Dynamic SLA Negotiation Infrastructure in Protected Shared Mesh Optical Networks

Alireza Nafarieh, Bill Robertson, William Phillips, and Shyamala Sivakumar

***Abstract*—This paper presents a dynamic service level agreement negotiation mechanism considering intra/inter-domain communications over shared mesh optical networks. The intra-domain negotiation mechanism propagates the link-availability as service level agreement parameters while inter-domain mechanism advertises a proposed service level agreement based traffic engineering constraint called maximum path availability. The paper shows how service level agreement negotiation protocols along with the proposedtraffic engineering metric improvethe performance of priority-aware algorithms.**

***Index Terms*—Priority-aware algorithm, service level agreement, dynamic service level agreement negotiation, maximum path availability algorithm, OSPF-TE extensions, BGP-TE extensions**

I. INTRODUCTION

Service level agreement (SLA) is one of the common means of communication between customers and service providers through which one of the most important parameters for the customers, connection availability, is requested. The service provider goal is to provide a reliable connection with the minimum allocated availability over a shared-mesh path restoration scheme in WDM networks. However, in some cases, the requested availability is beyond the capacity of the network, and the connection is easily rejected or blocked. To give the customer a chance to choose another provider, or in case of having only one provider, to comply with the provider’s network capacity as much as possible, an automatic mechanism for SLA parameters negotiation between the service provider and the customer is needed.

In a multi-homed network topology, the link availability information can be communicated using dynamic SLA negotiation mechanisms. The customer side of the network is exposed to SLA information from all the ISPs to which it is connected. The customer has the choice to pick the service provider that is the most suitable for satisfying the requested connection.

Routing within the optical network relies on knowledge of network topology and resource availability. This information may be gathered and used by a centralized system, or by a distributed link state routing protocol. In either case, the first step towards network-wide link state determination is the discovery of the status of local links to all neighbours by each router. To disseminate TE information among entire nodes of a network, the information should be propagated inside and outside the autonomous system (AS), along the path from source to destination. For intra-domain TE-information dissemination, OSPF-TE opaque LSAs with newly proposed extensions are used in this paper.For inter-domain TE-metrics propagation, new TE extensions on BGP are proposed.

II. RELATED WORK

Since OSPF and BGP are widely used as intra-domain and inter-domain routing protocols of networks respectively, the majority of the studies modify or add some extensions to these protocols to enhance their ability for serving in a traffic engineering (TE) environment. The authors in [1] describe extensions to the OSPF protocol version 2 to supportintra-area TE, using opaque link state advertisements (LSAs). In [1], different types of opaque LSAs and their associated format have been discussed. The document talks about LSA payload details in which one of the top-level Type/Length/Value (TLV) triplets is the link TLV which describes a single link, and is constructed of a set of sub-TLVs. In [2], extensions to the OSPF routing protocol in support of carrying link state information for Generalized Multiprotocol Label Switching (GMPLS) has been presented. The sub-TLVs for the link TLV in support of GMPLShave been enhanced in [2]. The proposed extensions in [1] and [2] can be considered as the base of any new extensions to OSPF supporting TE. In [3], an improved OSPF-TE protocol has been proposed so that rather than disseminating link state information through LSAs, they are sent througha newly designed path sub-TLV called path state advertisements (PSAs). Unlike the traditional OSPF-TE, the proposed protocol in [3] does not advertise the absolute value of available bandwidths. Instead, it only disseminates the increments or decrements of available bandwidths. Although [3] proposes a path-related extension to OSPF, it does not propagate link or path availability. In addition, inter-AS communications has not been considered in [3].

