Lightpath bundling and anycast switching: a good team for multilayer optical networks

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Abstract—**This paper proposes the combination of the so-called lightpath bundling (LB) and anycast switching techniques, as a simple and effective option to increase the performances of multilayer optical networks. LB means that the lightpaths between two nodes are treated as a single connection of aggregated capacity. Anycast switching is proposed for implementing a per-packet-granularity balancing of the traffic among the lightpaths in the same bundle. A simple anycast switching method is proposed for Virtual Output Queueing (VOQ) switches. Also, the LBA-MPA (Lightpath Bundling Aware-Multilayer Planning Algorithm) algorithm is presented to plan the multilayer network exploiting the LB and anycast switching combined benefits. Results obtained suggest that very significant performance improvements can be obtained in existing multilayer networks with minor changes. Finally, the paper discusses related fields open to be further investigated.**

Keywords:* *Multilayer optical networks, performance evaluation, network planning.

I. INTRODUCTION

Multilayer IP over WDM networks are widely deployed in the backbone of current Internet. In multilayer networks, the electronic traffic flows are routed on top of a virtual topology of transparent lightpaths, which are routed on the set of deployed WDM fiber links (or physical topology). The success of the multilayer networks is based on their ability to efficiently combine the electronic packet switching for a finer traffic granularity, and the optical circuit switching for a coarse granularity.

Fig. 1 shows a scheme of a switching node for multilayer networks with *N* input and output fibers, and *W* fibers per link. The OSF (Optical Switch Fabric) transparently switches the lightpaths. It has one input (output) port per input (output) channel, plus a set of input (output) ports for the lightpaths starting (ending) in the node. The electronic switching part of the node is commonly composed of a set input and output Line Cards (LC), connected by the ESF (Electronic Switch Fabric). LCs contain electronic buffers, and in coordination with the ESF, perform the packet switching functionality. The traffic of each lightpath ending (starting) in the node is processed by an input (output) LC, which contains an O/E (E/O) converter. Extra input and output LCs exist for injecting the ingress traffic in the network and receiving the egress traffic respectively. In commercial equipments, input and output LCs are commonly integrated in the same board, with their functions logically separated.

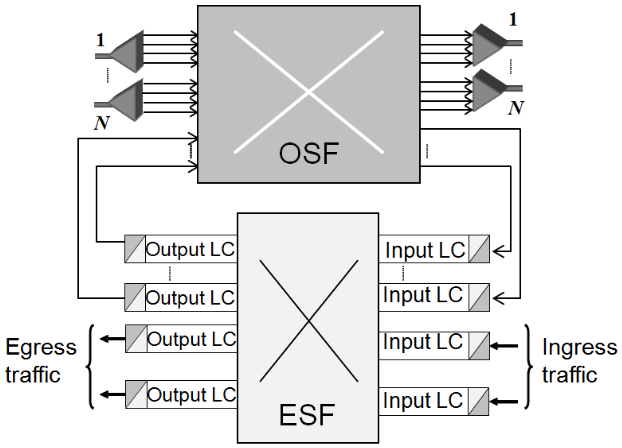

Figure 1. Multilayer switching node

A bundle of lightpaths refers to a set of lightpaths established between the same ending nodes. Lightpath bundling is not a new concept. It was already proposed in the Internet Draft “Link bundling in optical networks” (2001), and included later in RFC 3717 (2004), as a mechanism for reducing the signaling burden in the *control plane*: by bundling together the lightpaths between two nodes, there is a chance e.g. to advertise them together in the routing protocols. In this sense, the lightpath bundling is the natural application of the link bundling principle in GMPLS networks (RFC 4201). As a control plane technique, the lightpath bundling has been also investigated in [1] and [2]. In [1], the authors propose a model for bandwidth adaptation in GMPLS control plane. They assume that IP nodes are connected by bundles of lightpaths, and propose the adjustment of the number of lightpaths in a bundle as a form of capacity adaptation mechanism suitable for optical networks. In [2] the authors propose the application of lightpath bundling (using the expression *lightpath aggregation*) to perform a hierarchical GMPLS-based control plane for ASON networks.

