Network Protocols and Algorithms
ISSN 1943-3581
2011, Vol. 3, No. 2

# Wavelength Preference in GMPLS-controlled Wavelength Switched Optical Networks

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Received: July 28, 2011 Accepted: August 21, 2011 DOI: 10.5296/ npa.v3i2.819

**Abstract**

Given the potentialities in terms of high bandwidth, low costs, and low power consumption, Wavelength Switched Optical Networks (WSONs) are the most promising candidate for next generation backbone networks. In WSONs the optical signal is switched at the wavelength granularity, therefore the wavelength assignment process plays a crucial role in dynamic network operation.

Generalized Multi-Protocol Label Switching (GMPLS) is the standard control plane for WSONs. However, current GMPLS protocol suite does not envision a general mechanism to rank the wavelengths. The lack of wavelength preference in WSONs may cause high blocking probability, wavelength converter waste, and detrimental effects due to physical impairments.

This paper reviews several WSON scenarios where the wavelength preference concept is introduced to optimize the wavelength assignment: wavelength continuous, wavelength convertible, and quality of transmission aware WSONs. To enforce wavelength preference, an extension to the GMPLS signaling protocol is utilized. Simulation results show that wavelength preference can effectively reduce blocking probability, save wavelength converters, and guarantee lightpath quality of transmission.

**Keywords:** Wavelength preference, wavelength contention, wavelength conversion, physical impairments, GMPLS, WSON.

## 1. Introduction

Wavelength switched optical networks (WSONs) are considered the best candidate to fulfill the requirements of current and future backbone networks, since they achieve high flexibility and scalability with relatively low capital and operational expenditures [1].

As depicted in Figure 1, the WSON architecture consists of the data and the control planes. The data plane comprises wavelength division multiplexing (WDM) fiber links connecting optical cross-connects (OXCs) through a comb of up to 80 wavelength channels, with typical data rates of 10 or 40 Gb/s. Optical end-to-end connections (i.e., lightpaths) are established in the optical domain and switched by OXCs at the wavelength granularity [2]. The dynamic provisioning and maintenance of lightpaths is managed by the control plane. The control plane is implemented on a separate network and typically employs one network controller for each node in the data plane, as shown in Figure 1. In particular, the Generalized Multi Protocol Label Switching (GMPLS) protocol suite, which is the de facto standard control plane for WSONs proposed by the Internet Engineering Task Force (IETF), is composed of three protocols [3]. The routing protocol (i.e., Open Shortest Path First with Traffic Engineering, OSPF-TE [4]) is used to advertise network topology and wavelength availability information, thus enabling network nodes to perform effective path computation. The signaling protocol (i.e., Resource Reservation Protocol with Traffic Engineering, RSVP-TE [5]) is used to reserve the network resources used by lightpaths, e.g., wavelengths channels. The Link Management Protocol (LMP [6]) is used for monitoring point-to-point links.

Figure 1(a) exemplifies a WSON supporting two wavelengths per link. A set of lightpaths is shown: in particular, the OXC at node $E$ switches lightpaths $LP_1$ and $LP_2$, sharing the same incoming link $L_6$. The lightpath $LP_1$ on wavelength $\lambda_1$ is switched to link $L_5$, while $LP_2$ on $\lambda_2$ is switched to link $L_4$. In absence of wavelength converters, which are devices capable of converting the wavelength carrier of a lightpath to another wavelength carrier, lightpaths must be established using the same wavelength from the source to the destination node. Conversely, if equipped with wavelength converters, an intermediate node can perform wavelength conversion, achieving a more effective utilization of network resources. For instance, given that $\lambda_1$ is busy on $L_2$ and $\lambda_2$ is busy on $L_4$, lightpath $LP_4$ can only be established by using a wavelength converter in node $C$ as depicted in Figure 1.

Since in WSONs the switching is based on the utilized wavelength, the wavelength assignment has a huge impact on the network performance [2]. Wavelength assignment impacts at least on the following network performance metrics: i) lightpath blocking probability; ii) wavelength converters usage; iii) quality of transmission (QoT), i.e. physical properties of the lightpath. First, as shown in [7][8][9][10] for wavelength continuous WSONs, the wavelength assignment significantly influences the probability that a lightpath request is blocked, either during lightpath provisioning or restoration after a network failure. Second, the wavelength assignment strongly influences the network resource utilization also in wavelength convertible WSONs [10][11]. In particular, a smart wavelength choice would avoid unnecessary utilization of wavelength converters. For instance in Figure 1(b), destination node $B$ can either select $\lambda_2$ or $\lambda_3$: while the former requires one wavelength conversion to backtrack to the source node, the latter does not need any converter. Finally, since each wavelength is characterized by different physical properties [12][13][14], established lightpaths experience a different QoT depending on the specific physical impairments affecting the utilized wavelength.