Anew BGP-TE attribute which enables BGP to carry TE-information, has been presented in [4]. In [4], connection bandwidth at different priority levels and switching capability information as the attributes added to BGP for traffic engineering are presented. In [5], the efficiency of BGP-TE extensions under the GMPLS framework is evaluated. The idea of disseminating path-related (not domain-related) QoS-metric per destination within an extended TE-attribute has been presented in [5]. The

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proposed path-related TE-attribute in [5] is representative for the overall path from a certain node to the destination. In order to provide multiple paths per destination and to map the hop-by-hop BGP into the source-routing requirements of GMPLS, [5] proposes a behavioural modification of the protocol which consists of using the BGP only as a dissemination protocol, not as a path selection one. Since the proposed mechanism in [5] propagates TE-related information without affecting BGP path selection process, it has been considered as a good model for the proposed mechanism presented in this paper. However, in none of the mentioned work link-availability dissemination through a dynamic mechanism has been considered.

III. AN SLA-BASED TRAFFIC ENGINEERING CONSTRAINT DEFINITION

Some requests cannot be accommodated as they violate the best availability offered by the network. This condition can be counted as an unaccommodating request which is not fair to be counted as a blocked one and should be treated in a different way. Maximum path availability (MPA) algorithm presented in [6]calculates the highest path availability offered by an AS for any certain source and destination pairs of the label switching routers (LSRs). This parameter can be advertised in the dynamic SLA negotiation mechanism as the maximum path availability of any pair of source and destination in connection request matrix (CRM) in an AS.CRM has been defined in Definition 1. In a multi-homed network in which the customer can be served by several ISPs as shown in Fig. 1, the MPA algorithm calculates dynamically the highest path availability offered by the ISPs for any pairs of source and destination. The proposed TE-metric helps customers to manage their requests, specifically high priority requests, based on the network offered status. This may preserve higher priority requests and further reduce the blocking rate, improve availability satisfaction rate, and increase the chance of accommodating more high-priority connection requests compared to shared-mesh protection algorithms over wavelength-division multiplexing (WDM) optical networks.

Definition 1Connection request matrix (CRM): CRM is a 2*nxm* matrix of connection requests which is created for simulation purposes in which n is the number of the connection requests, 2*n* is the total number of establish and release requests, and m is the number of connection related parameters. Out of *m* connection parameters, connection sequence number (C_i), source node (S_i), destination node (D_i), requested availability (A_{ri}), arrival time ($T_{Arrivali}$), holding time (T_{Holdingi}), class of traffic/priority level (P_i=Gold/Silver), and type of the request (establish/release) are counted as connection parameters. The matrix of connection requests is in the following form.

$$CRM_{2nxm}=\begin{bmatrix} C_1 & S_1 & D_1 & A_{r1} & T_{Arrival\,1} & T_{Holding\,1} & \frac{Gold}{Silver} & \frac{Establish}{Release} \\ \vdots & & & & & & & \vdots \\ C_n & S_n & D_n & A_{rn} & T_{Arrivaln} & T_{Holding\,n} & \frac{Gold}{Silver} & \frac{Establish}{Release} \end{bmatrix}$$

For all unequal source-destination pairs of CRM, Algorithm 1 updates cost of the links per iteration using (1) and then applies *Dijkstra*'s algorithm to find the shortest primary path. If no primary path is found, it means the maximum availability for the requested path is zero, otherwise the MPA algorithm updates link-wavelength usage matrix [6] and calculates the shortest backup path using the same mechanism it does for the primary path. The MPA value for the specific pair of *(s,d)*, $MPA_{(s,d)}$,will be calculated through (2), (3), and (4). Algorithm 1 returns the MPA matrix defined in Definition 2.

Definition 2 MPA matrix: Algorithm1 calculates an *mxm* matrix of the following form in which m is the number of nodes in the network. Clearly, for all values of m, $MPA_{(m,\,m)}$=0. $MPA_{(i,j)}$is the maximum path availability between the pair of nodes i and j.

$$MPA_{mxm}=\begin{bmatrix} MPA_{(1,1)} & \cdots & MPA_{(1,j)} & \cdots & MPA_{(1,m)} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ MPA_{(m,1)} & \cdots & MPA_{(m,j)} & \cdots & MPA_{(m,m)} \end{bmatrix}$$

The stepsdescribing the MPA algorithm which result in calculatingthe MPA_{mxm} matrixare presented in Algorithm 1 which considers a network topology of *m* nodes.

