

Dimensioning of Optical Label Switched Networks: A QoS-based Approach

Yassine Khelifi, Sihem Guemara El Fatmi, and Nouredine Boudriga

Communication Networks and Security Research Lab. University of November 7th at Carthage, Tunisia

Corresponding author e-mail: nab@supcom.rnu.tn

Abstract— To support the growing demand for transmission, Optical Label Switching (OLS) technology is an attractive candidate for providing fast switching and Quality of Service (QoS) support. In this paper, we propose a planning and dimensioning approach suitable for OLS networking through the use of an enhanced core node architecture and dynamic QoS management. A dynamic differentiation is implemented using a contention resolution technique that is based on optical buffering and link capabilities. We also develop a theoretical model and formulate the dimensioning problem based on a conservation law and a queuing model. Finally, the proposed approach is evaluated through simulation work.

I. INTRODUCTION

With the fast growing of Internet traffic, optical switched networks must provide a large bandwidth and fast data transmission rates, as well as support for Quality of Service (QoS) provision. Currently, Dense Wavelength Division Multiplexing (DWDM), as a key transmission technology, can support transmission rates of more than 1 Tbps per fiber, [1]. To fully utilize such high data rates, Optical Label Switching (OLS) has been proposed, where data traffic are transmitted rapidly in the all-optical domain. Over OLS core, data traffics are transmitted using a set of labels built during an out-of-band signaling scheme. This scheme is performed in order to create the Label Switching Path (LSP) and update switching table of the core nodes along the related LSP [2].

OLS technology can support static or prioritized QoS model, where the service differentiation is provided based on IP packet priorities and the service requirements for a given class are defined using this priority. Unfortunately, the dimensioning task using this model cannot comply with constraining client application QoS requirements because QoS management is done based on class priority only. In [4] a QoS model and dynamic scheme was proposed to provide service differentiation based on a set of specific traffic parameters, such as loss and delay. The requested set of constraints can be guaranteed for the requester independently of the network behavior.

Planning is a critical task in optical switched network, since network design and data transmission costs are fundamental criteria in the networking and operation. Planning can be made based on two concepts: dimensioning and optimization. The formulation of the related problem is an important design consideration in OLS networks. The network cost optimization has the objective of minimizing network component cost while maximizing network resource utilization. The network traffic optimization aims at maximizing the accepted

traffic and guaranteeing its requested QoS requirements while reducing resource utilization.

To our knowledge, there is no previous work that has considered the optimization of network design cost and traffic management in OLS networks, especially providing the optimization of link and buffering capabilities. In most of the existing work related to dimensioning, authors have attempted to solve the problem by minimizing the link and lighthpath capabilities in wavelength routing networks [7]. Other works (e.g., [8, 9]) have addressed traffic grooming and virtual topology optimization for wavelength routing and resource assignment, using traditional methods including integer linear programming or heuristic methods, such as the genetic algorithm, Tabu-search, and simulated annealing. However, most of these methods do not take into account the QoS requirements.

In this work, we develop a scalable dimensioning scheme and formalize it using two QoS parameters: delay and loss. Our approach builds on a node architecture we have proposed in [3] and shows that it is suitable for OLS technology. It considers the optimization of buffering and wavelength capabilities at the network design phase. We also develop an analytic model and optimization/dimensioning problem formulation based on a conservation law [6] and queuing model. The analytic model considers dynamic QoS scheme in which contention is managed based on a dynamic buffering. We also provide a numerical simulation that validates the efficiency of the proposed models.

The paper is organized as follows. Section II briefly describes OLS network and core node architectures. It discusses the management of dynamic QoS. It also presents a dimensioning and optimization problem formulation suitable for node-based, path-based and network with general traffic. Section III develops an analytic model for planning and optimization and analyses a technique using a conservation law and queuing model. Section IV discusses the performance evaluation of the proposed models through simulation work. Section V concludes the paper.

II. OLS NETWORK ARCHITECTURE

A. OLS core node and network architectures

An OLS network consists of a collection of edge and core nodes. Newly arriving IP packet traffics are received at ingress edge nodes, which identify the switching information and QoS requirements. Based on the collected information, an out-of-band signaling scheme is performed in which a set of labels is created in order to build the optimum LSP. During LSP building, an appropriate lighthpath is set up and used to transfer the

data traffic over OLS core from ingress to egress nodes. The OLS core consists of a set of core nodes interconnected with DWDM links that insures switching process based on created LSP.