In this paper, we are interested on investigating the benefits that lightpath bundling can yield to the performance of the *data plane* of multilayer networks. The key requisite for exploiting the bundling benefits is the balancing of the traffic among the lightpaths in the bundle. To this aim, we explore the implementation of a so-called *anycast switching* functionality in the high-performance packet switches of the multilayer network. Anycast switching means that the output line card of a packet can be chosen among all the output line cards corresponding to the lightpaths in the bundle. Thanks to this new degree of freedom (with respect to unicast switching), electronic switches have the opportunity to improve their performance, while at the same time implementing a very fine (per-packet) granularity. The per-packet granularity of the balance makes this technique different to other traffic balancing alternatives (e.g. like Ethernet 802.1AX standard), which define a per-flow granularity balancing. Applying a per-flow granularity means that the flow the packet belongs to should be identified at wire-speed, and then the packets of the same flow are switched to the same output link, using conventional unicast switching.

The benefits of anycast switching are (i) a finer and more perfect balance, (ii) without the need of wire-speed packet flow identification. This comes at a cost of not guaranteeing that packets of the same TCP flow follow the same sequence of lightpaths, which may produce packet out-of-order. To avoid large differences in packet propagation times, all the lightpaths of the same bundle are forced to follow the same sequence of fibers. Still, some differences can happen in end-to-end delay between the packets traversing the same bundle. However, we conjecture that in the multilayer network context, this misordering will very likely not affect the TCP performance. This is because, in backbone links a large amount of TCP flows share the lightpaths, and packets of the same TCP connection are commonly interleaved with many packets from other connections, reducing the chances of packet-out-of-order within one TCP flow.

The seminal contribution of this paper is proposing the combination of lightpath bundling and anycast switching, as a promising option for enhancing the performance of multilayer networks. Then, a simple implementation of anycast switching is proposed, which can be seamlessly integrated in high-performance VOQ switches with little changes in the data path. Afterwards, we propose the Lightpath Bundling Aware Multilayer Planning Algorithm (LBA-MPA). This is a novel planning algorithm for multilayer networks, the first, to the best of the author knowledge, specifically designed to intensify the lightpath bundling and exploit their statistical multiplexing gain benefits. We assess the quality of this multilayer algorithm using several optimality bounds. Then, we evaluate the combined benefits of the lightpath bundling and anycast switching by comparing the average electronic buffering delay in multilayer networks with and without their application. Results show a reduction in the average network buffering delay in up to 40%, thanks to the application of these techniques.

The rest of the paper is organized as follows. Section II elaborates on a simple anycast switching technique and Section III presents the LBA-MBA algorithm. Evaluation results are presented in Section IV. Finally, Section V concludes.

II. ANYCAST ELECTRONIC SWITCHING

This section proposes a simple method to implement the anycast functionality in conventional electronic switching architectures like the one in Fig. 1, based on the Virtual Output Queueing (VOQ) technique. In these switches, arriving packets are buffered in the input LCs, wait their turn to traverse the electronic switching fabric (according to a scheduling algorithm), and are again potentially buffered in the output LC before being transmitted. The memory in the input LC is virtually split into separated queues (called VOQs), each containing the packets addressed to each output LC. Optionally, packets can be chopped in fixed size cells (e.g. 64 bytes) which are independently transmitted, and reassembled in the output LC.

We propose and test a quite simple scheme which can be seamlessly integrated in any VOQ switch. Let p be an arriving packet targeted to output bundle b. Let b_D denote the bundle degree. That is, the number of lightpaths in the bundle. Each lightpath in the output bundle has one VOQ associated in the input LC. Then, the proposed scheme consists of selecting the least loaded VOQ of the LC, among those ones associated to the lightpath in the bundles. After that, the rest of the data path remains unmodified. In particular, this method requires changes in neither the switching fabric hardware, nor the VOQ scheduler design. Naturally, if any chopping/reassembling scheme is present, all the cells of the packet should be targeted to the same output LC. Finally, note that the output LC decision is made independently by each input LC. This is a critical aspect that eases the practical feasibility of the scheme.