This paper shows how the aforementioned issues can be effectively solved in GMPLS-controlled WSONs by enforcing wavelength preference, i.e., by properly ranking wavelengths to realize an effective wavelength assignment. In particular, the benefits of wavelength preference are clearly shown in this paper to achieve better performance in terms of blocking probability, wavelength conversion usage, while guaranteeing the target lightpath QoT.

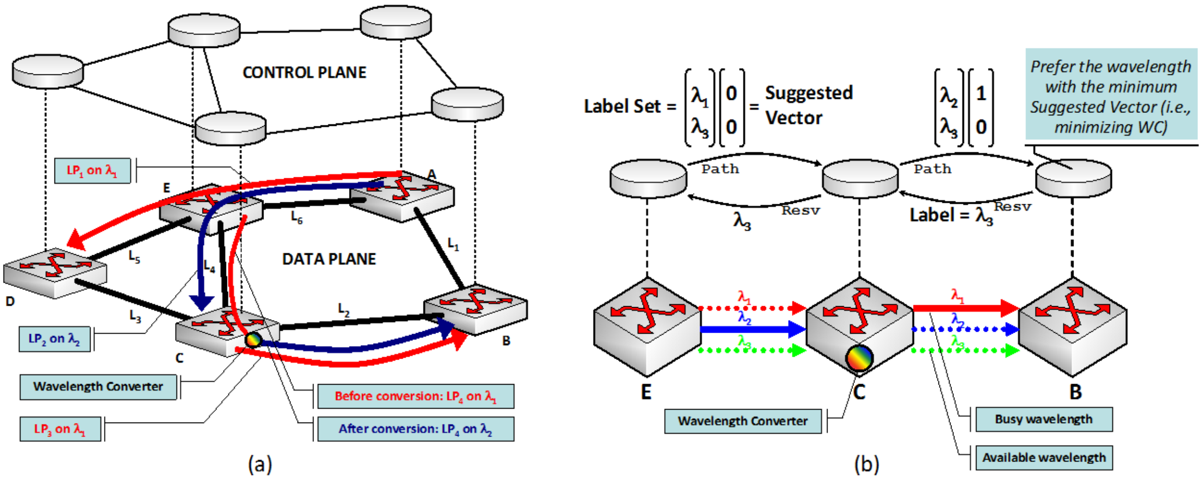


Figure 1: WSON architecture with the control and the data planes. (a) Network topology and established lightpaths in a WSON supporting two wavelengths per link. (b) Wavelength preference scheme for minimizing wavelength conversions in a WSON supporting three wavelengths per link.

Despite recent discussions within IETF [15], standard GMPLS protocol suite does not yet support wavelength preference. For this purpose, a GMPLS signaling protocol extension (RSVP-TE extension), called Suggested Vector, is exploited in this paper: it contains a preference level for each wavelength, and is used at the destination node for deciding the wavelength assignment. For instance, in Figure 1(b), showing a lightpath set up in a WSON with three wavelengths per link, the Suggested Vector at destination B indicates that if $\lambda_3$ ($\lambda_2$) is selected, zero (one) conversion is required to set up the lightpath.

Several other works on WSONs investigated topics related to the wavelength preference. In particular, the works in [16][17] propose two methods for the blocking reduction in wavelength continuous WSONs, the work in [18] considers wavelength convertible WSONs with Shared Path Protection (SPP) [1], and the work in [19] elaborates a set of modifications to the GMPLS control plane for taking into account the QoT. However, each one of these works propose a different solution based on heterogeneous ideas and requiring the introduction of several complex and not interoperable extensions to the GMPLS control plane, e.g., novel signaling messages and the modification of the OSPF-TE routing protocol. Conversely, all the schemes proposed in this paper are based on a single and simple extension (i.e., the Suggested Vector object), that is shown to be useful in all the considered WSONs scenarios.

In this paper, after a brief description of lightpath set up with wavelength preference, three WSON scenarios are considered in the paper: wavelength continuous, wavelength convertible, and QoT-aware WSONs. In each scenario the advantages of the proposed wavelength preference schemes are detailed with respect to the commonly used wavelength assignment schemes exploiting only standard objects.

## 2. Lightpath set up with wavelength preference

In GMPLS-controlled WSONs, lightpath set up exploits the RSVP-TE signaling protocol [5]. Upon lightpath request, a path is computed and the source node sends an RSVP-TE Path message in the forward direction (i.e., from the source node to the destination node) to gather wavelength availability information using the *Label Set* object, as shown in Figure 1(b). The Label Set is updated by intermediate nodes so that when it reaches the destination it contains the list of wavelengths that can be used for establishing the lightpath. For instance in Figure 1(b), destination node *B* receives a Label Set containing $\lambda_2$ and $\lambda_3$. The Path message may include also the optional *Suggested Label* object [5], which indicates a single preferred wavelength, contained in the Label Set, to be selected at destination. The Suggested Label object is usually initialized at the source node, but its content may be changed by intermediate nodes (e.g., if the Suggested Label is not available on a traversed link).