Algorithm 1 MPA computation

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Input: $C_n(s,d,A_r,p)$, GT matrix, $W$ matrix, $W_{int}$
Output: the MPA matrix
1. $s \leftarrow 1$ AND $d \leftarrow 1$
2. IF $s=d$ THEN
       $MPA_{(s,d)} \leftarrow 0$
3. WHILE $s \le m$ AND $d \le m$
   DO Steps 4-15
4.     FOR all values of $i$ , $j \in \{1,2,\dots,m\}$ AND $s,d$ $\{1,2,3,\dots,m\}$
           Modify cost of the links of the graph using Equation (1)
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$$C_{P(i,j)}=\begin{cases}\infty & \omega_{ij}=0\\ -ln(a_{(i,j)}) & \omega_{ij}>0\end{cases}\qquad(1)$$

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           where on the link between the nodes $i$and $j$:$C_{p(i,j)}$is the cost, $a_{(i,j)}$ is the availability,and $\omega_{ij}$is the number of free wavelengths
5.     Run Dijkstra's algorithm[8] to calculate the primary path for the given source, destination, and the pre-calculated cost function in Step 4
6.     IF no primary path is found THEN
           $MPA_{(s,d)} \leftarrow 0$
       Else
           Go to Step 7
7.     FOR all links forming primary path
           Update $W$matrix AND
           Save it as a new matrix {to be used by backup path calculation process}
8.     IF any elements of new link-wavelength matrix is zero $\{\lambda_{ij} \leftarrow 0\}$ THEN
           Same elements on the link-availability matrix is zero $\{A_{ij} \leftarrow 0\}$
9.     Save the modified link-availability matrix in a new matrix
10.    REPEAT Steps 4, 5 with the new link-availability matrix to find the backup path
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11. IF no backup path is found THEN
    $MPA_{(s,d)} \leftarrow 0$
    Else
    Go to Step 13
12. Calculate the path availabilities through Equations (2) and (3) for all links forming primary and backup paths

    $A_{pCn} = \prod_{(i,j) \in Cn\ primary\ -path} a_{(i,j)}$      (2)

    $A_{bCn} = \prod_{(i,j) \in Cn\ backup\ -path} a_{(i,j)}$      (3)

    where$A_{pCn}$ and$A_{bCn}$ are the availability of the primary and backup paths for the $n^{th}$ connection request
13. Compute $MPA_{(s,d)}$ for a specific pair of source-destination in the $n^{th}$ connection request through joint-availability function[9]using Equation (4)

    $MPA_{(s,d)} = A_{pCn} + A_{bCn} - A_{pCn} \cdot A_{bCn}$      (4)

    where $MPA(s,d)$ is the maximum offered path availability for a source-destination pair in the $n^{th}$connection request
14. $s \leftarrow s+1$ AND $d \leftarrow d+1$
15. END
16. RETURN the matrix MPA
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IV. PROPOSED TRAFFIC ENGINEERING EXTENSIONS

A. Intra-AS Negotiation

TABLE I: LINK TLV PAYLOAD FORMAT

Link Type	Link Length
Link Sub-TLV 1	
Link Sub-TLV 2	
…..	
Link Sub-TLV n	

TABLE II: NEW LA SUB-TLV

LA Type	LA Length
LA Value	

To disseminate the SLA parameters inside an area,type-10 opaque LSAs are suitable choice since type-10 opaque LSAs are not flooded beyond the borders of their associated area. In addition, as defined in [2], to disseminate the SLA parameters inside an AS, Type-11 opaque LSAs can be suitable choice. In OSPF-TE, a top-level link TLV in payload field describes the characteristics of a single link [1]. The link TLV and its sub-TLVs have a format of Table I. The new sub-TLV proposed to carry and propagate link availability (LA) inside an AS is defined in Table II. Using this new sub-TLV, an important SLA parameter, link availability, will be flooded all over an AS.