The proposed mechanism uniformly distributes the traffic among the lightpaths in the output bundle. To illustrate the benefits of this mechanism, Fig. 2 shows the average delay performance of packets arriving to a LC targeted to a given output bundle. Exponential interarrival times are considered. Packet lengths are independently chosen according to a trimodal distribution [3] (40, 552 and 1500 bytes, with probabilities 58%, 33% and 9%). The output bundle is supposed to receive traffic only from this LC. We also assume that the switch arbitration is able to emulate an output buffering operation. Results are plotted for bundle degrees b_D={1,…,20}, and system utilization u={0.1,…,0.95}. The average delay is normalized by the average packet length (340.36 bytes). Results are a sign of the potential benefits of the anycast switching, even for a moderate bundle degree.

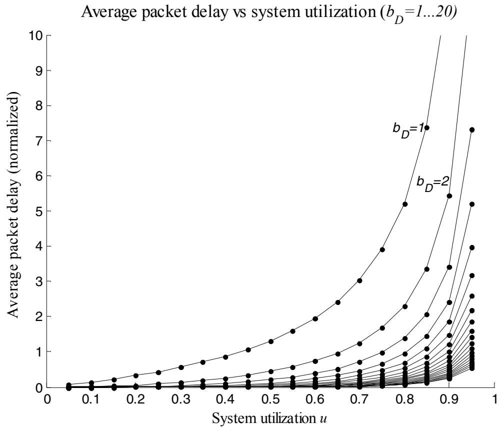

Figure 2. Potential lightpath bundling effects evaluation

III. BUNDLING-AWARE MULTILAYER PLANNING ALGORITHM

This section presents the LBA-MPA algorithm (Lightpath Bundling Aware Multilayer Planning Algorithm). Given an electronic traffic demand and a physical topology in the network, the LBA-MPA computes a valid multilayer planning. That is, the (i) set of lightpaths to establish and their routes, (ii) the allocation of the traffic flows on top of the lightpaths.

The planning objective is triple: (i) minimize the network cost evaluated as the number of transceivers required, (ii) choose lightpath routes which permit to maximize the bundling degree, and (iii) route the traffic on top the lightpath bundles taking benefit of the better delay performance in larger bundles.

A. LBA-MPA algorithm

LBA-MPA algorithm is composed of four consecutive steps:

Step 1. (Virtual Topology Design). The heuristic algorithm in [4] is used to calculate (i) the number of lightpaths to be established between each pair of nodes minimizing the number of transceivers used, and (ii) a valid flow allocation on top of this virtual topology. This step depends of input parameter $u \leq 1$: the maximum traffic in Erlangs that can be carried by a lightpath.

Step 2. (Lightpath routing). The lightpaths are routed on the fibers by optimally solving an integer multicommodity flow problem, where the lightpaths are the commodities, and the capacity in the links is given by the number of wavelengths in the interconnection fibers. The objective function is set to minimize the average number of physical hops of the lightpaths. As shown in the results section, this objective function has shown to find solutions which result in a high lightpath bundling degree.

Step 3. (Wavelength Assignment). The lightpaths are sequentially processed, and a wavelength is assigned to each one in a first-fit scheme. Wavelength converters are not permitted.

Step 4. (LBA Flow Allocation). A new flow allocation is calculated which intends to minimize the average network delay, taking benefit of the lightpath bundling. This new flow allocation substitutes the one calculated in Step 1 of the algorithm.

Note that the algorithm may terminate after Step 2 when it does not find a feasible routing for the set of lightpaths calculated in Step 1, or in Step 3 if a valid wavelength assignment is not found. Step 2 determines the routes of the lightpaths and thus the lightpath bundles: all the lightpaths with a common input node, output node, and sequence of traversing nodes are supposed to be bundled together. Step 4 of the algorithm intends to find a flow allocation which exploits the statistical multiplexing gain of the lightpath bundles. The average network delay minimization is chosen as a suitable mean to achieve this end. By minimizing the average network delay, more traffic is allocated in bundles of higher degree, which may have now an utilization higher than the threshold u defined in Step 1. The exact procedure is described in next subsection.

B. LBA Flow Allocation

Let N denote the set of nodes and D denote the set of demands (or flows) in the network. For each $d \in D$, $d^{(i)}$ and $d^{(e)}$ denote the initial and end nodes of the demand respectively, and h_d the demand size in Erlangs. Let B denote the set of lightpath bundles in the network. For each $b \in B$, b_D denotes the bundling degree, and $b^{(i)}$, $b^{(e)}$ denote its initial and end node respectively.