Upon reception of the Path message, the destination node selects one of the wavelengths contained in the Label Set by applying a specific wavelength assignment. Then, as depicted in Figure 1(b), an RSVP-TE Resv message is sent in the backward direction (i.e., from the destination node to the source node) to reserve the selected wavelength ($\lambda_3$ in the example). When the Resv message reaches the source node the lightpath is established and traffic can be transmitted in the data plane.

To implement the wavelength preference, an RSVP-TE signaling protocol extension, called Suggested Vector object, is exploited. Suggested Vector, first proposed in [11], is included in the Path message. It contains a numeric value expressing the preference level for each wavelength contained in the Label Set. Intermediate nodes update the Suggested Vector entries, by applying proper policies. In particular, the more a specific wavelength is preferred the more the associated Suggested Vector entry is kept low. Then, the Suggested Label is set to the wavelength associated with the minimum value in the Suggested Vector. The destination node to optimize the wavelength assignment by choosing the wavelength indicated in the Suggested Label.

In the IETF draft [15], the *Wavelength Set Metric* object, having the same structure of the Suggested Vector, has been recently proposed to include within GMPLS a “desirability” metric for wavelengths. The discussion within IETF confirms that wavelength preference mechanism is strongly desirable and would provide a common tool for solving several issues in WSONs. Also, IETF is discussing on how to include QoT information within GMPLS. For this purpose, the IETF drafts [20][21] propose to account for physical impairments by exploiting GMPLS extensions which include wavelength-by-wavelength physical parameter values, again with a structure similar than the ones of Suggested Vector.

The following sections describe wavelength preference schemes specifically designed for the considered WSONs scenarios.

## 3. Wavelength continuous WSONs

With the described lightpath set up procedure, blocking in a wavelength continuous WSON occurs due to two main reasons: lack of resources or wavelength contention [8][9], see Figure 2. Blocking due to lack of resources occurs during the forward signaling phase (i.e., forward blocking) when the Label Set results to be empty, thus no wavelength can be selected for the lightpath. Blocking due to wavelength contention occurs during the backward signaling phase (i.e., backward blocking) when two or more lightpaths try to concurrently reserve the same wavelength on the same link.

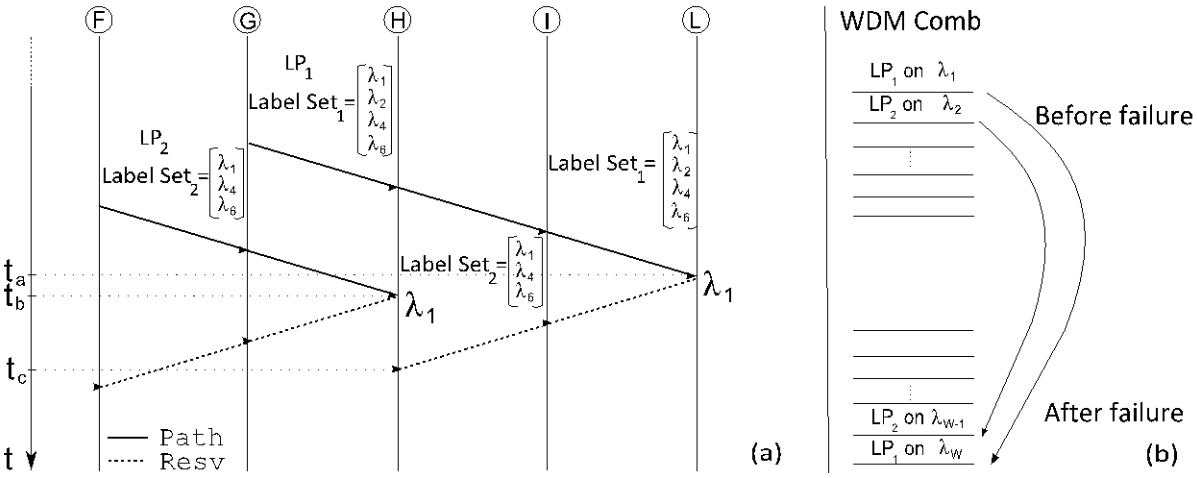


Figure 2: Lightpath set up with wavelength contention (a), wavelength preference during restoration (b).

