the same number of wavelengths in each direction. The transmission speed of each wavelength is set to 10 Gbps. The number of PSC ports p is assumed the same in each node. The required eLSP capacity is set to 500 Mbps. Requests for eLSP setup follow a Poisson distribution. The holding time of each source and destination node pair is considered to follow an exponential distribution. Note that when an existing oLSP does not accommodate any eLSP, the oLSP is disconnected.

Fig. 5 shows the performance of the proposed scheme, DM1, compared to optical oriented routing algorithms with protection (O1, O2) and IP/MPLS oriented routing algorithm with protection (M1). Results show that the proposed DM1 outperforms optical schemes because of the finer granularity. O2 uses a first-create a direct oLSP procedure used to allocate the eLSP. Thus, each oLSP may traverse several physical links, consuming high amount of wavelengths. Hence, most of the eLSPs have low number of hops. This is the reason why the request rejection ratio is not affected by the number of hops. In the figure, M1 performs better than DM1 from $H > 6$, this is due to the fact that there are not many disjoint paths with number of hops less than 6 and, consequently, a large number of requests are not accepted when $H < 6$.

Fig. 6 shows the influence of the number of PSC ports per node when $H = 6$. M1 operates under multihop full grooming ($p = w$), however, the results are shown in order to present the IP/MPLS bound of the solution in terms of capacity when $H = 6$. In this case DM1 is able to achieve a similar behavior to M1. DM1 outperforms both O1 and O2, throughout the simulation (independently of the number of PSCs). Near a 50% less of request rejection is achieved using multilayer protection than using optical protection.

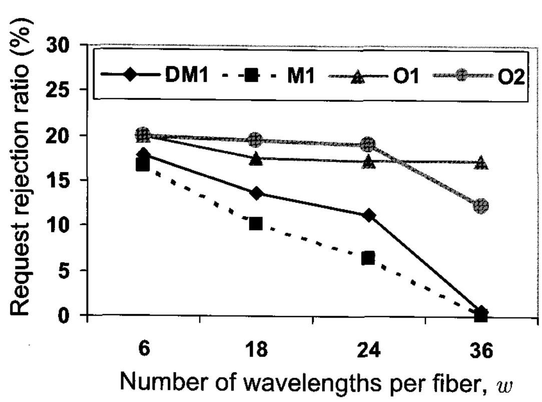
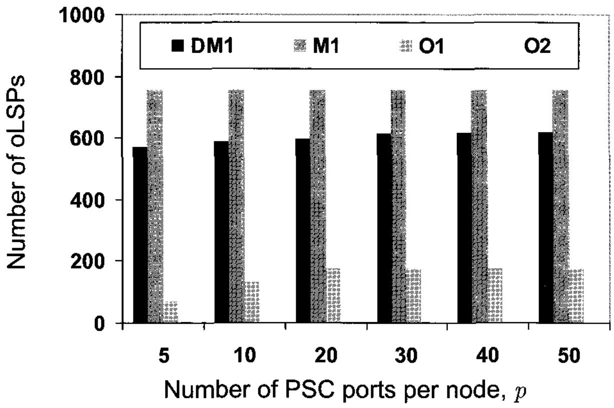


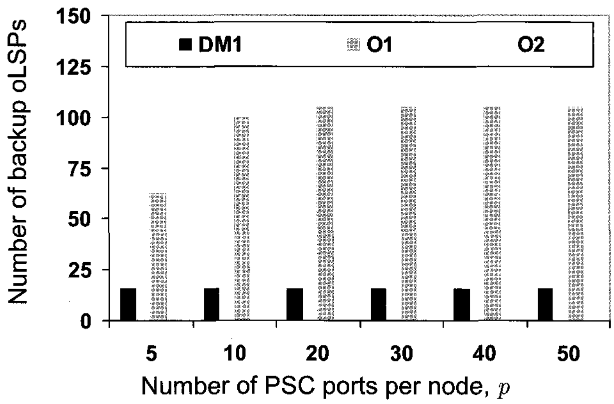
Fig. 7. Request rejection ratio vs. number of available wavelengths.

Fig. 7 shows the influence of the number of wavelengths (w) per fiber when $p = 10$ and $H = 6$. As shown, the number of rejected requests lineally decreases for M1 and DM1 as the number of wavelengths increases. In this case, O2 prioritizes oLSPs that directly connects source and destination nodes, outperforming O1 when there is a high number of available wavelengths (in the figure $w > 24$). Again, DM1 offers better performance than O1 and O2, and is able to achieve a similar performance as M1 for $w = 36$.

In Fig. 8, the total number of oLSPs and backup oLSPs established is evaluated. Fig. 8(a) shows the total number of oLSPs created. Due to the fact that M1 operates under multihop full grooming, each wavelength is assumed as an oLSP. Due to the network topology features (number of links = 21, bi-directional fiber per link, and 18 wavelengths per fiber) the total number of oLSPs in the network for M1 is 756. This number is an upper bound of the maximum number of oLSPs that can be created. In the case of using DM1, when the number of PSC ports increases, the number of new oLSPs slightly increases. The number of PSC ports has higher impact to O1 and O2 schemes, due to the optical protection. This is shown in Fig. 8(b). O1 has similar number of new oLSPs than O2. However, O1 has lower number of new backup oLSPs respect to O2; O1 shares higher number of backup oLSPs. In the case of DM1, major backups are created at IP/MPLS domain, this is the reason for few number of protected oLSPs.



(a)



(b)

Fig. 8. The evaluation of total number of oLSPs and backup oLSPs vs. the number of PSC ports per node: (a) Number of oLSPs, and (b) backup oLSPs created.

V. CONCLUSIONS

An enhanced proposal of current dynamic multilayer routing schemes has been introduced for scenarios with protection requirements. The dynamic multi-layer routing with Protection (DMP) scheme takes into account a dynamic cooperation between packet and wavelength switching domain in order to minimize the resource consumption. Optical-based and IP/MPLS-based protection schemes have been compared with our proposal. Results have shown that IP/MPLS protection techniques and Multilayer protection are the best schemes in terms of network resources. The use of IP/MPLS recovery mechanisms with finer granularity results into better filling of the capacity and less number of rejected requests comparing to optical protection. Another conclusion is that when the number of o-e-o conversions is limited (due to the number of hops), the proposed dynamic multilayer routing outperforms the IP/MPLS protection-based schemes. In summary, our enhanced dynamic multilayer routing with protection algorithm has shown to be a suitable selection, reducing the number of o-e-o operations and making an efficient use of the network resources, when computing new oLSPs/eLSPs and their backups.

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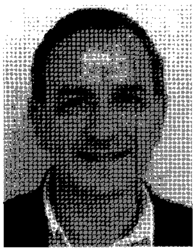

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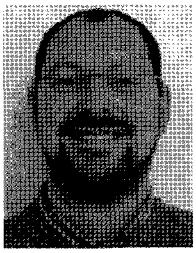

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