The LBA-FA step we propose consists of solving a multicommodity flow allocation problem of the demands D, into a network with set of nodes N, and set of links given by the bundle set B. The problem to solve is given by (1):

Find:

- f_{db}, $d \in D$, $b \in B$:Erlangs of traffic of demand d allocated in bundle b.
- f_b, $b \in B$, Erlangs of traffic allocated in bundle b.

Subject to:

$$\sum_{b|b^{(i)}=n} f_{db} - \sum_{b|b^{(e)}=n} f_{db} = \begin{cases} h_d, if\ n = s \\ -h_d, if\ n = d, n \in N, d \in D \\ 0\ otherwise \end{cases} \tag{1a}$$

$$f_b = \sum\nolimits_{d \in D} f_{db}, d \in D \tag{1b}$$

The objective function is given by (1c).

$$\text{Min} \frac{\sum_{b \in B} f_b \times \overline{T}(f_b)}{\sum_{d \in D} h_d} \tag{1c}$$

In equation (1c) the function $\overline{T}(f_b)$ represents the average delay suffered by the packets traversing bundle b.

We consider the delay suffered by a packet in each hop across the network as a random variable independent in each traversed bundle (*Assumption* 1). Under this assumption, the objective function (1c) represents the average network delay. Still, a further assumption is made (*Assumption* 2) by considering this average delay as dependent of solely two factors: the traffic in the bundle f_b and the bundling degree, which is an input parameter for the LBA-FA problem (since it was obtained after Step 2).

The key point in this method is that:

1) The expression (1c) is known to be a convex function, as long as $\overline{T}$ is a non-decreasing convex function of f_b. This holds for the traffic models of interest in communication networks. Therefore, the underlying problem is also convex and can be solved in polynomial time.

2) The formulation (1) can be approximately solved even if a closed expression for $\overline{T}(f_b)$ does *not* exist.

In particular, the per hop average delay function $\overline{T}$ can be estimated by means of simulation assuming any selected traffic pattern, in different (f_b,b_D) pairs. Then, the function $f_b \times \overline{T}$ can be approximated by a piecewise linear interpolation traversing the simulated points, resulting in an LP formulation which can be solved with a standard software. This is the approach followed in this paper, making use of the estimation of $\overline{T}$ displayed in Fig. 2.

A note should be made regarding the assumptions 1 and 2 related to the construction of the objective function (1c). The assumptions were suggested by Gallager in the seminal study on the Minimum Delay Routing Problem (MDRP) [5], and resemble the Kleinrock independence assumption for analyzing networks with Poissonian traffic. However, it is well known that both assumptions tend to create (sometimes strongly) optimistic average network delay estimations in networks fed with more realistic traffics. This is mainly because they neglect the extra burstiness in the traffic after traversing the nodes. However, the interest of this objective function is not obtaining an accurate average network delay estimation. Its target is to serve as a useful optimization function which balances the traffic in the bundles, granting a higher utilization to the bundles of higher degree, and exploiting the statistical multiplexing gain. In this sense, other strategies could be applied in the Step 4 of the LBA-MPA algorithm.

IV. RESULTS

A. Testing scenario

To test the validity of the approach, we conduct a series of experiments for the Internet2 network topology, and the traffic matrix *M* proposed in [6] for this network. We assume W={40,80} wavelengths per fiber. In each case, we compute the maximum multiplying factor α_W, for which the traffic matrix $\alpha_W M$ could be satisfied by the network. This can be solved by the linear program (2). It follows a similar notation as in (1), changing the set of bundles *B* by the set of fibers in the Internet2 topology *E*, and using traffic matrix *M* for defining the demand set *D*. Note that $\alpha_W \cdot M$ is then the maximum multiple of traffic matrix *M* that can be carried by the network.

