Suggested Vector Scheme with Crankback Mechanism in GMPLS-controlled Optical Networks

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***Abstract*—The GMPLS distributed control plane is used in wavelength-routed networks to dynamically establish end-to-end lightpaths. During the signaling phase, lightpath requests can be blocked due to lack of available resources or due to resource contentions. Blocking due to resource contentions is the dominant source of blocking, when network is lightly loaded or lightpath requests are highly dynamic.**

To reduce the contentions, solutions based on extension of GMPLS signaling protocol (i.e., RSVP-TE) can be exploited, such as the Suggested Vector (SV) scheme proposed by the authors.

This paper, first, thoroughly reviews the SV scheme and, then, it compares different wavelength selection policies to be applied to the SV scheme. Also, crankback mechanism of RSVP-TE is explored as a way to reduce the blocking.

A comprehensive simulation analysis is carried out in a GMPLS-controlled wavelength-routed network, based on RSVP-TE and OSPF-TE routing protocol. Simulation results demonstrate the effectiveness of SV scheme and crankback mechanism in strongly reducing resource contentions.

I. Introduction

THE distributed Generalized Multi-Protocol Label Switching (GMPLS) control plane is used in wavelength-routed WDM networks to dynamically establish lightpath requests. Within GMPLS, two are the main protocols used for this purpose: the resource reservation protocol with traffic engineering extensions (RSVP-TE) [1] that reserves the required resources and the open shortest path first routing protocol with traffic engineering extensions (OSPF-TE) [2] that advertises resource information.

Based on these protocols, the lightpaths are set up in three steps: 1) the path computation carried out at the source node and based on the information disseminated by OSPF-TE, 2) the collection of wavelength availability along the path, performed during forward signaling phase of RSVP-TE (i.e., from the source to the destination node), and 3) the reservation of a wavelength along the path, performed during the backward signaling phase of RSVP-TE (i.e., from the destination to the source node).

An unsuccessful completion of any one of these three steps can block the lightpath establishment. In particular, the lightpath establishment can be blocked 1) during the path computation step if the path cannot be found with available resources toward the destination node (i.e., *routing blocking*) or 2) during the forward phase of RSVP-TE (i.e., *forward blocking*) due to wavelength unavailability on the computed path links, or 3) during the backward phase of RSVP-TE (i.e., *backward blocking*) due to resource contentions [3]. Resource contentions are caused by the concurrent attempts of two or more RSVP-TE signaling instances to reserve the same wavelength on a link.

The impact of the different blocking types mainly depends on the traffic scenarios. Backward blocking is evident in networks that are lightly loaded, and when the lightpath arrival process is highly dynamic. In the latter case, backward blocking is important because the information collected in the forward signaling phase may be already outdated when received by the destination node. For instance, backward blocking becomes evident in case of dynamic restoration, when all the lightpaths affected by a link failure need to be promptly re-established [4]. Notice that the impact of backward blocking cannot be neglected, even when OSPF-TE promptly advertises link-state information [5], [6].

Several solutions for the distributed GMPLS control plane have been proposed aimed at reducing the backward blocking in WDM networks. One solution is to over-reserve the resources. The work in [7] proposes the use of parallel signaling instances along disjoint paths, for each lightpath request. Each signaling instance may reserve one or more wavelengths. The paper shows that the forward blocking can be reduced by increasing the number of parallel signaling instances, while the backward blocking can be reduced by increasing the number of reserved wavelengths. In other words, the wavelength domain is shown to be more effective in avoiding resource contentions than the routing. Other solutions exploit advanced wavelength selection strategies [4], [8]–[10] to be implemented in the RSVP-TE protocol. In particular, the work in [8] uses a circular wavelength-list managed by intermediate nodes and requires an additional signaling message with respect to the RSVP-TE signaling. The works in [4], [9], [10] propose an advanced management of the standard Suggested Label [1] object to provide the destination node with an indication of the wavelength to be reserved. Among those, the *Suggested Vector (SV)* scheme [10], that we proposed, has been shown to outperform the others by strongly reducing the backward blocking, without degradation of the forward blocking. In addition, the scheme is compliant with RSVP-TE signaling

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message exchange (i.e., no additional messages or instances are required). An RSVP-TE extension is, however, required to support two additional objects: the Contention Detection and the Suggested Vector objects.