A node is composed of M input and M output ports. Each port can handle a number of wavelengths and a set of multiplexers and demultiplexers. k wavelengths are dedicated to data traffic transport and one wavelength is used for signaling and survivability. The main components of the OLS switch are: the input processing unit (IPU), switch control unit (SCU), switch fabric unit (SFU), waiting unit (WU), and output processing unit (OPU). The readers can find in [3] a detailed description of the core node components. We present now a briefly description of the main components.

- The SCU is responsible for monitoring the switching labels in contention case. It supervises the switching process of new label framework [4] with the contented packets when using wavelength conversion or ODL buffering. The SCU is used by the core nodes to switch the packet based on the labels to the intended destination.

- The WU is composed of a set of shared multi-wavelengths ODL buffers. ODL length is equal to packet time slot duration which is represented the required buffering delay for a contented packet. WU uses feedback ODL buffers [5] which may increase the node buffering capacity. This ODL kind allows the opportunity that a packet emerging from an ODL may be buffered more than once when successive contentions occur.

B. Dynamic QoS engineering

An important issue in OLS networks aims at providing differentiated service in order to support applications requirements. The existing QoS schemes focus on the loss and delay differentiation, or bandwidth guarantees. In static scheme, the data traffic is processed based on a priority concept stored in the switching labels. The priority is used to resolve contention. This approach is characterized by an inefficient performance control and the independence of performance of the high-priority traffic with respect to the low-priority traffic. In addition, all constraints cannot be guaranteed and the traffic performance can be affected by node behaviors.

In a dynamic model, the differentiation is made based on a set of QoS performance parameters. The reader can find in [4] the details description of this scheme in which each traffic type, T_i requires a maximum packet blocking delay, D_i^{max} , and a maximum packet loss, L_i^{max} . The end-to-end packet delay constraint is expressed by an ODL buffering number and each core node ensures that buffering does not exceed a certain delay bounded by D_i^{max} . Also, each core node maintains a loss guarantee, L_i^{dyc} , for the traffic type, T_i , and the packet loss is calculated using established LSPs. Consequently, if L_i^{dyc} is guaranteed for each core node, L_i^{max} is guaranteed for related LSP. Then, L_i^{max} is equal to the sum of L_i^{dyc} depending on node number.

The algorithm calculates the buffering delay D_i^{dyc} of traffic of type i on each core node. When contention occurs, the algorithm compares the differences ($D_i^{max} - D_i^{dyc}$ and $D_j^{max} - D_j^{dyc}$) and differences ($L_i^{max} - L_i^{dyc}$ and $L_j^{max} - L_j^{dyc}$) for the contented packets (traffic i and traffic j). Based on these differences, the contented packet can be

switched to original/alternative path or buffered/dropped. An out-of-band signaling is used to circulate the label controls between LSP nodes.

C. OLS network Dimensioning and Optimization

The objective of an optimization method is to achieve the best possible performance within the limits of physical constraints provided by the architecture described in the previous section, [3]. In this architecture, we have implemented a contention resolution mechanism based on wavelength converting and buffering capability (in that order). The architecture uses a large buffering capability (in WU), which can be optimized in order to minimize node cost and maximize node performance.

For this, we introduce two new approaches to optimize node design and enhance performance. Our first approach is to provide an appropriate optimization formulation of WU capacity with the goal to maximize buffering efficiency. In the second approach, we provide another formulation to find the least wavelength number. In first approach, a node-based model uses a dynamic engineering based on two QoS performance parameters: loss and blocking delay. The model is then extended to provide a suitable formulation of the lighthouse dimensioning through the use of the node architecture discussed previously. Finally, the global optimization problem formulation is discussed in the presence of traffic flowing from everywhere.

III. ANALYTICAL MODEL FOR PLANNING

A. Node-based modeling

1) Modeling

We assume an OLS core node with N traffic types labeled 0,1,...,N-1 which composed of variable-length traffic packets. Let T , d , and k denote respectively a mean packet length, ODL number in WU, and wavelength number available at the output port. The accepted traffic is assumed to require a maximum packet loss, L^{max} , and a maximum packet blocking delay, D^{max} . We specify the end-to-end packet delay constraints as an integer number, m_i that is used to resolve contention. Let $PT_{i,j}$, for $0 \leq j \leq m_i$, represents the traffic sub-type consisting of packets of type i which have been switched and buffered j times. $PT_{i,0}$ represents new arriving packets of type i at the related node. The arriving packets of type i flowing to a specific output port of a node follow Poisson process with rate λ_i . Packet addressed to a given output port are transmitted with needed QoS parameters, status of QoS parameters and integrate the adequate traffic sub-types.