B. Inter-AS Negotiation

Since in a general case there is no IGP peering between two different ASs, to find a way to get LSAs describing its TE properties into the TE database, [10] suggests that the edge routers (ERs) advertise the external link states, internally to its AS and generates an LSA describing its own side of a link. Since in BGP, no topological and/or state information is allowed to be disseminated beyond domain boundaries, the link availability information cannot be disseminated from inside one AS to another. The proposed TE-based SLA-constraint defined in this paper, MPA, not only distributes the maximum path availability which iscalculated in any internal routersand sent from the ERs of an AS to the other ASs, but it also reduces the routing protocol packets' overheadcaused by propagating link availability.

Based on [10], the link state of the links connecting different ASs is advertised inside the ASs by ERs of the same ASs. Using the new defined TE-metric discussed in Section III, an SLA-related path-attributewill also be propagated among ASs.

The MPA of any source to any ERs inside an AS should be propagated among different ASs. Then the ERs need the related information in the MPA matrix of a neighbouring AS. Since there is no IGP peering between ERs of different ASs, we need another mechanism (other than OSPF-TE) to send the required information from an ER in one AS to another ER in another AS. Since the communications between ERs of different ASs are done through the BGP protocol, we need to define an extension on BGP to support the TE-based SLA-constraint and also to transfer a part of the MPA matrix of the remote AS to the neighbouring onewithout changing the path selection process of the IGP and BGP protocols.To do so, we need to use OSPF-TE and BGP-TE packets with specific extension for carrying SLA-related constraints. Since BGP supports a hop-by-hop routing paradigm and is a path-vector protocol, whereas OSPF is a source routing and a link-state protocol, the proposed mechanism combines these two protocols to work together for multi-domain SLA parameters disseminating.

In the conventional BGP [11], the advertisements propagated between BGP routers are encapsulated in the UPDATE messages. To consider TE-constraint, a new path attribute is added into BGP as an extension. The proposed TE-metricis advertised along with the path information in both intra-AS and inter-AS manners using IBGP and EBGP. The proposed format of the extension is a TLV format, where the proposed TE-attribute carries a group of TLV fields, specifying the value of the corresponding TE metric.

Among different ASs, the EBGP is used to exchange information about paths and related TE-metrics. ERs within an AS will advertise MPA values for each destination to their neighbours that are the ERs in other ASs. The IBGP runs among routers within the same AS. According to IBGP with TE extension, when anER in an AS receives the TE path-attribute for a destination from another AS, it will send these externally-learned paths to internal nodes. In order to cope with legacy BGP routers, the proposed TE-attribute is optional and transitive which means theattribute may not be recognized by some legacy BGP routers and this attribute should be passed on even if it is not recognize. Accordingly, the BGP routing table is extended to keep the TE-related information, as well. Since we are just transferring TE-related information through BGP and we are not going to letBGP path selection process be affected by these TE-related changes, we do not need to define any new state machines.

The MPA calculation procedure is discussed in Section III. The new path-attribute sub-TLV in BGP-TE UPDATE packets for carrying MPATE-constraint in an ER calculated from any node inside the corresponding AS (including the other ERs) is presented in Table III. Figure1showshow the mechanism disseminates the TE-related SLA-related packets.

The packet routed from one AS to another AS should be routed through one of the edge routers. The routers inside an AS advertise the link availability of the associated links into the AS. Using this information, the MPA matrix is built in all routers inside an AS including edge routers. Then all the edge routers of an AS have the matrix of form defined in Definition 2.