This paper describes the SV scheme and thoroughly analyzes its performance during lightpath provisioning. In particular, the paper goes beyond the contribution of [10] by comparing two different implementations of the SV scheme, based on two distinct wavelength selection strategies. Also, the possibility to use multiple (sequential) set up attempts for the unsuccessfully established lightpaths is explored for the first time and the impact of such mechanism, known as crankback mechanism [11], on the blocking is evaluated. Finally, the performance study is here carried out on a realistic network scenario where the OSPF-TE protocol is used for advertising network resources, while the study in [10] neglected the advertisement latency caused by the routing protocol.

The simulation results are compared against standard RSVP-TE and other contention avoidance schemes [8] to evaluate the effectiveness of the SV scheme when implemented with different wavelength selection strategies and when crankback mechanism is available.

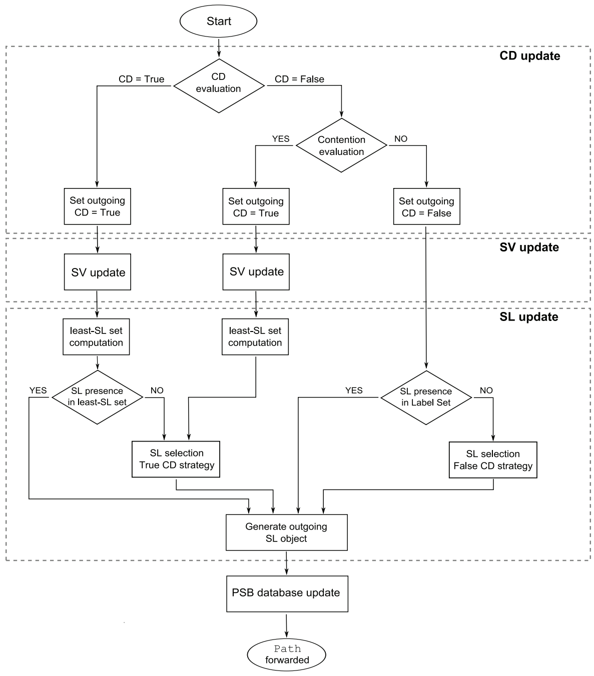


Figure 1. Flow chart of the `Path` message processing operations.

II. Lightpath Setup in GMPLS Networks

The considered scenario is a wavelength-routed optical network without wavelength conversion capabilities. Network nodes are connected by WDM links and are equipped with optical cross-connects.

In each node, the GMPLS control plane maintains the traffic engineering database (TED) with the network topology information and the number of wavelength channels available on each link. This information is periodically disseminated by OSPF-TE using link state advertisement (LSA) messages [6].

Upon arrival of a lightpath request, the source computes the path toward the destination, based on the information stored in the TED, and initiates the signaling procedure utilizing RSVP-TE. The RSVP-TE is based on two messages: the `Path` and the `Resv` messages that are sent in the forward and backward direction, respectively.

The `Path` message includes the Explicit Route object and the Label Set object. The Explicit Route object specifies the path to be followed by the `Path` and the `Resv` messages. The Label Set object is implemented as an array of labels identifying the wavelengths that can be used for the requested lightpath. At destination, the Label Set contains the wavelengths, that are available on the end-to-end path satisfying the wavelength-continuity constraint.

Upon reception of the `Path` message, the destination selects one of the available wavelengths contained in the Label Set object, according to a wavelength selection strategy. A `Resv` message is sent to reserve the selected wavelength on each link of the route. Upon reception of the `Resv` message, each intermediate node locks the selected wavelength, updates the list of available wavelengths on its outgoing link and forwards the `Resv` message to the next node toward the source. Once the `Resv` message reaches the source, the lightpath is established and data transmission takes place.