Finally, $B_{i,j}$ and $F_{i,j}$ denote the blocking probability due to the lack of wavelengths and ODLs for the traffic sub-type $PT_{i,j}$. Once the above assumptions are made, it becomes clear to model an output port at core node. This model is an open queuing network system where node composed of two queues, as depicted in Figure 1. Queue 1 (say q1), which represents the output port transmission packet, has an $M/D/k/k$ preemptive dynamic QoS parameters. Queue 2 (say q2), which represents the WU, has an $M/D/d/d$ type. The whole system is assumed to handle $N*(m_i+1)$ packet sub-type, $PT_{i,j}$.

Let us consider now the path followed by a packet through the queuing network. The newly arriving packet

($PT_{i,0}$) can be serviced immediately or be moved. In the first case, q1 is allocated to this packet during a fixed service time T , and then leaves the system. In the second case, the packet is sent to q2 where it can be served or be dropped. When the packet is served, the q2 is allocated during a deterministic service time equal to T . Once its service at q2 is completed, it moves to q1 as a packet of the traffic of sub-type $PT_{i,1}$. It tries again to get hold of q1, and so on, until it succeeds to get hold of q1, or be dropped. Let note that each time the packet returns to q1, its traffic sub-type is updated to define $PT_{i,1}, PT_{i,2}, \dots, PT_{i,m_i}$. Because the upper bound is fixed in terms of packet buffering number (m_i), a packet of the traffic sub-type PT_{i,m_i} that cannot seize one server at the packet transmission queue will be dropped. Recall that each packet transmitted from q1 to q2, where j is less than m_i , needs to be buffered, or discarded if all ODLs are busy.

2) Model analysis

• Performance metrics analysis

Let $PLMR_i$ and $PBMD_i$ denote the packet loss mean rate and the packet-blocking mean delay for traffic type i , $0 \leq i \leq N-1$. Based on the proposed queuing model, we can establish the expressions for evaluating the considered performance metrics for traffic type i .

$$PLMR_i = \left[\begin{array}{l} B_{i,0} F_{i,0} + \prod_{j=0}^{m_i} B_{i,j} \prod_{j=0}^{m_i-1} (1 - F_{i,j}) \\ + \sum_{k=0}^{m_i-1} \prod_{j=0}^k B_{i,j} \prod_{j=0}^{k-1} (1 - F_{i,j}) F_{i,k} \end{array} \right] \quad (1)$$

$$PBMD_i = \sum_{j=1}^{m_i} jT (1 - B_{i,j}) \prod_{k=0}^{j-1} (1 - F_{i,k}) B_{i,k} \quad (2)$$

The expressions can be stated as follows: Let $PLMR_{i,0}$ denotes the loss probability of a new arrival packet of traffic type i to q1. If the packet is blocked at the queue server, then it is immediately sent to q2. If the packet is also blocked at q2, then it is discarded from the whole system, $PLMR_{i,0}$ is given by:

$$PLMR_{i,0} = B_{i,0} F_{i,0} \quad (3)$$

Let $PLMP_{i,m_i}$ denotes the loss probability of an arrival packet of traffic type i which is blocked (m_i-1) times at q1 and accepted at q2 (m_i-1) times, where m_i represents maximum delay threshold. If the packet is blocked again in q1, then it immediately is dropped from the system, $PLMP_{i,m_i}$ is given by:

$$PLMR_{i,m_i} = \prod_{j=0}^{m_i} B_{i,j} \prod_{j=0}^{m_i-1} (1 - F_{i,j}) \quad (4)$$

Let $PLMP_{i,j}$ denotes the loss probability of an arrival packet of traffic type i which can be blocked j times at q1 and be also accepted j times at q2. For each traffic sub-type $PT_{i,j}$, a packet can be blocked and be dropped at q2, where $0 \leq i \leq N-1$, $1 \leq j \leq m_i-1$, $PLMP_{i,j}$ is given by:

$$PLMR_{i,j} = \sum_{k=0}^{m_i-1} \prod_{j=0}^k B_{i,j} \prod_{j=0}^{k-1} (1 - F_{i,j}) F_{i,k} \quad (5)$$

By computing $PLMP_{i,j}$ at q1 and q2, and by summing $PLMP_{i,j}$ for each traffic sub-type $PT_{i,0}$, where $0 \leq i \leq N-1$,