Find: $\alpha_W, f_e, e \in E$, which Max $\{\alpha_W\}$, subject to:

$$\sum_{e|e^{(i)}=n} f_{de} - \sum_{e|e^{(e)}=n} f_{de} = \begin{cases} \alpha_W h_d, if\ n = s \\ -\alpha_W h_d, if\ n = d, n \in N, d \in D \\ 0\ otherwise \end{cases} \tag{2a}$$

$$\sum\nolimits_{d \in D} f_{de} \le W, e \in E \tag{2b}$$

Next, the LBA-MPA algorithm is executed 18 times for each W={40,80}, u={0.6,0.9} instance, one for each network load factor ρ={5%, 10%,…,90%}. The input traffic matrix to the algorithm is given by $M(W,\rho)=\alpha_W \cdot \rho \cdot M$. That is, a fraction ρ of the maximum traffic the network could optimally satisfy with the traffic profile *M*, if the lightpaths were loaded at 100%. Naturally, no valid planning can be found for a problem with a parameter $u<\rho$. As will be shown later, the algorithm succeeds in finding multilayer feasible solutions for values of ρ very close to u.

The LBA-MPA algorithm was implemented in the MatPlanWDM tool [7], which links to the TOMLAB/CPLEX solver [8]. The running time of the algorithm was below 3 seconds in all the cases. If a feasible solution is found by LBA-MPA, the performance of the resulting network is evaluated by means of simulation. The target is observing the improvements in the packet delay performance in the network thanks to applying the lightpath bundling.

The simulations are implemented in the OMNeT++ framework [9]. Scripts are used to automate the generation of the network models from the solutions obtained by the LBA-MPA algorithm. Traffic injection is implemented as virtual circuits with the sequences of traversed lightpath bundles given by the network plan. The ingress traffic pattern in each virtual circuit follows the same packet length and interarrival time distribution as the one described for Section II. For the sake of simplicity, each node is assumed to have infinite memory, and to implement a VOQ arbitration able to emulate output buffering behavior. The buffering delay of the packets to traverse the switch in the destination node is removed from the computation. This is because its buffering delay does not depend on the bundling policy, and just on the number and load of the egress line cards. The simulation stops when at least 5E8 packets are processed by each node. Five samples are obtained in each simulation point, and confidence intervals are calculated by the *t*-Student method.

B. Quality of the LBA-MPA bundling algorithm

This section is targeted to assess the quality of the solutions provided by the LBA-MPA algorithm in terms of: (i) carried traffic, (ii) network cost, and (iii) average bundling degree in the network.

Table I shows the maximum load factor ρ for which the LBA-MPA algorithm finds a feasible solution, together with the resulting total carried traffic. As shown, feasible solutions are found for a load ρ close to the upper bound given by *u*.

TABLE I. MAXIMUM LOAD FACTOR ρ

	***u*=0.6**	***u*=0.9**
***W*=40**	0.55 (188.5 E)	0.80 (274.2 E)
***W*=80**	0.55 (377.1 E)	0.85 (582.8 E)

Table II illustrates the quality of the algorithm from the perspective of its ability to find solutions with a low cost (low number of lightpaths). The number of lightpaths planned $|L|$ is compared to a lower bound ($|L_{min}|$) to the optimum minimum cost. $|L_{min}|$ is calculated by (3). It is the maximum between two lower bounds: the one given by counting the minimum number of E/O transmitters in each node to carry the injected traffic, and the analogous lower bound for the egress traffic and O/E receivers.

$$|L_{\min}| = Max\left\{ \sum_{n\in N}\sum_{d|d^{(i)}=n} \frac{h_d}{u}, \sum_{n\in N}\sum_{d|d^{(e)}=n} \frac{h_d}{u} \right\} \quad (3)$$

Only some representative load values are shown in Table II. The rest of the values calculated follow the same trend, and show that the cost of the network planned is very close to the lower cost bound calculated.

TABLE II. NETWORK COST COMPARISON (|L| / |L_{MIN}|)

	W=40		*W=80*	
	u=0.6	*u*=0.9	*u*=0.6	*u*=0.9
ρ=0.2	124 / 119	87 / 80	238 / 233	163 / 157
ρ=0.3	183 / 177	124 / 119	353 / 349	238 / 233
ρ=0.4	238 / 233	163 / 157	467 / 462	316 / 309
ρ=0.5	296 /288	201 / 195	582 / 575	394 / 386
ρ=0.55	325 / 318	221 / 214	639 / 632	429 / 423
ρ=0.7	**	279 / 272	**	543 / 537
ρ=0.8	**	316 / 309	**	620 / 614
ρ=0.85	**	**	**	659 / 653