If the j^{th} node is one of the edge routers as shown in Fig. 1, the ER_jwill advertise the MPA value of all routes ending it. This information is summarized in the j^{th} column of the MPA matrix. In the current operation of TE-OSPF, the LSRs at each end of a TE link emit LSAs describing the link. Unlike regular routers inside the AS that only advertise the link availabilities, ER_j will advertise all the information of the j^{th} column of MPA matrix of the associated AS through the proposed sub-TLVs of opaque LSAs presented in Table III, in addition to the link availability of the external link.The total maximum path availability of a path traveling from node s insiden^{th} AS, AS_n, to$d$ insidep^{th} AS,AS_p, will be calculated through (5) in which MPA is the maximum path availability matrix in an AS,MPA_{AS_k} is the maximum path availability value of k^{th}ASfromaningress edge router $ER_i$to an egress edge router ER_j as shown in (6).

$$MPA_{total} = MPA_{AS_n}(s,t) \times \prod_{k=n+1}^{p-1} MPA_{AS_k} \times MPA_{AS_p}(q,d) \tag{5}$$

$$\forall (i,j) \in AS'_k s\ nodes\colon\ MPA_{AS_k} = Max\{MAP_{(ER_i,ER_j)}\} \tag{6}$$

TABLE III: NEW MPA SUB-TLV

MPA Type	MPA Length
$MPA_{(1,j)}$	
$MPA_{(2,j)}$	
……	
$MPA_{(i,j)}$	
……	
$MPA_{(m,j)}$	
MPA_{total}	

Here, each edge router keeps two matrices. One from its associated AS which is to be advertised to the other AS, and the other which is received from another AS informing about the conditions on the neighbouring AS. In the case of NSFNet network topology shown in Figure 2, j^{th}edge router will advertise an MPA sub-TLV of 14 MPA values including j^{th} column of the MPA matrix plusMPA_{total}.

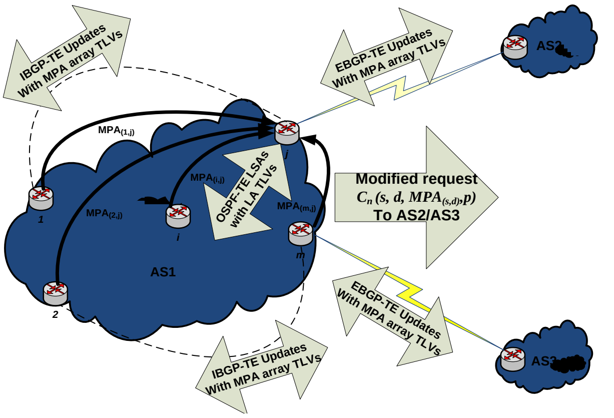

Fig. 1. Inter-AS dynamic SLA-related packets dissemination

V. PERFORMANCE ANALYSIS

A. Simulation Environment

The negotiation system proposed in this paper has been evaluated using a simulation environment developed in MATLAB. The topology selected for the simulation is NSF Net shown in Fig. 2. The links have wavelength conversion capability with 8 wavelengths per each link. The link availabilities are uniformly distributed between 0.99 and 0.9995. Connection availability requests are uniformly distributed between three classes of traffic: Gold class with the availability of 0.9999, Silver class with the availability of 0.9990, and Bronze class with no availability significance. A Poisson process with arrival rate of β is considered for the arrival process of connection requests. The holding time of the connections follows an exponential distribution with the mean value of μ=1. The primary and the backup paths are considered totally disjointand the failure of primary links at the same time is very unlikely. The total number of connection requests over whole simulation period is 10^5.

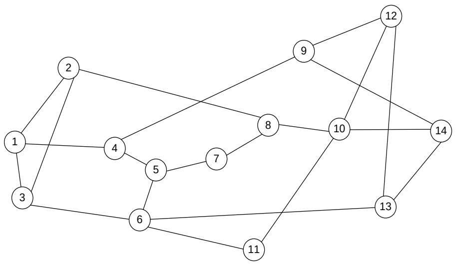

Fig. 2. NSF net network topology

In this paper, the availability satisfaction ratio (ASR), the blocking rate (BR), the pre-provisioned number of blocked connections (PPBC) of the SPA algorithm, and the average assigned wavelengths per connection (AWPC)arecompared with other existing algorithms. ASR represents the percentage of provisioned connections whose availability requirements are met over all provisioned connections. BP denotes the percentage of blocked connection requests over all arriving requests. PPBC shows the percentage of pre-provisioned blocked connections over all impossible cases. AWPC shows the average number of assigned wavelength per connection.