$0 \leq j \leq m_i$, we obtain the expression of the $PLMP_i$ as is presented in (1). Let $PBMD_{i,1}$ denotes the blocking mean delay of an accepted packet of traffic type i at the core node. This packet is blocked one time at q1 and it is served successively by q2 and after by q1, $PBMD_{i,1}$ is given by the following expression:

$$PBMD_{i,1} = T (1 - B_{i,1})(1 - F_{i,0}) B_{i,0} \quad (6)$$

Let now $PBMD_{i,2}$ denotes the blocking mean delay of an accepted packet of the traffic type i , $PT_{i,2}$ at the core node. $PBMD_{i,2}$ is given by the following expression:

$$PBMD_{i,2} = 2T (1 - B_{i,2})(1 - F_{i,1}) B_{i,1} (1 - F_{i,0}) B_{i,0} \quad (7)$$

After computing the previous expression for each sub-type $PT_{i,j}$ and summing $PBMD_{i,j}$ at core node, one can obtain the expression of $PBMD_i$ as is presented in (2). As shown in the established expressions of the considered performance metrics, we notice that the evaluation of these metrics require the analysis of the blocking probabilities for the considered traffic sub-types ($B_{i,j}$, $F_{i,j}$ and $0 \leq j \leq m_i$). The analysis has been conducted based on the use of a conservation law that was initially proposed for the evaluation of burst blocking probabilities in an OBS network with multiple priorities, equal mean burst lengths, and in the presence of preemption scheme [6].

• Blocking probabilities analysis

In order to analyze the blocking probabilities of the different traffic sub-types of the analytical model, we follow the analysis based on the conservation law. Let $\lambda_{i,j}$ and $\rho_{i,j}$ denote the arrival rate and the traffic intensity of the traffic sub-type $PT_{i,j}$, $0 \leq i \leq N-1$, $0 \leq j \leq m_i$. $\lambda_{i,j}$ and $\rho_{i,j}$ are given by the following expressions:

$$\lambda_{i,j} = \lambda_{i,0} \prod_{k=0}^{j-1} B_{i,k} (1 - F_{i,k}), \quad 1 \leq j \leq m_i, \quad \lambda_{i,0} = \lambda_i \quad (8)$$

$$\rho_{i,j} = T \cdot \lambda_{i,j} = \rho_{i,0} \prod_{k=0}^{j-1} B_{i,k} (1 - F_{i,k}), \quad 1 \leq j \leq m_i, \quad (9)$$

Let's recall that $B_{i,j}$ and $F_{i,j}$, $0 \leq i \leq N-1$, $0 \leq j \leq m_i$, denote the blocking probability due to lack of wavelengths and ODL for the traffic sub-type $PT_{i,j}$. Using the conservation law, we could establish the expressions for the analysis of $B_{i,j}$ and $F_{i,j}$ ($B_{0,0}$ and $F_{0,0}$). The blocking probabilities of the traffic sub-type $PT_{0,0}$ the blocking probabilities of the traffic sub-types $PT_{0,j}$, $1 \leq j \leq n$. $B_{i,j}$ and $F_{i,j}$ are given by:

$$B_{i,j} = \frac{\left(\rho_{i,0} \prod_{l=0}^{j-1} B_{i,l} * (1 - F_{i,l}) \right) / k!}{\sum_{l=0}^k \left(\rho_{i,0} \prod_{l=0}^{l-1} B_{i,l} * (1 - F_{i,l}) \right) / l!} \quad (10) \quad F_{i,j} = \frac{\left(\rho_{i,0} \prod_{l=0}^{j-1} B_{i,l} * (1 - F_{i,l}) \right)^d / d!}{\sum_{l=0}^d \left(\rho_{i,0} \prod_{l=0}^{l-1} B_{i,l} * (1 - F_{i,l}) \right)^l / l!} \quad (11)$$

Now, we start solving the node architecture design problem by formulating it as an optimization problem. In this formulation, we consider a node which performs dynamic model and the accepted traffic handled using its QoS requirements (L^{max} and D^{max}). The node maintains for this traffic a dynamic loss guarantee and dynamic blocking delay guarantee. Based on this information, the node can characterize the traffic behavior in contention case. Then, the two functions that we need to minimize successively for a given traffic type i are given by the following set of tasks:

- Minimize (d) such that $PLMR_i \leq L_i$ and $PBMD_i \leq D_i$

For all i in $\{0, \dots, N-1\}$ (12)

