Fully-Distributed Control Plane for Elastic Optical Network with GMPLS with RMSA

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Abstract This paper proposes a fully-distributed GMPLS framework through the use of extended RSVP-TE both for signaling and for routing, modulation and spectrum assignment (RMSA). Our proposed solution achieves lower blocking probability and shorter signaling-latency than does the state-of-the-art GMPLS/PCE architecture.

Introduction
The routing, modulation and spectrum assignment (RMSA) is one of the most important issues in elastic optical networks (EON). EON has the constraint that all allocated basic slots of a frequency slot must be continuous across all fiber links end-to-end. Generalized multi-protocol label switching (GMPLS) path is a promising candidate to address RMSA with a distributed control plane.

There are two different network designs so far GMPLS and GMPLS with path computation element (GMPLS/PCE). In GMPLS design, each node maintains its own network state information and work for routing, modulation, and optical spectrum assignment. In contrast, in GMPLS/PCE design, centralized stateless PCE maintains its own network information.

However, both GMPLS based EONs present two well-known issues. First, routing protocol requires large control plane overhead due to the dissemination of the OSTP-TE protocol. Second, GMPLS distributed signaling cannot avoid reserve collision among requests due to the signaling-latency.

In this paper, we propose fully-distributed RMSA and signaling with the possibility for reduced collision as an extension to GMPLS. The solution contains three key steps: (1) look for K routes (K is a pre-determined number) from the source node to the destination node using Path message broadcasting; (2) attempt to establish multiple paths, and (3) tentatively reserve slots for later arriving Path messages to avoid “over-reservation” (a connection request establishes more than one path).

K-candidate Routing and Resource Assignment in GMPLS Networks
Previous works used centralized PCE with OSPF-TE to disseminate changes and to update traffic engineering database (TED). Here, we propose to use extended RSVP-TE to perform the RMSA. As a result, each node need not have a global view of TED. Fig. 1 shows an example of RMSA for source-destination (5-3). Firstly, the source node transmits Path messages for all ports (Fig. 1(a)). Path messages include the set of the source address and the LSP-ID (“connection ID”) to distinguish each request.

![Fig. 1: Example of a K-candidate path search](image)

When an intermediate node receives a Path message, the node checks whether it is the first Path message of the connection ID. If true, the node transfers the message to all of the other ports (Fig. 1(b)). If not, the node terminates the received Path message (see nodes 0 and 1 on Fig. 1(d)). The destination node does not transfer the received Path message to the other ports (see node 3 in Fig. 1(c)). As a result, the total number of Path messages greatly reduces. Each Path message records the list of transferred node IDs for the routing and unused slot numbers for spectrum assignment on the destination node, and it is updated hop by hop.

Upon receiving a Path message, the destination node checks whether the receiving message arrives within $K_{in}$ Path message. If true, the destination node tries to establish a lightpath along the route for the propagated received Path message. In this spectrum assignment phase, the destination node first checks the distance of the route, then...
determines the modulation format and the number of slots to assign for the route. Then, the destination node looks for available slots as a first fit. If there are enough slots, the destination node assigns the slots for the route, and if not, the destination node returns PathErr message to the source node. The above method can include advanced RMSA methods, e.g. fragmentation-aware RMSA\(^8\).

In Fig.1, the destination node found four routes (5->4->3, 5->2->3, 5->2->0->3, 5->2->1->3). Two important observations are: (1) when there are not enough spectrum slots to assign, the destination node may find another path with available spectrum slots, (2) it also works when a collision happens during the signaling process.

**Extension to traditional GMPLS RSVP-TE**

To avoid over-reservations of multiple path requests, we introduce a tentative reservation for the later attempted routes. We use the conventional Path-Resv protocol only for the first path request (Fig. 2(a)). We define the new status for the spectrum slot, called “requested” for this tentative reservation, and also define three new types of control messages for this “requested” status: (1) the “request (Req)” message is generated by the destination node to make a tentative reservation for a later path; (2) the “activate (ACT)” message is generated by the source node to change the status of slots from “requested” to “reserved”; (3) the “acknowledgement (ACK)” message is generated by the destination node to inform the source node about the success of the activation.

When a first Path message arrives at the destination node, the destination node returns a Resv message to the source node. The node that receives the Resv message reserves the assigned spectrum slots (changes the status of slots to “reserved”). If some slots cannot be reserved due to collision, the intermediate node transmits the PathErr message to the source node and PathTear message to the destination node (Fig.2 (b)).