The example in Figure 2(a) illustrates a backward blocking. Two lightpaths $LP_1$ and $LP_2$, between source destination pairs (G, L) and (F, H), have to be set up close in time along paths (G-H-I-L) and (F-G-H), respectively. At instant times $t_a$ and $t_b$, *Label Set*$_1$ and *Label Set*$_2$ arrive at the proper destination carrying the list of available wavelengths $\{\lambda_1,\lambda_2,\lambda_4,\lambda_6\}$ and $\{\lambda_1,\lambda_4,\lambda_6\}$, respectively. For instance, in case of first-fit wavelength assignment strategy (i.e., the lowest indexed wavelength in the list is selected), $\lambda_1$ is selected for both lightpaths. At $t_c$, the reservation attempt for $LP_1$ finds that $\lambda_1$ has been already reserved for $LP_2$ on link (G-H). Therefore, the reservation attempt for lightpath $LP_1$ is blocked during the backward signaling phase due to wavelength contention.

While forward blocking typically emerges at high network loads, backward blocking can be relevant also at low network loads. Indeed wavelength contentions likely occur when the lightpath inter-arrival time is comparable with the lightpath set up time, i.e., when the traffic is very dynamic or during restoration when, after a link failure, the recovery of all disrupted lightpaths is almost simultaneously attempted [9]. Therefore, backward blocking is particularly deleterious because it appears also when there are still many available wavelengths in the network.

Wavelength contentions can be reduced by selecting different preferred wavelengths for *contending lightpaths* (i.e, lightpaths traversing at least a common link). This target can be achieved by keeping track of the wavelength preference of lightpaths currently under establishment: if a wavelength is the preferred one for a lightpath, its choice should be discouraged for the contending lightpaths.

The following sections describe two wavelength preference schemes specifically designed for reducing wavelength contentions during provisioning and restoration, respectively. Both schemes are based on the common idea of avoiding contentions in the wavelength domain, and exploit the Suggested Label object and the Suggested Vector object.

### *3.1 Provisioning Case*

As illustrated in Figure 3, the lightpath source node, initializes the Path message objects. In particular, all the entries of the Suggested Vector are set to zero.

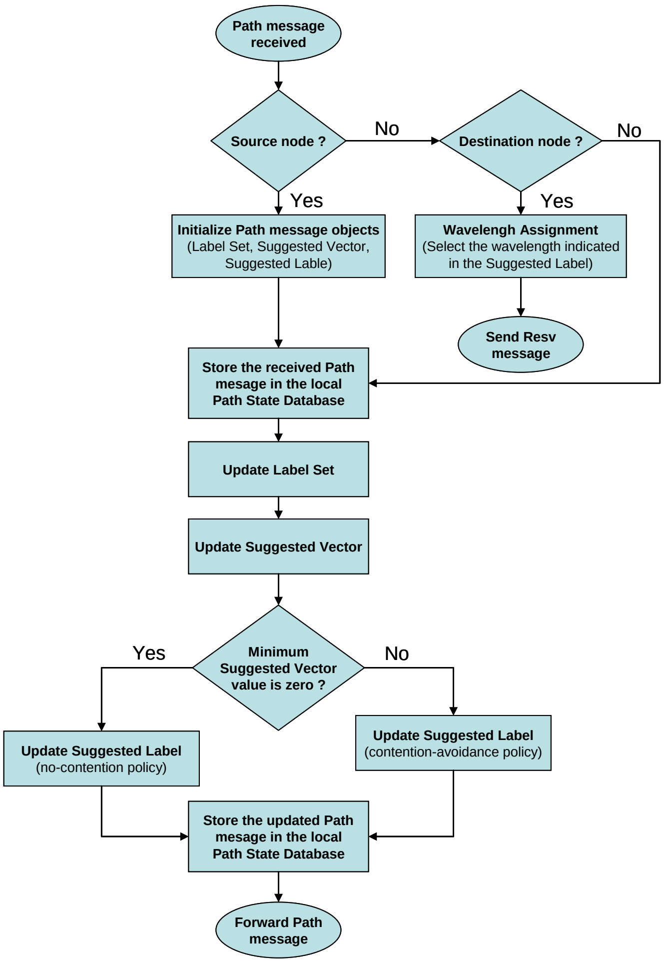


Figure 3: Flowchart illustrating the Path message objects update procedures at source and intermediate nodes, and the wavelength assignment at destination node.