- Minimize (k) such that $PLMR_i \leq L_i$ and $PBMD_i \leq D_i$

For all i in $\{0, \dots, N-1\}$ (13)

Where $PLMR_i$ and $PBMD_i$ can be formulated based on two functions F_i and G_i such that: $PLMR_i = F_i(d, k, \lambda_i, \rho_i, m_i)$ and $PBMD_i = G_i(d, k, \lambda_i, \rho_i, m_i)$. For each traffic of type i , we can compute $PLMR_i$ and $PBMD_i$ using expressions (1) and (2). We can also express the aggregate optimization problem by minimizing jointly d and k in F_i and G_i .

B. Path-based modeling

1) Modeling

To develop a path model, we consider a set of n core nodes having the same architecture used for developing node model. The arriving packet of traffic of type i , $PT_{i,j}$, at an output port follows the path through queue network as described in previous section. For the sake of simplicity, Figure 1 shows two consecutive OLS nodes. Using the dynamic model, the traffic of type i is assumed to require L_i^{max} and D_i^{max} , during its transfer from the 1st to the last nodes of the lightpath. Also, each node maintains useful information such as number of packet arrivals and number of packets dropped. The end-to-end packet delay constraint is expressed as integer ODL buffering number, m_i , which is used to resolve contention along the path. In addition to buffering, packet loss mechanism handling is used to guarantee QoS requirements for the accepted traffic. Using the above assumptions, it becomes easy to model an OLS path.

Let $PT_{i,j}^l$, $0 \leq j \leq N-1$, $0 \leq j \leq m_i$, represents the traffic sub-type at the 1st node consisting of packets of type i that have been switched j times to WU of the 1st node in which packets have been buffered successfully j times. $PT_{i,0}^l$ is a new arriving packets of type i at the 1st node. Moreover, we assume that the arriving packets of type i that are addressed to a specific output port of a node follow Poisson process with rate λ_i^l . Let $\delta_{i,0}^l$ output rate of a new arriving traffic type i at 1st core node. We denote the blocking probability due to lack of wavelengths at output port by $B_{i,0}^l$ and the blocking probability due to lack of available ODL in WU by $F_{i,0}^l$, $0 \leq j \leq N-1$, $0 \leq j \leq m_i$ for the traffic sub-type $PT_{i,j}^l$. By using expression in (8), $\lambda_{i,l}^l$ and $\delta_{i,0}^l$ are given by expressions in (14) and (15):

$$\lambda_{i,j}^l = \lambda_{i,0}^l \prod_{l=0}^{j-1} B_{i,l}^l (1 - F_{i,l}^l) \quad (14)$$

$$\gamma_{i,0}^l = \lambda_{i,0}^l (1 - B_{i,0}^l) \quad (15)$$

Let us now consider a path traversed by a packet through the queuing network of the path nodes and suppose that the arriving packet is an element of sub-type $PT_{i,0}^l$, $1 \leq l \leq n$, when path contains n nodes. This packet follows the path through the queuing model as described above and its traffic sub-type is updated according to the duration of stay ($\in PT_{i,j}^l$). We also note that each packet successfully served at $q1$ of the related core node of the path, its traffic sub-type is updated according to following definition $PT_{i,j}^l, PT_{i,j}^{l+1} \dots PT_{i,j}^n$, $1 \leq l \leq n$. Using this, we can defined the output rate of traffic sub-type $PT_{i,j}^n$ at n^{th} node, $\delta_{i,j}^n$ by the following expression:

$$\gamma_{i,j}^n = (1 - B_{i,j}^n) \left(\gamma_{i,j}^{n-1} + \sum_{k=0}^{j-1} \gamma_{i,k}^{n-1} \prod_{l=k}^{j-1} B_{i,l}^n (1 - F_{i,l}^n) \right) \quad (16)$$

The above expression can be proved as follows: Let $\delta_{i,l}^2$ denotes the output rate of traffic sub-type $PT_{i,l}^2$ which defines the output rate of traffic sub-type i have been served one time in first node or in second node at $q2$, $\delta_{i,l}^2$ is given by the following expression:

$$\gamma_{i,1}^2 = \gamma_{i,1}^1 (1 - B_{i,1}^2) + \gamma_{i,0}^1 B_{i,0}^2 (1 - F_{i,0}^2) (1 - B_{i,1}^2) \quad (17)$$