When in an intermediate node the Label Set array is empty (i.e., forward blocking), an error message (i.e., `PathErr`) is generated and sent toward the source. When the `Resv` message attempts to reserve an already reserved wavelength (i.e., backward blocking), an error message (i.e., `PathErr`) is generated and sent toward the source to report the blocking while another error message (i.e., `ResvErr`) is generated and sent toward the destination to free the already reserved wavelength on the various links. For tearing down a lightpath, a `PathTear` message is sent by the source in the forward direction, to release the wavelength used by the lightpath.

When crankback mechanism is exploited, upon reception of a `PathErr` message at the source, another signaling procedure with a new RSVP-TE instance is triggered, if the number of reservation attempts is below the maximum number of crankback attempts [11].

III. The Suggested Vector (SV) scheme

This section describes the Suggested Vector (SV) scheme that extends the RSVP-TE protocol for minimizing the probability of resource contentions among concurrent reservation attempts. In particular, the destination node is provided with a preferred label (in the Suggested Label (SL) object) and a label ranking (in the Suggested Vector (SV) object) that are jointly used to identify the wavelength to be selected.

A. Required Objects and Databases

The proposed SV scheme requires three objects in the `Path` message: the Suggested Label (SL) object, the Contention Detection (CD) object and the Suggested Vector (SV) object. The

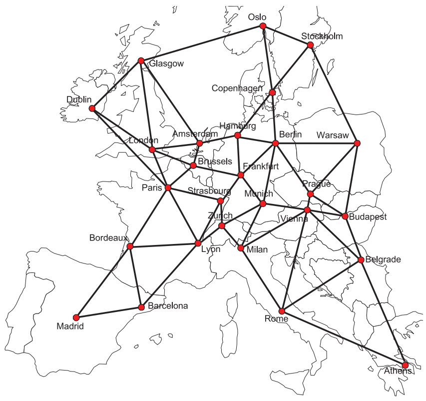


Figure 2. Pan-European network topology

SL object is an optional standard object defined by RSVP-TE in [1] and it is used here to identify the suggested wavelength. CD and SV objects are proposed here for inclusion in the `Path` message. The CD object [12] is a one-bit flag that indicates whether the current reservation attempt is likely to experience (i.e., CD bit set to True) a backward blocking or not (i.e., CD bit set to False). The SV object [13] is a vector containing a weight for each label contained in the Label Set object that allows to synthetically evaluate the label preference level.

As described in [14], each node maintains a database of path state blocks (PSBs) and a database of reservation state blocks (RSBs). A PSB stores the information contained in each received and forwarded `Path` message (i.e., incoming and outgoing `Path` message), including the carried objects. An RSB stores the information contained in each received `Resv` message. The information in a PSB (RSB) is valid for the period of time elapsing between the passage of the `Path` message and the passage of the corresponding `PathTear` message (in case of successful reservation attempt), or the passage of the corresponding `PathErr` or `ResvErr` message (in case of unsuccessful reservation attempt).

B. SV Scheme Description

When using the SV scheme, the RSVP-TE protocol provides the destination with a preferred label, which is indicated in the SL object, and with an array (i.e., the SV object) containing the weight for each label in Label Set object.

Upon reception of a lightpath request, the source node initializes the CD object to False and the SL object to a label ID that depends on the considered wavelength selection strategy (e.g., the lowest indexed wavelength available on the outgoing link to implement the first-fit strategy). Moreover, all the entries of the SV object are initialized to zero.

The source node and each intermediate node can modify the objects, based on the CD object, on the SL, and on the information stored in the PSBs and RSBs. In particular, the weights in the SV objects are updated to keep record of the labels suggested by the upstream nodes and of the potential contentions occurring on the wavelengths in the Label Set.