Now, we are interested in assessing the quality of the LBA-MPA algorithm, according to its capacity to find lightpath routes which allow a high bundling degree. For this, the average bundling degree $b_D^{AV} \geq 1$ of each planning is compared against a suitable comparing value selected (b_D^*). The former is given by the number of lightpaths divided by the number of bundles. The latter is obtained as if each demand $d \in D$ is routed by direct lightpaths (without traffic grooming) and that all the lightpaths for the same demand traverse the same route, and thus are bundled together. Note that b_D^* is an upper bound to the bundling degree if traffic grooming is not present in the network. Both are calculated as shown in (4).

$$b_D^{AV} = \frac{|L|}{|B|}, \qquad b_D{*} = \frac{\sum_{d\in D}\left\lceil \frac{h_d}{u} \right\rceil}{|D|} \quad (4)$$

Table III displays the obtained values. The average bundling degree of the network is higher for a higher number of lightpaths in the network, which itself is favored by: (i) higher load factors ρ, (ii) higher number of wavelengths W, and (iii) lower utilization values u. In fact, an almost exact linear relation was found between the number of lightpaths and the average bundling degree. Finally, the proximity of the b_D and the b_D^* values is a sign that supports the quality of the algorithm.

TABLE III. AVERAGE BUNDLING DEGREE (|B_D| / |B_D[*]|)

	W=40		*W=80*	
	u=0.6	*u*=0.9	*u*=0.6	*u*=0.9
ρ=0.2	1.7 / 2.0	1.2 / 1.6	3.3 / 3.6	2.3 / 2.6
ρ=0.3	2.5 / 2.9	1.7 / 2.0	4.9 / 5.3	3.3 / 3.6
ρ=0.4	3.3 / 3.6	2.3 / 2.6	6.5 / 6.9	4.4 / 4.7
ρ=0.5	4.1 / 4.5	2.8 / 3.2	8.1 / 8.5	5.5 / 5.8
ρ=0.55	4.5 / 4.9	3.1 / 3.4	8.9 / 9.2	6.0 / 6.3
ρ=0.7	**	3.9 / 4.2	**	7.5 / 7.8
ρ=0.8	**	4.3 / 4.7	**	8.6 / 8.9
ρ=0.85	**	**	**	9.0 / 9.4

As a conclusion, the results in this section validate the LBA-MPA algorithm according to its ability to: (i) carry an amount of traffic close the theoretical maximum, (ii) providing low cost solutions, and (iii) with a high lightpath bundling degree quality.

C. Link delay benefits

The objective of this section is to support the validity of the lightpath bundling and anycast switching techniques, as a suitable and successful combination for multilayer networks. To do so, we conduct two different simulations for each value of *W*, *u* and ρ for which a valid planning was found:

1. We simulate a network of electronic switching nodes connected by the lightpaths planned by the LBA-MPA algorithm, applying the anycast switching feature described in Section III.

2. We simulate a conventional multilayer network planned according to Step 1-3 of LBA-MPA algorithm. Therefore, the lightpaths with the same route are not bundled together, and the flow allocation is the one obtained in Step 1, which limits the utilization of a lightpath by *u*.

The average network delay performance with respect to the carried traffic is shown in Fig. 3-(a)(b). The graphs show that the lightpath bundling is able to decrease the average network delay between 10% and 40% with respect to the conventional multilayer approach. The average delay is approximately constant with the network load in conventional networks, since a constant maximum utilization *u* of the lightpaths is applied. However, a slight trend is observed in LB case, where the *higher* the carried traffic, the *lower* the network delay when the lightpaths can be bundled. This slight trend is explained by the fact that more traffic results in better chances to bundle lightpaths together. Then, higher bundle degrees are the source of a more intense traffic balancing. The steep increase in network delay for low loads is caused by the higher proportion of traffic grooming that Step 1 of the LBA-MPA algorithm introduces at these loads: low loaded lightpaths are filled with traffic groomed to minimize the transceivers cost. Higher grooming means higher burstiness in the electronically switched traffic, and higher average packet delay. The small irregular variations found in the average delay for *u*=0.9 are caused by the discrete nature of lightpath bundling, and are coherent with the (larger) confidence intervals found for these simulations.