Let now $\delta_{i,j}^2$ be the output rate of traffic sub-type $PT_{i,j}^2$ which defines the output rate of traffic sub-type $PT_{i,j}^2$ have been served j times in first node or in second node at $q2$ server. By using the following definition $\delta_{i,l}^2, \delta_{i,2}^2 \dots \delta_{i,j}^2$ at $q1$ and $q2$ of 2nd node, $\delta_{i,j}^2$ is given by:

$$\gamma_{i,j}^2 = (1 - B_{i,j}^2) \left(\gamma_{i,j}^1 + \sum_{k=0}^{j-1} \gamma_{i,k}^1 \prod_{l=k}^{j-1} B_{i,l}^2 (1 - F_{i,l}^2) \right) \quad (18)$$

By computing $\delta_{i,j}^1, \delta_{i,j}^2 \dots \delta_{i,j}^n$ at $q1$ and $q2$, and by summing $\delta_{i,j}^n$ for traffic sub-type $PT_{i,j}^n$, where $0 \leq l \leq n$, $0 \leq i \leq N-1$, $0 \leq j \leq m_i$, we obtain the expression of $\delta_{i,j}^n$ as presented in (16).

2) Model analysis

• Performance metrics analysis

Let $PLMR_i$ and $PBMD_i$ denote the packet loss mean rate and the packet-blocking mean delay for traffic type i , $0 \leq i \leq N-1$. Based on the proposed queuing network model, we easily establish the following expressions for evaluating the path-based performance metrics.

$$PLMR_i = \left[\sum_{l=1}^n \left(\sum_{k=0}^{m_i-1} \prod_{j=0}^k B_{i,j}^l \prod_{j=0}^{k-1} (1 - F_{i,j}^l) F_{i,k}^l + B_{i,0}^l F_{i,0}^l \right) \right] \quad (19)$$

$$PBMD_i = \frac{\sum_{l=1}^n \sum_{j=1}^{m_i} jT (1 - PLMR_i^l)}{\sum_{l=1}^{n-1} (1 - PLMR_i^l)} \quad (20)$$

The above expressions can be proved as follows: Let $PLMR_i^l$ be the loss probability of a new arrival packet of traffic type i to queuing system of the 1st core node. $PLMR_i^l$ can be computed for this node based on Expression (1) developed for the node-based model. By computing the loss probability of traffic i from the 2nd to

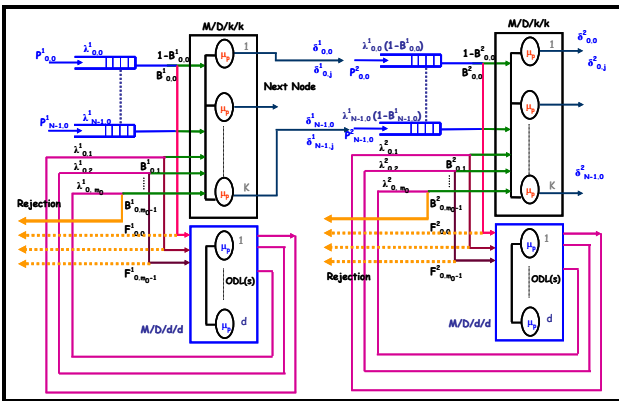


Figure 1: Queuing model of an output port of two successive nodes

the n^{th} node, and by summing the computed loss probability for the initial traffic i , we obtain the Expression (19). Let $PBMD^i$ denotes the packet blocking mean delay of the accepted traffic of type i . $PBMD^i$ can be computed for the 1st core node based on Expression (2). To compute the blocking probability at the 2nd node, we must take into account the packets accepted at 1st node and dropped at the 2nd node. This is because in the blocking probability computation only the accepted packet at the 2nd node can be considered. By considering this definition, and by computing the loss probability as presented by (2) from the 1st to n^{th} nodes, we obtain Expression (20).

Similarly to the optimization problem discussed for a node, we can state and minimize two functions (F and G) for path-based model. In this case, we can compute $PLMR_i$ and $PBMD_i$ using the expressions (1) and (2). We then express the optimization problem similarly expressions (12) and (13).