The operations performed by the nodes are depicted in Fig. 1. Upon initialization at the source or upon reception of a `Path` message at an intermediate node, the Label Set is computed and the following steps are executed:

- *Update of the Contention Detection (CD) object.*
  - *Evaluation of the incoming Contention Detection object*. The value of the incoming CD bit is checked: if True, the outgoing CD bit is set to True; if False, the contention evaluation operation is performed as explained next.
  - *Contention evaluation*. Let us define a reservation attempt as *potentially contending* with the ongoing reservation if 1) it has a PSB in the node and passes on the same next hop of the incoming `Path` message, and 2) it has not an RSB (i.e., a `Resv` backward message for this attempt has not been received yet). The outgoing CD bit is set to False in case of empty intersection between the outgoing Label Set object and any Label Set of the potentially contending reservations, stored in the PSBs. Otherwise, the CD bit is set to True.
- *Update of the Suggested Vector (SV) object*.
  The weight $W_o(l)$ for the label l included in the outgoing Label Set is calculated as:
  $$W_o(l) = W_i(l) + \alpha \cdot n_{LS}(l) + \beta \cdot n_{SL}(l) \qquad (1)$$
  where $W_i(l)$ is the weight associated with label l in the incoming SV object, $n_{LS}(l)$ is the number of times that label l is present in the outgoing Label Set objects of the potentially contending reservations, stored in PSBs, and $n_{SL}(l)$ is the number of times that label l is present in the outgoing Suggested Label objects of the potentially contending reservations, stored in PSBs.
  The parameters $\alpha, \beta > 0$ are tuned so that a minimum weight is assigned to the wavelength to be selected by the destination node. The following selection criterion is proposed for minimizing the resource contentions probability: select the wavelength that the potentially contending reservations chose as suggested label the minimum number of times and, in case of ties, that the potentially contending reservations included in the Label Set objects the minimum number of times. To apply such criterion, it is necessary to select $\beta \gg \alpha$.
- *Update of the Suggested Label (SL) object*. Depending on CD bit, the presence of the SL object is checked in the set of the least suggested labels (i.e., the least-SL defined in the following) or in the Label Set object as explained next.
  - *Computation of the least-SL set*. The least-SL set is generated by including the labels present in the outgoing Label Set, with the minimum weight in the outgoing Suggested Vector object.
  - *Presence of the SL object in the least-SL set*. When the incoming CD bit is True, the presence of the incoming Suggested Label object is checked in the

least-SL set. If present, the outgoing SL object is the same as the incoming one. If absent, it is computed following the *SL selection* operation detailed below.
    - *Presence of the SL object in Label Set object*. When the outgoing CD bit is False, the presence of the SL object in the Label Set is checked. If present, the outgoing SL object is the same as the incoming one. If absent, the outgoing SL object is computed following the *SL selection* operation detailed next.
    - *SL selection*. The suggested label is selected by applying a specific strategy when the outgoing CD bit is False (i.e., False CD strategy) and a distinct strategy when the outgoing CD bit is true (i.e., True CD strategy). Options for False and True CD strategies may include, for example, first-fit, last-fit and random selection, and are evaluated in Sec. IV. The set of labels on which the strategies are applied is the least-SL set or the Label Set, depending on whether the outgoing CD bit is True or False, respectively.
- *PSB database update*. A new PSB is added in the database containing the information of the incoming `Path` message and the outgoing Label Set and SL objects.
- `Path` *message forwarding*. The outgoing `Path` message is generated with the described objects and it is forwarded to the next hop.

Upon reception of a `Path` message, the destination generates a `Resv` message for reserving the wavelength indicated by the received SL object.

In the backward direction, each intermediate node receiving a `Resv` message reserves the selected wavelength, adds an RSB in the database, and forwards the message to the next node toward the source.

C. The SL selection strategy

The strategy adopted for the selection of the suggested label in SL object is expected to have a significant impact on the performance of SV scheme.

The first-fit strategy has been chosen as False CD strategy. Indeed first-fit is able to guarantee an efficient utilization of network resources and to achieve a low forward blocking [9].

On the contrary, the choice of the True CD strategy is more complicate. On the one hand, last-fit strategy is expected to be most effective in avoiding contentions, because maximizes the distance between the wavelengths selected by False and by True CD strategy. On the other hand, a random strategy could be more appropriate for very dynamic traffic conditions, where resource contentions can involve more than two concurrent signaling instances. Thus, both strategies are considered and their performance is compared. The two considered implementations of the SV scheme are:

- SV-FF/LF using first-fit as False CD strategy and last-fit as True CD strategy;
- SV-FF/RD using first-fit as False CD strategy and random as True CD strategy.