B. Performance Analysis

The simulation was performed to compare the performance of no protection (NP) scheme [12], standard shared mesh path protection (SSPP) algorithm [12] and [13], conventional shared path protection,the priority-aware algorithm (PAA) algorithm presented in [14], and the SPA algorithm discussed in [7].The CSPP algorithmhas been considered in this paper as a generalized case of the SSPP scheme in which link availabilities are involved in the path calculation process. The results show considerable improvements on the connections with higher class of traffic. Unlike the static traffic type [14], in dynamic traffic pattern, lightpaths are requested dynamically with randomly generated availability requests. In this case, the algorithm has no knowledge about the coming request. As shown in Fig. 3, the SPA algorithm makes a huge improvement on the high-priority requests whose requirements are met. In fact, Gold connection requests are more preserved in the SPA algorithm than any other priority-aware algorithms. Although the SPA algorithm has no significant effect on the lower priority traffic flows, Silver connection requests, in terms of ASR compared to the algorithm proposed in [14], the SPA still has better performance than the SSPP.

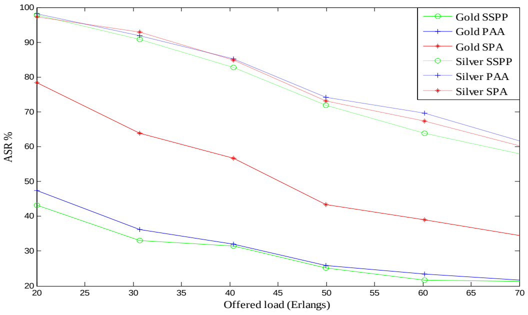

Fig. 3. The effect of SLA negotiation on availability satisfaction rate of different priority levelprotection schemes

Fig. 4 shows that the proposed algorithm has better blocking rate than the conventional scheme for the offered loads bigger than 25 Erlangs. It also shows that the algorithm does not degrade BR performance significantly and has almost the same BR as the priority-aware algorithm presented in [14].

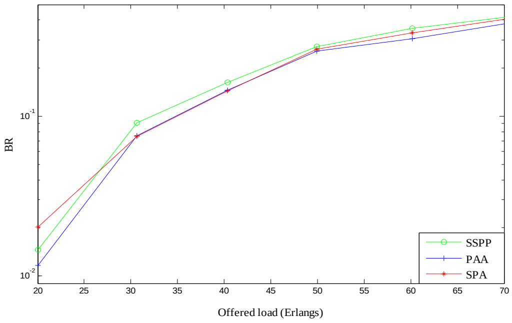

Fig. 4. The effect of SLA negotiation on blocking rate of different priority-aware protection schemes

As noticed in Fig. 5, in average 60% of high priority connections, Gold class, which are impossible to accommodate by the algorithm presented in [14] are pre-provisioned and are not blocked anymore. This proves that the proposed pre-provisioning algorithm increases the level of the priority awareness in comparison to other algorithms.

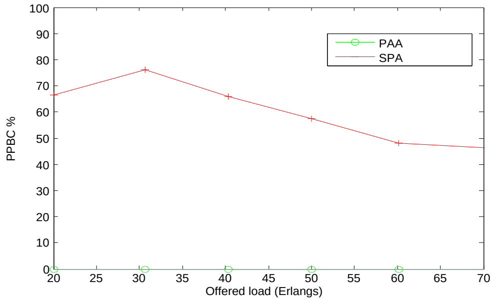

Fig. 5. The effect of SLA negotiation on number of pre-provisioned blocked connections of different priority-aware protection schemes

Fig. 6 shows how employing the negotiation mechanism proposed in this paper affects the performance of the standard shared mesh protection scheme. Since the CSPP scheme benefits from the negotiation mechanism and uses link availability as a constraint in the path computation, it makes a significant improvement on the number of the connections whose availability requests are satisfied. Clearly, the NP scheme has the worst ASR since it does not provide protection for the paths.