C. OLS network modeling

To evaluate the performance of an OLS network, we have found it useful to extend the traffic and extract the optimization problem formulation as discussed for the node-based and path-based models. Using the assumptions made for the aforementioned models, it becomes easy to develop an OLS network model. Let $\beta_{i,j}$ denotes the arrival rate of traffic of type i from the 1st node, $\alpha_{i,j}$ denotes output rate of the accepted traffic of type i from another path arriving at node p , and $\theta_{i,j}$ denotes the output rate of overall traffic at this node. $\theta_{i,j}$ can be computed at the p^{th} node based on expressions in (15) and (16) and it is given by the following expression:

$$\theta_{i,j} = \gamma_{i,j} + \alpha_{i,j} \quad (21)$$

Using the computed output traffic rate, one can establish the appropriate expressions to evaluate the considered OLS network performance metrics for traffic of type i in presence of traffic extension.

IV. NUMERICAL RESULTS

A. Simulation Model

1) *OLS network and core node models*: We consider an OLS network with three core nodes organized in a unidirectional ring. Each link between two nodes can support w wavelengths, of which k wavelengths are used to transmit data traffic, and one wavelength is used in signaling and survivability. The configuration of core nodes supposes optical channels with transmission capacity equal to 40 Gbps. The node is equipped with buffering capability used to resolve contention. The traffic generated by an input channel at an edge node is composed of packets with variable lengths. The inter-arrival time between two successive packets is assumed to be exponentially distribution. The traffic generated by an input channel is assumed to be uniformly distributed between the output channels.

2) *Traffic model and performance metrics*: We have considered four traffic types for the arriving packets denoted by $T0$, $T1$, $T2$ and $T3$. $T0$ has the lowest traffic loss and transmission delay tolerance. $T3$ has the highest loss and blocking delay. We assume that the input traffic

ratios of packet traffics are 10%, 20%, 30%, and 40% for traffic types $T0$, $T1$, $T2$, and $T3$, respectively. All packets have a variable length generated uniformly distributed in the interval [250, 1500] bytes. Two metrics have been selected to evaluate the performance of our approach: packet loss mean rate and average packet-blocking delay. The following input parameters have been considered ODL number (d) and wavelength number (k).

B. Numerical Results

We present hereinafter the obtained numerical results to show how the input parameters affect the performance of the proposed model. Before going to present some of these results, we observe that, for all figures, the service differentiation is guaranteed based on the requested performance parameters in terms of loss and delay.

1) *Traffic loss*: Figure 2 shows the impact of ODL number (d) on packets-loss mean rate. The simulation investigates various traffic types that differ according to the requested QoS requirements (D^{max} and L^{max}) using dynamic scheme. The figure shows that the output parameter decreases with the increase of the input parameter especially for $T2$ and $T3$. This is because the increase of d increases the buffering capability, since the contented packets have a better chance to be successfully buffered than being dropped directly (due to the lack of available ODLs). This behavior decreases the packet loss especially of the lowest traffic types due to the assumed traffic ratios. This figure also illustrates mean loss of all traffic types, $PLMR$ and plots maximum loss requirements, L^{max} . As shown, we can clearly determine the minimum ODL number (d_{min} is equal to 6) which solves the dimensioning problem.

Figure 3 shows the impact of wavelength number (k) on the packet-loss mean rate. The figure shows that the output parameter decreases with the increase of k for all traffic types. This is because the increase of k maximizes the use of available resources, wavelength conversion capability and traffic distribution, which decrease the contention case and so packets-loss mean rate. This figure also illustrates $PLMR$ metric and plots L^{max} . As shown, one can clearly determine a minimum number of wavelengths (k_{min} is equal to 7), which can resolve the dimensioning problem.

2) *Blocking delay*: Figure 4 depicts the packet-blocking mean delay versus the impact of ODL number. The figure shows that the output parameter increases with the increase of d , especially for $T2$ and $T3$. This is because the increase of d forces the increase the buffering capability and the chance of successful buffering. The figure also illustrates $PMBD$ and D^{max} in which we can clearly determine minimum d (d_{min} is equal to 6) which can resolve dimensioning problem.

Figure 5 plots the packet-blocking mean delay versus the wavelength number. The figure shows that the output parameter decreases with the increase of the input parameter for all traffic types. This is because the increase of k increases the switching capability and creates a flexible traffic distribution, which decreases the contention probability. Like figure 4, this figure also illustrates $PMBD$ values and plots D^{max} in which we can

determine minimum to number of wavelengths (k_{min} is equal to 7) which can resolve the dimensioning problem.

