Experimental Evaluation of a Full-Meshed Domain Abstraction Design Model for Reduced State Information Dissemination in Multi-domain PCE-based WSONs

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Abstract: A novel full-meshed domain abstraction model for scalable state information in PCE-based WSONs is presented. We experimentally evaluate the state information update reduction and the blocking improvement with regard to a shortest path model.

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1. Introduction

The hierarchical Path Computation Element (PCE) [1] architecture has arisen as the leading standard for inter-domain route calculations in Wavelength Switched Optical Networks (WSONs). In this architecture, the parent PCE, having (aggregated) visibility of the entire multi-domain network topology, is the responsible for computing the end-to-end domain sequences from source to destination nodes, while the child PCEs in every traversed domain are devoted to computing the intra-domain route in their respective domains.

Optimal inter-domain route computation, however, is a complex challenge that still poses some difficulties. In fact, domains in such large network scenarios may belong to different operators. This makes the parent PCE unable to gain access to the intra-domain information (i.e., resources, topology etc.) due to both scalability and confidentiality reasons. As a consequence, a fully detailed view of the multi-domain network is impossible.

In order to address both problems, topology aggregation techniques, also named virtual topology abstraction strategies, have been proposed in the literature [2]. These techniques allow representing the internal topology of each domain in a compact and abstract manner. They transform the physical topologies of the network domains into a set of logic topologies that contain information about their state, being the logic topologies typically smaller than the physical ones. Those abstract topologies are the ones that are then made visible to the parent PCE.

Multiple abstraction techniques have been proposed so far, being the full-meshed abstraction the one that generally gives the best resource usage [3]. In such a full-meshed abstraction, each domain is transformed in a sub-graph that summarizes the cost of traversing it. Hence, the domain graph is composed by all Border Nodes (BNs) connected through a fully meshed set of virtual links, each one representing the cost of traversing the domain through any pair of them. For improved route computation, a cost is assigned to each virtual link, containing information about the state of the physical resources (e.g., wavelengths) over which the specific virtual link is mapped. The new attributes of a virtual link should be disseminated to the parent PCE every time a change occurs on the availability of the underlying physical resources. This can be either due to the provisioning or release of a lightpath over the virtual link or over any other virtual link sharing physical resources with it. As a consequence, the state information that needs to be finally advertised to the parent PCE is substantially increased in contrast to simpler domain abstraction techniques.

In this paper, we present a novel Mixed Integer Programming (MIP) formulation that provides a static mesh layout of virtual links aiming to minimize the amount of information that needs to be advertised due a state change of a virtual link in a full-meshed domain abstraction scenario. The benefits of such a model have also been quantified in the CTTC ADRENALINE test-bed, using a single TE domain (OSPF-TE area) with a child PCE responsible for the topology aggregation and notification.

2. MIP formulation

Let *N* be the set of nodes in the domain and *E* the set of arcs or edges. Each edge in *E* is defined as $\{(i,j), (j,i) : i,j \in N\}$. The physical topology of the domain is represented by the directed graph $G = [N,E]$. We define $p_{sd} = \{i_1, (i_1,i_2), i_2,\ldots, (i_n,i_{n+1}), i_{n+1} : i_1 = s, i_{n+1} = d; s,d \in N\}$ as the directed path from source node s to destination node d; $B = \{b_1,\ldots, b_n : b_i \in N\}$ as the set of BNs in *G*; Q_{sd} as the set of candidate paths from node s to d with $s,d \in B$; and R^{k}_{sd} as the set of paths in *G* that share at least one physical link with Q^{k}_{sd}. The MIP statement is:

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Minimize:

$$\alpha \cdot Z + \beta \cdot M \qquad (1)$$

Defining:

$$a_{sd}^{k} = \begin{cases} 1 \text{ if } Q_{sd}^{k} \text{ is activated} \\ 0 \quad \text{otherwise} \end{cases} \qquad (2)$$

$$z_{sd}^{k} = \sum_{R_{sd}^{k}} y_{\substack{sd \\ op}}^{k,j}, \forall\, o, p : o \neq p\,; s, d, o, p \in B \qquad (3)$$

$$M = \sum_{i} \sum_{j} \sum_{k} z_{ij}^{k}, \forall\, i, j \in B \qquad (4)$$

Subject to:

$$Z \geq z_{sd}^{k}, \forall\, Q_{sd}^{k} : s, d \in B; s \neq d \qquad (5)$$

$$\sum_{k} a_{sd}^{k} = K, \forall\, s, d \in B; s \neq d \qquad (6)$$

$$y_{\substack{mn \\ op}}^{i,j} \geq a_{mn}^{i} + a_{op}^{j} - 1, \forall m, n, o, p \in B; m \neq n, o \neq p \qquad (7)$$

The idea behind the model is to minimize the overlapping of virtual links in any of the physical paths associated to them. By minimizing this metric, the number of resources shared between virtual links is reduced and so the amount of information to be advertised due a change in the state of a virtual link. Objective function (1) is composed by the weighted sum of two terms *Z* and *M*, containing the information associated to the maximum and the mean overlapping respectively. α and β are tuning variables that range from 0 to 1 used to put more emphasis in one of the terms to adjust the model to the traffic profile and the network physical topology. Equation (2) represents the binary variables used to determinate the choice of paths between BNs during the optimization process, (3) represents the overlapping of virtual links in a physical path and (4) represents the overall overlapping in the graph. Constraint (5) ensures that the maximum overlapping in the graph will be minimized; constraint (6) is used to fix K, that is, the number of physical paths associated to a virtual link, being K a number equal or greater than 1 if k-branching is considered in the routing process; and constraint (7) arises due to the fact that in a natural formulation of the problem, equation (3) would have been composed by the summation of products of binary variables, leading to a non-linear formulation, so a new set of continuous variables *Y* is introduced. Each of those variables is strictly non negative and associated to the product of a particular pair of binary variables in (2). Constraint (7) is used to lead the value of *Y* to the value that the product would have, thus linearizing the formulation.