IV. Simulation scenario

The performance study of SV scheme has been carried out on the Pan-European network with 27 nodes and 55 links (Fig. 2). Each link is bi-directional and carries 32 wavelengths per direction. The length of each link is set to the geographical distance between the terminating nodes.

It is assumed that: 1) control messages are served using First-Come-First-Serve policy; 2) the considered processing times in each network node are: 1 ms for RSVP-TE `Path`, `PathErr`; 2 ms for RSVP-TE `Resv` and `ResvErr` and `PathTear` packets; 1 ms for OSPF-TE LSA packets [15]; 3) the switching time of the optical cross-connects (OXC) is 10 ms [16]; 4) the `Resv` message is forwarded after the successful configuration of the local OXC; 5) the time for path computation at the source node and for wavelength selection at the destination node is constant and equal to 0.5 ms; 6) and the control plane uses 1 Gpbs interfaces.

Lightpath requests are dynamically generated following a Poisson process and are 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 λ/μ Erlang.

Lightpath requests between the node pair (s, d) are dynamically routed along one of the pre-computed candidate paths belonging to the set $P_{s,d}$. $P_{s,d}$ contains all the paths between the node pair (s, d) within one hop from the shortest path. Each node maintains the TED with the number of available wavelength channels on each link. Using TED information, the path with the largest number of available wavelength channels on its most congested link is selected for routing.

LSA messages are generated for each link. Upon transmission of a LSA message, a timeout is triggered on the link. A new link-state change on such link can be advertised only after the expiration of the timeout. The timeout is set to 30 s during simulations [2], [6].

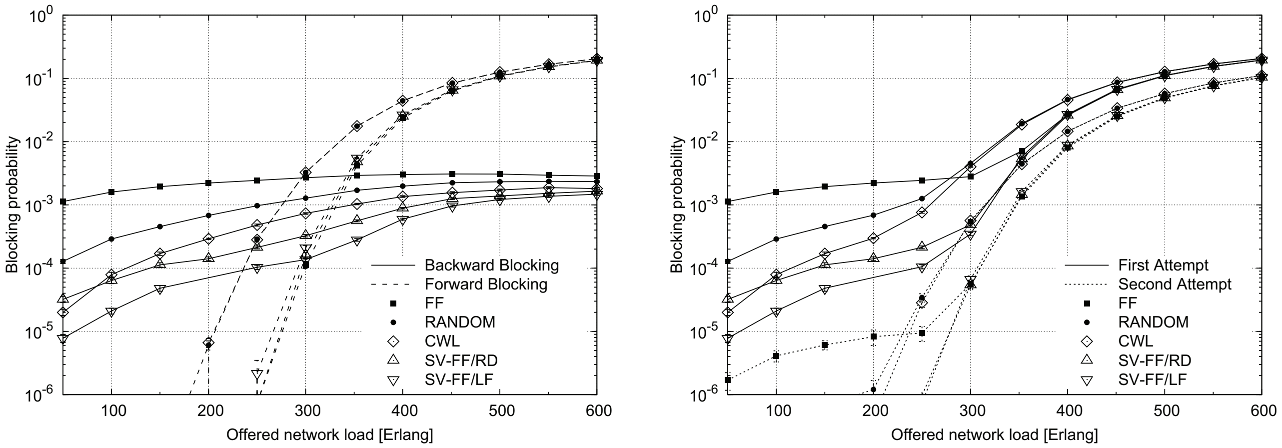
The maximum number of crankback attempts is set to 2. The second set up attempt is performed along the same path or along another path in $P_{s,d}$ if the first set up failed due to backward or forward blocking, respectively.

In the SV schemes the parameters α, β of Eq. (1) are set to 1 and 500, respectively.