A note should be made regarding the average packet delay measures. The absolute values of normalized average delay obtained even for high loads (<12), are much lower than the ones observed in real networks. This is caused by the adoption of the exponential interarrival time. As a further work, a battery of tests is planned applying a more realistic self-similar traffic pattern, and observing other network indicators like packet delay jitter or memory usage in the LCs. Definitely, the absolute values of average delay obtained will be higher in this case. However, the relative decrease in the average packet delay obtained by the bundling is expected not to vary significantly.

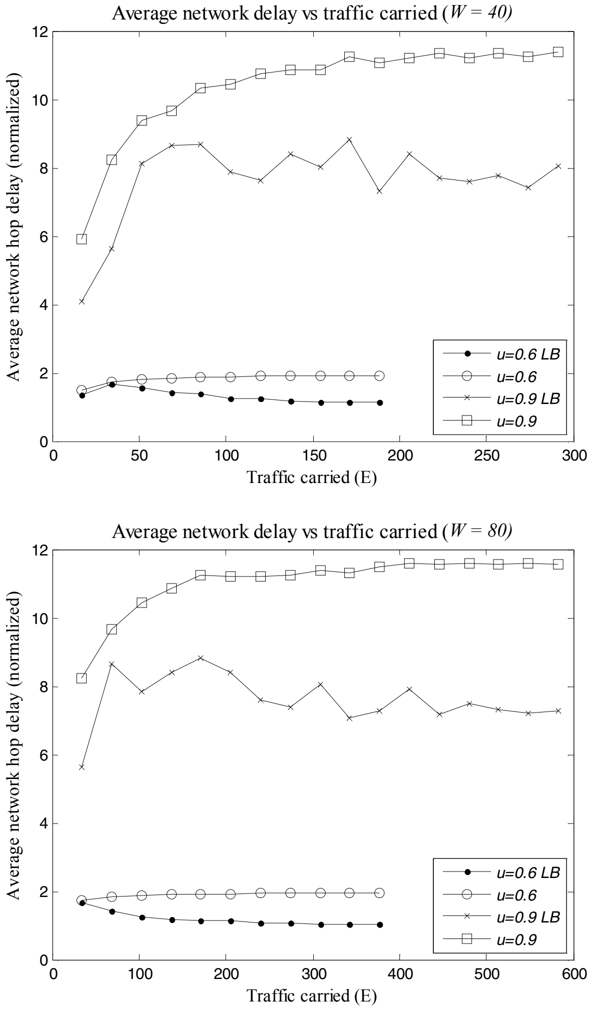

Figure 3. Average network delay performance. (a) *W*=40, (b) *W*=80

V. CONCLUSION AND FINAL REMARKS

This paper presents the lightpath bundling and anycast switching techniques, as a promising alternative for cost-effectively improving the performances of existing multilayer optical networks. A simple implementation of anycast switching, and a LB-aware multilayer planning algorithm are proposed. Preliminary results obtained, support this approach. The field is open to further studies which investigate on the many network engineering aspects related to the application of lightpath bundling and anycast switching concepts. The rest of this section is devoted to add some final remarks in this line.

From the network planning point of view, a LB-aware planning suggests the introduction of a figure like the average bundling degree in the network as a merit to optimize. In the network resilience side, the bundling of lightpaths can be a natural way of providing fault tolerance to lightpath failures. In its turn, the capacity planning may be addressed by using concave link dimensioning functions to capture the fact that higher bundle sizes result in higher traffic that can be carried with the same network performance (thanks to the statistical multiplexing gain). These functions add significant complexity to the planning problem, and challenge the design of effective planning algorithms.

From the switching architecture point of view, this paper suggests the introduction of *anycast switching* capabilities in the existing high-performance packet switches. We preferred to coin the term anycast switching, which strangely seems to be new in the literature. This is because the switching architecture determines the cost vs. performance trade-offs in its implementation. Thus, it is fair to emphasize the leading role of the switch in this technique. Open research topics to consider are the switching of multicast-anycast traffic, packet-out-of-sequence minimization, implementation of anycast switching in multistage or multiplane switching architectures, or matching algorithms specifically designed to take benefit of the anycast degree of freedom.

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