For the second or later arriving Path message, the destination node returns the Req message to the source node. The node that receives the Req message tentatively reserves assigned spectrum slots (that is, changes the status from “available” to “requested”). If some slots cannot be reserved due to collision, the intermediate node transmits the PathErr message to the source node and the PathTear message to the destination node.

When the Req message arrives at the source node, the source node checks whether it has already established a lightpath. If a lightpath is established, the source node transmits the PathTear message to the destination node (Fig. 3(a)). If it is not, the source node transmits an ACT message to the destination node. The node receiving the ACT message changes the port status from “requested” to “reserved”. If a node fails to activate slots because some slots are reserved by the Resv message, the node transmits the PathErr message to the source node and PathTear messages to the source and destination nodes (Fig.3 (b)). When the ACT arrives at the destination node, the destination node returns the ACK message to the source node (Fig.3 (c)). The source node can start to transmit data traffic once receiving the ACK.

**Simulation Setup and Results**

Fig. 4 shows 14-node simulation topologies of (a) Japan and (b) NSF networks. We assumed (a) bidirectional links, (b) 128 individual spectrum slots, (c) dynamic requests arriving at the rate \(\lambda\) according to a Poisson distribution or at the rate \(\mu\) according to an exponential distribution, (d) the network offered load, \(\rho\), defined as \(\lambda/\mu\) in our simulations, and (e) the requested signal data rate follows an integer random variable, uniformly distributed in the range \([1,100]\) Gb/s. Table. 1 shows the number of slots assigned to each request mapped to 10, 40 or 100Gb/s. We use 16 QAM for paths shorter than 600km and 4QAM for paths longer than 600km. We assume that there are about 100,000 requests arriving at the network. Fig. 3 shows the distances in \(km\) and each fiber delays the signal by 5.5\(\mu s/km\). We used the fixed inter-
arrival time \((=1/\lambda = 1s)\) for the Japan topology and the fixed holding time \((= 1/\mu = 100s)\) for the NSF topology. The PCE nodes are located at node 11 for Japan and node 9 for NSF topology.

Fig. 4: (a) Japan topology, (b) NSF topology

<table>
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<tr>
<th>Tab. 1: The number of slots to assign</th>
<th>4QAM</th>
<th>16QAM</th>
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<tbody>
<tr>
<td>10 Gbps</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>40 Gbps</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>100 Gbps</td>
<td>14</td>
<td>7</td>
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Figure 5 shows the simulated blocking probabilities in the Japan network. The \(K=2\) and \(3\) in our solution have smaller blocking probabilities than the conventional GMPLS/PCE solution. Especially when \(p=60\), our solution for \(K=3\) achieves 44\% lower blocking probability than does the GMPLS/PCE solution. Our solution considers two or more routes.

Fig. 5: Blocking probability on Japan topology

Figure 6 shows the blocking probabilities for the NSF topology. Since the signaling delay is larger than the Japan topology, many collisions happen during the reservation, and the blocking probability is large even at low load. Our proposed solution with \(K=2\) and \(3\) achieves much smaller call loss probability than do the cases of GMPLS/PCE and \(K=1\). Especially when \(p=60\), our solution for \(K=3\) is 89\% smaller blocking probability than for the GMPLS/PCE solution.

We also simulate the signaling time for both networks. We consider only the sum of propagation delay as the signaling time. In Japan topology, our proposed solutions with \(K=1,2,\) and \(3\) produce a signaling delay of about 4.2ms, while the GMPLS/PCE solution produces a signaling delay of about 7.7ms. The GMPLS/PCE solution must ask for the PCE node to determine a route. Therefore, the round trip time between the source node and the PCE node increases the signaling delay in the GMPLS/PCE solution. Similar advantageous reduction is found in the NSF topology.

Conclusions
In this paper, we have proposed a modified GMPLS elastic optical network with \(K\)-candidate path search and tentative reservations. Numerical results show that our proposed network, when \(K\) is two or more, achieves much better performance in terms of reducing the blocking probability and signaling delay than does the state-of-the-art GMPLS/PCE network. In addition, our proposed network achieves significantly better performance in the case of the possibility of reservation collisions being large, such as a large scale network, due to the proposed tentative reservation.

Acknowledgements
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References