3. Test-bed description and experimental results

The performance of the proposed model has been evaluated on the CTTC ADRENALINE test-bed [4], where a 14 node network with a single child PCE has been configured (Fig. 1). For the virtual topology design, a K value equal to 1 in the model has been considered, as no k-branching is used during route provisioning. In turn, α and β have also been set to 1, equally minimizing the maximum and the mean virtual link overlapping. The obtained virtual topology mapping is statically provisioned, namely, the correspondence between virtual links and physical paths remains untouched throughout the experiments.

In the test-bed, each TE link has 10 bidirectional wavelengths. Unidirectional transit domain connections between BNs arrive to the network following a Poisson process, with an inter-arrival time of 3 s and a varying holding time according to the offered traffic load (Erlangs). Connection requests are uniformly distributed amongst all BNs pairs, where BNs are the ones labeled as 1, 2, 10, 11 and 13. The PCE in the network assigns routes to the incoming connections using a proprietary PCE objective function code and given the offline pre-computed layout.

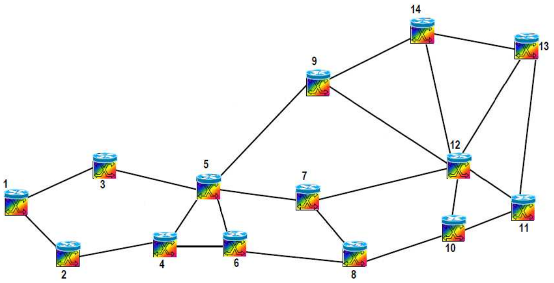

Fig. 1. Network topology used for the experimental results, composed of 14 nodes and 22 links.

Fig. 2 depicts the blocking probability and update rate resulting from the model application for different offered load scenarios, ranging from 20 to 50 Erlangs. Moreover, a full-meshed domain abstraction based on a virtual link to shortest path static mapping has been also implemented and evaluated for comparison purposes. The update rate

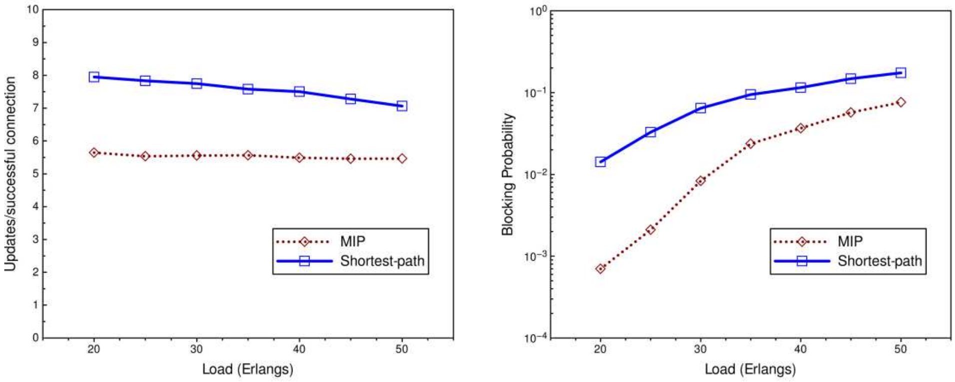

Fig. 2. Average number of updates per connection established (left) and blocking probability (right) for 20-50 Erlangs.

involves the notifications to the parent PCE when the virtual link attributes change after a successful path establishment, and it is computed by checking which virtual links share the physical links that OSPF-TE updates within the domain. Every affected virtual link is accounted as a single notification. This calculus also takes into account the updates associated with the release of the lightpaths. The values plotted in the graphs have been averaged over a set of 10^4 connection requests, thus providing statistically relevant results.

As shown in Fig. 2 (left), the virtual link to physical path mapping that results from the proposed model leads to a reduction of the state information to be disseminated of 27% in average when compared to the virtual link to physical shortest path mapping. In fact, extracting statistics of both the shortest path mapping and the model mapping, we can calculate the average overlapping of virtual links on a physical path, being 4.0 for the shortest path and 2.8 for the proposed model, so a theoretical reduction of 30% is expected. We can observe indeed that the experimental results agree with such a theoretical prediction.

Looking now at Fig. 2 (right), the model also attains a substantial reduction of the inter-domain blocking probability. Interestingly, around one order of magnitude blocking probability reduction for an offered traffic load between 20 and 30 Erlangs is achieved. This phenomenon is a consequence of the objective function of the model. In the model, we are minimizing the amount of resources shared among the physical paths associated with the virtual links. As a result, the physical paths are distributed through a larger set of the network resources, so an overall better resource usage is achieved when compared with the shortest path criterion, where paths tend to concentrate on a smaller set of resources.

4. Conclusions

In this paper, we have presented a novel design model for full-meshed topology abstractions for PCE-based WSONs aiming to provide scalable state information dissemination. From the experimental results, a reduction of around 27% of the state information to be disseminated compared to a virtual link to physical shortest path mapping is achieved in average, also leading to blocking probability improvements around one order of magnitude.

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