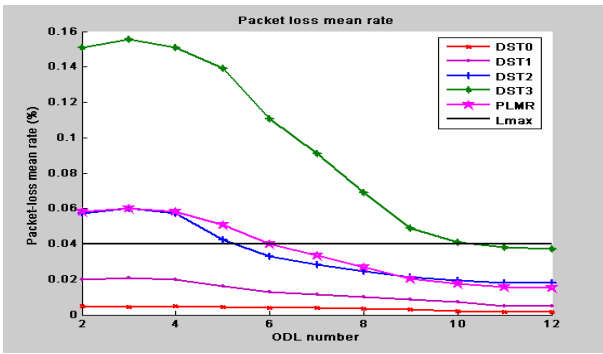


Figure 2: Packets-loss mean rate versus ODL number

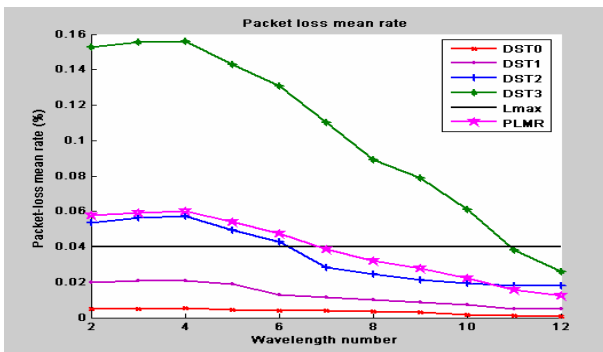


Figure 3: Packets-loss mean rate versus wavelength number

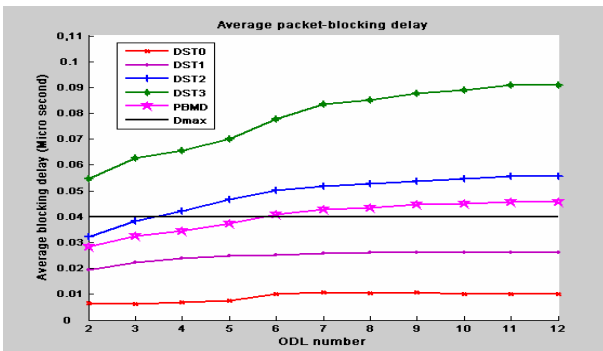


Figure 4: Average packet-blocking delay versus ODL number

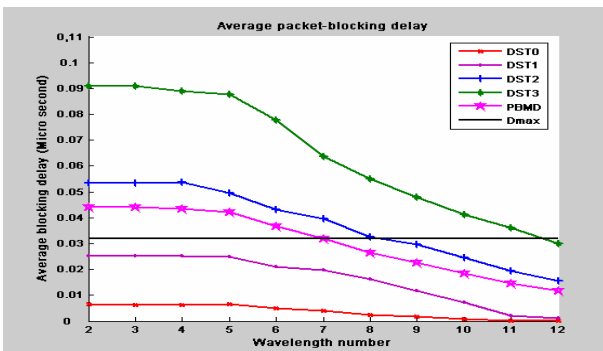


Figure 5: Average packet-blocking delay versus wavelength

As seen in the figures, the minimization of d and k has been considered separately. One can solve the dimensioning/optimization problem by determining k_{min} and d_{min} simultaneously. This task can be achieved by repeating the minimization of each equation using the results obtained with the equation already processed.

To our knowledge, a few works have addressed the problem of resource dimensioning. However, these works have only addressed wavelength routing networks. For this reason our simulation did not include any comparison with a previous work. Nevertheless, we have performed a comparative study between static and dynamic QoS models in [4]. This study has been used here to build our dimensioning approach using the dynamic model and can provide a dimensioning scheme based on the static model. Convinced that latter scheme will have worst performance, we made the choice to not include it in our simulation. Another series of simulation were performed. Due to the lack of space, these results are not mentioned. However, it is worth to notice that these results show that delay and loss increase when the number and the length of packets per traffic grow. These results also show that the aforementioned output parameters decrease with the increase of packet inter-arrival mean rate.

V. CONCLUSION

In this paper, we addressed the issue of dimensioning an OLS network and optimizing the resource allocation. We used a dynamic traffic differentiation and resource provisioning in which the resource is allocated dynamically based on QoS requirements. We proposed a dimensioning approach that is flexible, scalable and suitable for addressing various QoS parameters. This approach is well detailed for node dimensioning and discussed along the transmission lightpath. Moreover, the extension to the whole network and traffic is shown, but its expressions are not established. The formulation of expressions is developed by means of a conservation law and queuing model. We also evaluated the performance of the proposed approach in the simulation work which shows that our models represent a flexible solution suitable for handling the varying traffic demands.

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