Network Protocols and Algorithms
ISSN 1943-3581
2011, Vol. 3, No. 2

The source and the intermediate nodes store each received and transmitted RSVP-TE Path message, along with the contained objects (i.e., the Label Set, the Suggested Vector, and the Suggested Label) in a local Path State Database, till the corresponding RSVP-TE Resv message is received in the backward direction. Then the Label Set is updated by removing the wavelengths that are busy on the outgoing link. The Suggested vector is updated by incrementing the entries included in Suggested Label and Label Set objects of colliding (i.e., routed on the same outgoing link) lightpath requests stored in the local Path State Database. In particular, each entry of the Suggested Vector is incremented by an integer value $\alpha$ or $\beta$ each time it is included in a stored Label Set or Suggested Label, respectively (with $\beta \gg \alpha$). Finally, the Suggested Label is set to the wavelength with the minimum value in the Suggested Vector. If more than one wavelength satisfies the aforementioned condition, a tie-breaking policy is used, depending on the minimum Suggested Vector value. If it is equal to zero, i.e., no contending lightpaths have been identified, the *no-contention policy* is applied. Otherwise, contention may occur, thus the *contention-avoidance policy* is applied.

Finally, before forwarding the Path message, the updated objects are stored in the local Path State Database.

The destination node simply perform the wavelength assignment by selecting the wavelength contained in the Suggested Label object.

### *3.2 Restoration Case*

Previous works proved that wavelength contention is the main source of blocking during restoration in GMPLS-controlled WSONs [8]. However, due to the high dynamism of the restoration phase, the wavelength preference scheme used in the provisioning case does not work properly. To avoid wavelength contentions during restoration it is necessary to exploit also the fact that, before the failure occurrence, all the disrupted lightpaths were routed on a different wavelength.

The aforementioned wavelength preference idea is implemented with a specific initialization of the Suggested Vector. For each disrupted lightpath, the entry of the Suggested Vector corresponding to a specific wavelength, i.e., $\lambda_r$, is set to zero while all the other entries are set to the value $\gamma$, with $\beta > \gamma \gg \alpha$. In this way the wavelength $\lambda_r$ is more likely to be selected as Suggested Label.

The wavelength $\lambda_r$ is computed as a function of the wavelength $\lambda_p$ utilized before the failure, i.e., $\lambda_r = f(\lambda_p)$. The mapping function *f(.)* is designed respecting two main conditions. First, it is biunique (i.e., distinct $\lambda_p$ corresponds to distinct $\lambda_r$) for reducing wavelength contentions. Second, it computes wavelengths that are likely to be available along the whole recovery path.

In the example detailed in Figure 2(b), $\lambda_r = f(\lambda_p) = W+1- \lambda_p$. With that function, if the lightpath was routed along the first wavelength ($\lambda_1$) of the WDM comb, the preferred wavelength for restoration is the last wavelength of the comb ($\lambda_W$), if the lightpath was routed along the second wavelength ($\lambda_2$) of the WDM comb, the preferred wavelength for restoration is the penultimate wavelength of the comb ($\lambda_{W-1}$), and so on. This guarantees that the Suggested Label of each disrupted lightpaths is initialized with a distinct value. This criterion is also particularly efficient if the network is provisioned with first-fit wavelength assignment. Thus, the lowest indexed wavelengths are more likely to be busy, while the highest indexed wavelengths are more likely to be available and can be used during restoration.

Besides the aforementioned Suggested Vector initialization, the Path message objects are updated using the same procedures illustrated in Figure 3 and previously described for the provisioning case.

## 4. Wavelength convertible WSONs

Wavelength converters in WSONs allow establishing a lightpath even though no single wavelength is available on the whole path from source to destination (as shown in Figure 1(a)). However, since wavelength converters are an expensive resource, their usage should be optimized. Unfortunately, in standard GMPLS it cannot be determined if the wavelength selected at destination requires the use of wavelength converters or not, resulting in converter waste and thus poor network performance.

In this scenario, preference should be assigned to wavelengths which ensure a wavelength continuous path, so that the use of wavelength converters is minimized. In particular, the aim is to provide the destination node with a wavelength ranking, showing for each available wavelength the number of wavelength converters required to backtrack to the source node.

The Suggested Vector can be exploited for this purpose, by storing the number of wavelength conversions needed to use the related wavelength on the next hop. The source node fills the Suggested Vector with zeros since no wavelength conversion is needed. Intermediate nodes check every wavelength within the Label Set for the next hop to determine if it is available also on the previous hop. If the condition is true, the specific wavelength can traverse the node without conversion, so the related Suggested Vector value remains the same as on the previous hop. On the contrary, if the wavelength is busy on the previous hop, a wavelength conversion is necessary to use it on the next hop. In this case the related Suggested Vector value is the minimum Suggested Vector value on the previous hop, incremented by one, as depicted in Figure 1(b).

The destination node reads in the received Suggested Vector the number of wavelength converters needed for each available wavelength, and chooses the one minimizing this value. If more than one wavelength satisfies the aforementioned condition, a tie-breaking policy is used.

## 5. Wavelength continuous WSONs with QoT-awareness

In this scenario, wavelength preference accounts for the quality of transmission (QoT) experienced by each wavelength. Indeed, in WSONs, physical impairments (e.g., attenuation, amplified spontaneous emission, cross-talk, cross-phase modulation – XPM) degrade the QoT of established lightpaths. In particular, some physical impairments, such as cross-talk and XPM, strongly depend on the utilized wavelength.