The results are obtained by running a custom-built C++ event-driven simulator, until the confidence interval of 5% at 95% confidence level or the maximum number of independent trials (i.e., 5000) is reached. Each trial is composed of 10000 lightpath requests. All results are plotted with the confidence interval at 95% confidence level.

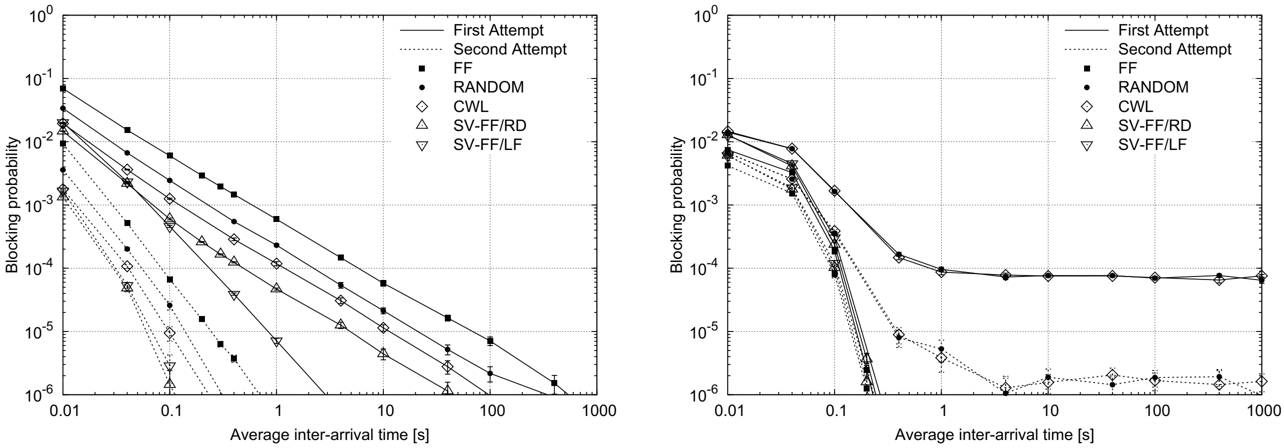
V. Simulation results

The performance of the proposed SV schemes is evaluated in terms of *overall blocking probability* and its contributions, i.e., routing, forward, and backward blocking. Notice that in the considered simulation scenario, where OSPF-TE advertises aggregated bandwidth availability information, the routing blocking is negligible [6] and does not appear in the figures.



(a) Forward and Backward blocking probabilities after the first setup attempt. (b) Overall blocking probability after the first and the second setup attempts.

Figure 3. Blocking probabilities vs. network load (in Erlang), for $1/\mu = 60s$.



(a) Backward blocking probability.

(b) Forward blocking probability.

Figure 4. Forward and backward blocking probabilities vs. mean inter-arrival time [s], after the first and the second setup attempts, for $\lambda/\mu = 250$ Erlang.

The SV schemes are compared against:

- RSVP-FF and RSVP-RD: the standard RSVP-TE protocol with a first-fit (FF) and a random (RD) wavelength selection strategy, respectively, applied to the Label Set object by the destination node;
- CWL: the scheme introduced in [8], based on the Circular Wavelength List (CWL) object. In this scheme the source randomly selects a suggested label in the CWL. At an intermediate node, if the suggested label is unavailable or is already suggested by another concurrent reservation attempt, another suggested label is selected using a first-fit strategy applied to CWL.

Fig. 3 shows the blocking probabilities as a function of the network load, when the mean holding time is $1/\mu = 60\ s$. The offered network load is varied by changing the mean inter-arrival time.

Fig. 3(a), shows that the backward blocking experienced by the first set up attempt dominates over the forward blocking, for low network loads. Moreover, the comparison of RSVP-FF and RSVP-RD schemes reveals that the random strategy achieves a backward blocking lower than first-fit strategy. However, the first-fit strategy achieves a lower forward blocking, thanks to its ability to compact the lightpath on the low-indexed wavelengths. The CWL scheme is able to further reduce the backward blocking of RSVP-RD scheme. However, the forward blocking of CWL scheme is as high as in RSVP-RD scheme, since the selection of the suggested label at the sources is performed randomly. In addition, the proposed SV schemes outperform the CWL scheme in both backward and forward blocking. In particular, both implementations of SV scheme achieve a forward blocking similar to the one of RSVP-FF since they both use first-fit as False CD strategy. Among the two implementations of SV scheme, SL-FF/LF scheme achieves the best performance, by significantly overcoming the SL-FF/RD scheme in terms of backward blocking.