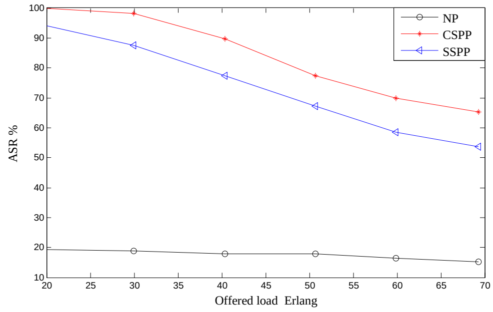

Fig. 6. The effect of SLA negotiation on availability satisfaction rate overdifferent protection schemes

The CSPP scheme has better wavelength utilization (AWPC) than the SSPP scheme as shown in Fi. 7 since the CSPP decreases the average number of assigned wavelengths to each path by 25% on average compared to the SSPP. However, the NP scheme has a lower wavelength usage in this case since it does not reserve any resources for backup paths.

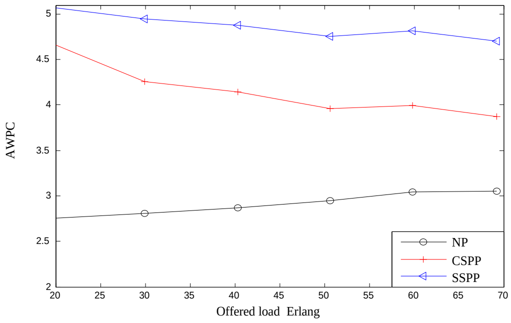

Fig. 7. The effect of SLA negotiation on average wavelength usageover differentprotection schemes

Since the routing and wavelength assignment process for both the CSPP and SSPP schemes is the same, the CSPP is not expected to have a significant improvement in blocking probability compared to SSPP, as shown in Fig. 8. Blocking probability of the NP is expected to be low since wavelength usage of this scheme is the lowest which keeps the network resources free for future connection requests.

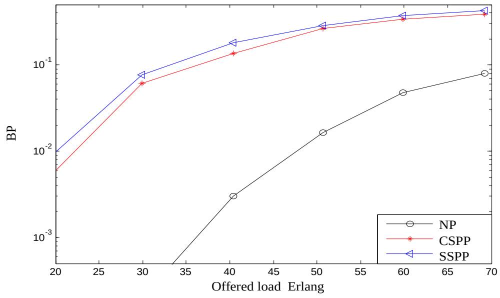

Fig. 8. The effect of SLA negotiation on blocking probability over different protection schemes

VI. CONCLUSION

The paper is presenting a dynamic SLA negotiation mechanism for shared mesh optical networks. The proposed traffic engineering extensions applied to OSPF and BGP protocols consider both intra and inter domain communications. Link-availability as an SLA parameter is negotiated via intra-domain mechanism, and an SLA-based traffic engineering path-attribute, maximum path availability, is advertised through inter-domain negotiation mechanism as an example of the negotiated parameters. To evaluate the performance of the proposed dynamic negotiation mechanism, an algorithm presented in previous work which has been designed assuming the existence of such mechanism is presented and investigated. Performance analysis shows that the statically pre-provisioned priority-aware algorithmwhich benefits from the proposed SLA dynamic negotiation mechanism has better availability satisfaction ratio performance while it does not degrade the blocking probability.

In addition, the algorithms using dynamic SLA negotiation do not apply more overhead in terms of the total number of allocated wavelengths than standard and other priority-aware algorithm.The capability of the dynamic SLA negotiation will be well shown when it uses the spare maximum capacity of the network dynamically. That is, the customers will be informed dynamically by the service provider about the maximum available capacity of the network and the new release time of the already occupied resources.This may help customers to know if their request will be accommodated, and if not, when is the proper time to send the request to have the best chance to get the connection established. This can be the basis of new algorithms which can bring the number of the blocked connections down.

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