Currently WSONs are designed guaranteeing that any lightpath can be established with an acceptable QoT, which implies small all-optical domains and thus high network costs. To increase the transparency domain size, WSONs can be planned without the aforementioned constraint. In this case, for each lightpath under establishment, the control plane must dynamically check the lightpath QoT and the impact on already established lightpaths [13], since the utilization of some wavelengths could excessively degrade their QoT. In QoT-aware WSONs, wavelength dependent physical impairments can be considered using different approaches: i) wavelength independent with worst-case scenario ii) wavelength dependent.

For instance, the former approach always considers the worst-case impairment scenario, i.e., the impairments generated on the most impaired wavelength channel when all other wavelength channels are lit. With this approach, if a lightpath achieves an acceptable QoT, it can be established on any wavelength and its QoT remains acceptable when any other lightpath is established in the network. Therefore in the worst-case approach the QoT estimation, not depending on the wavelength channel, is simplified but rather pessimistic, e.g., a lightpath could be rejected due to unacceptable QoT even though it could attain an acceptable QoT using specific wavelengths.

In the latter approach, two solutions are possible. In a first case, illustrated in this paper, lightpath QoT and the impact on already established lightpaths are dynamically estimated wavelength-by-wavelength. In a second case, QoT estimation could be relaxed by indicating wavelengths which experience negligible inter-channel effects. Indeed, for many inter-channel effects, such as XPM, the largest the distance among active wavelengths, the less detrimental the impairment effects [13].

Wavelength preference schemes accounting for QoT are implemented using the Suggested Vector object, which carries the QoT value of each wavelength and is updated by each intermediate node [14]. Moreover, at every node, the wavelengths excessively degrading the QoT of already established lightpaths are removed from the Label Set. The destination node checks the estimated QoT values in the received Suggested Vector and selects a wavelength with acceptable QoT. If more than one wavelength satisfies the aforementioned condition, a tie-breaking policy is used.

## 6. Performance Evaluation

Performance evaluation of the wavelength preference (WP) schemes is carried out using a custom-built C++ event-driven simulator [22]. The three WSON scenarios, have been evaluated on the Pan-European topology illustrated in Figure 4, consisting of N = 17 nodes and L = 33 links. Each link is bi-directional and carries W = 40 wavelengths per direction. All the simulation results illustrated in Figure 5, Figure 6, and Figure 7 are plotted with the confidence interval at 95% confidence level.

Lightpath requests are dynamically generated following a Poisson process and uniformly distributed among the source-destination pairs. The inter-arrival time and holding time of the lightpath requests are exponentially distributed with an average of $1/\lambda$ and $1/\mu$ seconds, respectively. The load offered to the network is, therefore, expressed in Erlangs as the ratio $\lambda/\mu$. In particular, the average holding time has been fixed to $1/\mu = 30$ seconds, while the average inter-arrival time is varied in accordance with the desired network load.

Provisioned and restored lightpaths are routed along the shortest path (in terms of number of hops) on the network topology, only links with at least one available wavelength are considered. In the case of multiple shortest paths, one of the shortest paths is randomly selected each time.

Wavelength preference schemes are compared with the Standard FF and Standard RD schemes which are based on standard GMPLS objects only and respectively perform first-fit and random wavelength assignment.

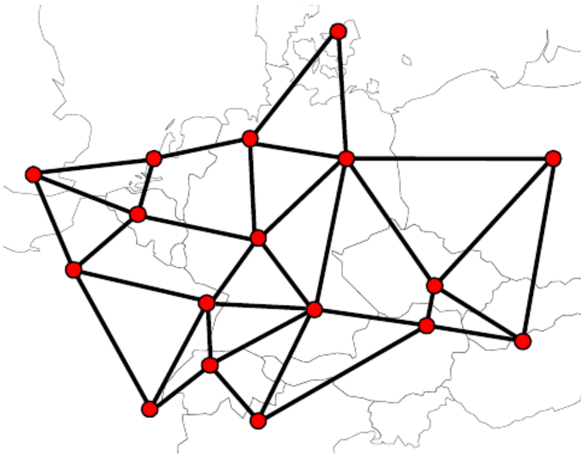

Figure 4: Pan-European Test Network.

*6.1 Wavelength continuous WSONs*

Two WP schemes, namely WP FF-LF and WP FF-RD, are evaluated in this scenario. Both schemes use first-fit as no-contention tie-breaking policy. While they use last-fit and random as contention-avoidance tie-breaking policy, respectively.