Fig. 3(b) shows the overall blocking probability after the first and the second set up attempts. The effectiveness of the second set up attempt in strongly reducing the backward blocking is appreciable especially at low loads, when forward blocking is negligible. Indeed, the backward blocking of RSVP-FF is reduced by more than two orders of magnitude and the backward blocking of RSVP-RD, CWL and SV becomes negligible. Moreover, the second set up attempt significantly reduces the forward blocking, too.

Fig. 4 shows the forward and backward blocking probabilities as a function of the mean inter-arrival time, when the mean holding time is also varied to achieve a fixed network load of $\lambda/\mu = 250$ Erlang.

The comparison between Fig. 4(a) and Fig. 4(b) demonstrates that the backward blocking dominates for inter-arrival times shorter than few seconds. Moreover, the figures confirm the relative performance of the different schemes. In particular, in Fig. 4(a) the proposed SV-FF/LF scheme is the most effective in reducing the backward blocking, for inter-arrival times higher than $0.1\ s$. The reason is that, for these values of inter-arrival time, resource contentions usually occurs between two concurrent reservations and SV-FF/LF succeeds in avoiding contentions by selecting a low-indexed and a high-indexed wavelengths. However, for lower values of inter-arrival time (i.e., extremely dynamic requests), the SV-FF/RD scheme achieves the best performance. Since resource contentions may occur among various concurrent reservations, the random selection used by SV-FF/RD is able to resolve multiple contentions more effectively. By applying crankback mechanism, after the second setup attempt, the ranking among the schemes is confirmed. In particular, backward blocking is almost nullified at inter-arrival times higher than 1 second, and is decreased also for highly dynamic traffic.

Fig. 4(b) confirms that RSVP-FF and SV schemes are more effective in terms of forward blocking with respect to RSVP-RD and CWL. In particular, all the schemes experience rapidly decreasing forward blocking for increasing inter-arrival times. Indeed, at high inter-arrival times, the TEDs are updated and consistent with network state; on the contrary, with fast arrivals, the information stored in the TEDs becomes inconsistent with the network state, thus rapidly degrading forward blocking. More specifically, the forward blocking of RSVP-FF and SV drops rapidly and becomes negligible, but the blocking of RSVP-RD and CWL stabilizes around 10^{-4}. The poor performance of RSVP-RD and CWL is due to inefficient wavelength allocation of the random wavelength selection. As for the backward blocking, for highly dynamic requests, the second set up attempt does not considerably reduce the forward blocking, due to outdated information used in the path selection.

VI. Conclusion

This paper investigated the blocking of lightpath requests experienced in GMPLS-controlled wavelength-routed networks, subject to wavelength continuity constraint. When considering a highly dynamic traffic scenario, the main reason of blocking is the backward blocking due to resource contentions, rather than the forward blocking due to lack of resources or outdated TEDs.

To alleviate this problem, the paper proposed the Suggested Vector (SV) scheme. The SV scheme aims at suggesting to the destination the wavelength to be selected for the lightpath. In SV scheme, using the weights carried in the SV object of RSVP-TE messages, the label is carefully selected at each intermediate nodes, by avoiding contentions with other ongoing reservation instances.

Two different wavelength selection strategies were applied to SV scheme, along with RSVP-TE crankback mechanism. SV-FF/LF is shown to be more effective in reducing backward blocking compared to SV-FF/RD unless an extremely dynamic traffic scenario is considered. Both schemes achieve also a low forward blocking. Moreover, if the SV schemes are used in combination with the crankback mechanism, backward blocking becomes negligible, in most of the considered scenarios.

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