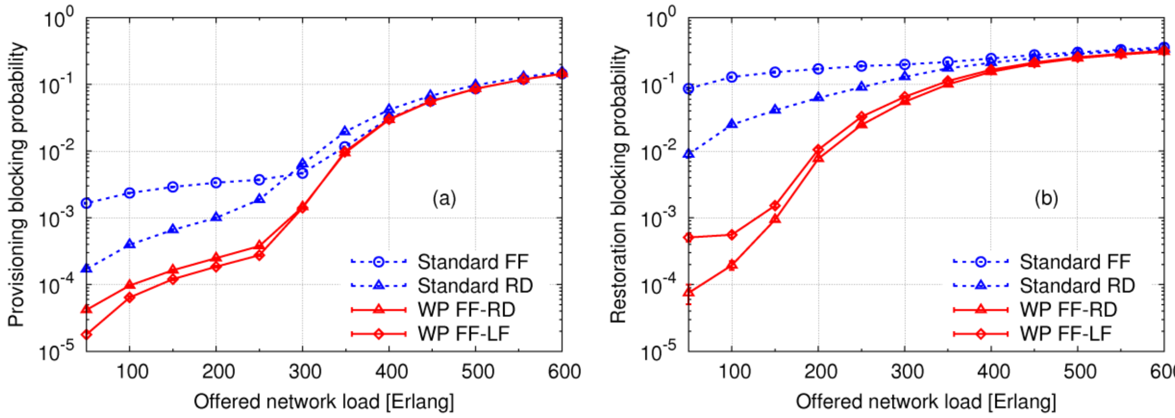


Figure 5: Provisioning blocking probability (a) and Restoration blocking probability (b), vs. traffic load in a wavelength continuous WSON.

Since the WP schemes use first-fit as no-contention policy, the considered mapping function during restoration is the one indicated in Sec. 3.B: $\lambda_r = f(\lambda_p) = W+1- \lambda_p$. In this way low-indexed wavelengths used during provisioning are biuniquely mapped to high-indexed wavelengths during restoration.

Results in terms of blocking probability during provisioning and restoration are shown as a function of the offered network load in Figure 5(a) and Figure 5 (b), respectively. During provisioning, Standard RD obtains lower blocking than Standard FF at low loads, where backward blocking dominates, and higher blocking at high loads, where the forward blocking dominates. This is due to the fact that random wavelength assignment is more effective than first-fit in avoiding wavelength contentions but achieves a worse resource utilization at high loads. This behavior is confirmed during restoration where Standard RD overcomes Standard FF for all the loads, since in this case wavelength contention is the most important source of blocking at all network loads.

WP schemes significantly outperform the standard schemes during both provisioning and restoration. In particular, WP FF-LF is the most effective scheme in the provisioning case, while WP FF-RD provides the best results in the restoration case. Indeed, during provisioning wavelength contentions typically involve only two lightpaths, therefore WP FF-LF obtains the best result maximizing the distance between the wavelength selected for the two contending lightpaths. During restoration wavelength contentions typically involve multiple lightpaths, therefore WP FF-RD, randomizing the wavelength assignment, achieves the lowest blocking.

*6.2 Wavelength convertible WSONs*

The network performance is evaluated in the same scenario described above, with the addition of 10 wavelength converters in every node. Two WP schemes, namely WP FF and WP RD, are evaluated, which use first-fit and random tie-breaking policy, respectively.

Results in terms of blocking probability and wavelength converters usage as a function of offered network load are shown in Figure 6(a) and Figure 6(b), respectively. Both WP schemes significantly outperform the standard schemes, allowing around one third traffic increase at $10^{-3}$ blocking probability. Moreover, by comparing Figure 5(a) and Figure 5(a), it can be noticed that wavelength converters significantly reduce the blocking only if WP schemes are used: indeed WP schemes allow an efficient use of wavelength converters to improve network utilization and solve wavelength contentions.

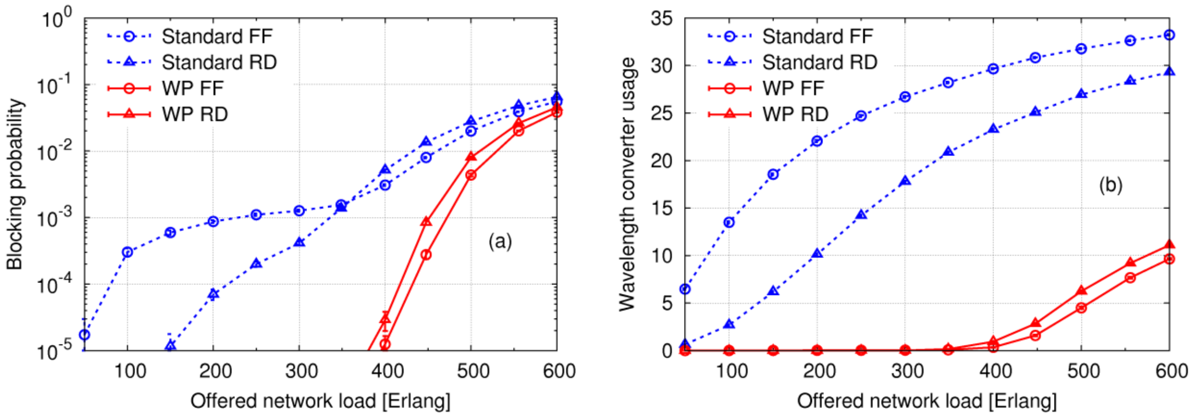


Figure 6: Blocking probability (a) and wavelength converter usage (b) vs. traffic load in a wavelength convertible WSON.

The advantage of WP schemes is relevant also in terms of wavelength converters usage. Standard schemes tend to exploit many wavelength converters even for low loads, especially Standard FF. On the contrary, WP schemes use a significantly smaller number of wavelength converters: almost no converter is exploited below 300 Erlang, demonstrating the excellent behavior of properly designed wavelength preference schemes in wavelength convertible WSONs.

*6.3 Wavelength continuous WSONs with QoT-awareness*

This scenario considers physical impairments and, in particular, it is assumed that QoT is not guaranteed for all possible lightpaths. Thus, the QoT is estimated during lightpath set up using the worst-case and the dynamic QoT estimation approaches described in Sec. 5, whose model is detailed in [14]. Therefore, a lightpath establishment can be blocked due to both unacceptable estimated QoT and lack of wavelength resources.

Three WP schemes, namely WP FF, WP RD, and WP MAX are considered. They exploit dynamic QoT estimation approach. WP FF and WP RD use first-fit and random tie-breaking policy, respectively, while WP MAX selects the wavelength characterized by the best QoT. Standard FF and Standard RD use the worst-case approach.

Figure 7 shows the blocking probability as a function of the offered network load. WP schemes significantly reduce the blocking probability with respect to both standard schemes. The wavelength-by-wavelength QoT estimation performed by WP schemes permits to establish lightpaths which are rejected in the worst-case approach. In particular, with Standard FF and Standard RD the use of worst-case approach causes the rejection of lightpaths traversing more than 3 hops or 655 km. In this case the blocking due to unacceptable QoT dominates, therefore both standard schemes achieve the same performance.

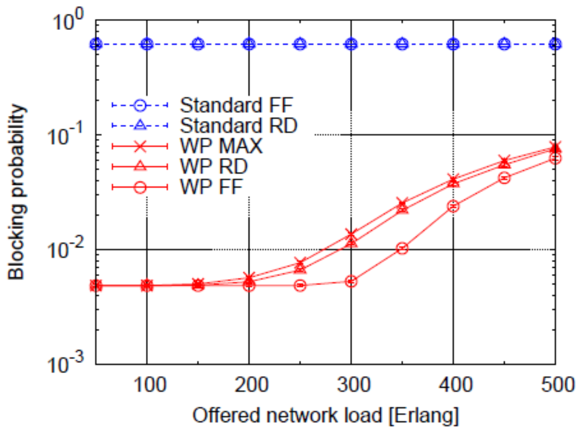


Figure 7: Blocking probability vs. traffic load in a wavelength continuous QoT-aware WSON.

With WP schemes, lightpaths up to 6 hops (i.e., the network diameter) can be accepted and the maximum lightpath length is 1794 km. Figure 7 also shows that WP FF obtains better performance than WP RD and WP MAX. Indeed, although WP FF does not maximize QoT, it nevertheless guarantees an ordered QoT-aware wavelength assignment able to maximize the number of wavelengths satisfying the wavelength continuity constraint. The latter effect dominates, resulting in the lowest blocking probability.

## 7. Conclusion

This paper discussed the relevance of wavelength preference in several Wavelength Switched Optical Networks (WSONs) scenarios controlled by the GMPLS protocol suite. In particular, wavelength continuous, wavelength convertible, and QoT-aware WSONs are considered.

Wavelength preference schemes are presented with the aim of reducing blocking probability, saving wavelength converters, and guaranteeing QoT. However, wavelength preference is not supported by the current standard control plane, which does not include protocol objects enabling a preference rank. Then, this paper also shows how to implement proposed wavelength preference schemes, by exploiting a simple RSVP-TE extension, named Suggested Vector. The Suggested Vector object, which has the same structure of the standard Label Set, permits to associate a preference level to each candidate wavelength for establishing the lightpath. Simulation results showed the significant benefits achieved by wavelength preference schemes in all the considered scenarios. Therefore the proposed Suggested Vector object appears a manifold and simple candidate extension to be included in the standard version of the GMPLS protocol suite.

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