Broker-based Orchestration for Service Provisioning in Multi-domain Networks

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Abstract: This paper discuss a new networking paradigm introducing the broker-plane above the management planes of Autonomous Systems. The brokers communicate with the network manager of each AS to assist coordinate end-to-end resource management and multi-AS path provisioning.

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1. Introduction

Single operators’ transport networks are usually created as multi-domain networks a result of deploying nodes from different vendors and/or different technologies. In such scenarios, the topology of the different domains is fully visible from outside each domain and therefore it is possible to compute end-to-end paths. Several approaches can be considered to automate end-to-end provisioning in single-operator multi-domain networks, where a Path Computation Element (PCE), possibly with other functional blocks to create an Application-Based Network Operations (ABNO) architecture, is in charge of computing paths in each of the domains. Each PCE (named as child PCE) has full visibility of the topology and resources of the underlying domain. A parent PCE can be connected to every child PCE to compute the sequence of domains, and it can compute paths for the end-to-end connection, or it can delegate intra-domain paths computation to child PCEs.

In contrast, because of privacy policies, in multi-operator multi-domain networks only an abstraction of the topologies is visible from outside the domain, which prevents from computing paths traversing more than one domain. In such scenarios, the standardized backward path computation procedure allows computing an end-to-end path through a chain of PCEs, where each PCE computes a sub-path for the underlying domain. Since this procedure results in sub-optimal path computation, the backward recursive PCE-based computation procedure was standardized to compute optimal constrained paths. Recent works proposed using market-driven brokers on top of child PCEs or Software Defined Networking (SDN) controllers in charge of each Autonomous Systems (AS). Note that the interactions between the network management systems or network controllers and the broker are based on mutual agreements and negotiations (e.g., service level agreement) especially because each heterogeneous AS will have different requirements and agreements. Such scheme provides autonomy to the domains and improves scalability.

From the technological perspective, today’s transport networks are mostly based on Elastic Optical Networks (EONs), enabled by the flexgrid technology [1]. In EONs, when a connection (named as lightpath) request arrives, the routing, modulation format and spectrum allocation (RMSA) problem needs to be solved [2]. One of the main causes of connection blocking in EONs is the fragmentation of the optical spectrum [3]. In the absence of optical converters, the authors proposed a re-optimization algorithm to defragment the optical spectrum that it is reactively triggered after a connection request cannot be served; the algorithm reallocates already established connections so as to make enough room for the incoming connection request. Experimental validation of hitless spectrum defragmentation was reported in [4] for single domain networks. Defragmentation can also be applied in the contexts of multi-domain single operator scenarios, where the visibility of the resources within the domains is available in a centralized element. However, because of the lack of coordination among ASes, in multi-AS scenarios, transparent optical connections are rarely used. Instead, signals traversing two ASes are converted to the electrical domain and back again to the optical domain, which can be relaxed and applied only in the case of a transparent end-to-end path cannot be found.

In this paper, we study the benefits derived from brokered orchestration by applying per-domain defragmentation in multi-operator multi-domain optical networks compared to the use of optical converters.

2. Broker-Based Multi-Operator Network

Let us assume a multi-operator multi-AS flexgrid optical network, where each AS is controlled by an SDN/OF controller or an ABNO-based architecture. On top of the ASes, a broker coordinates end-to-end multi-AS provisioning (Fig. 1).
Since the broker will be requested to perform complex computations, each AS is assumed to advertise inter-domain nodes and links (while updating the available spectrum for each inter-domain link to follow updates) independently from path computation requests (Fig. 2a). In addition, each AS might agree to expose further features, named as capabilities, which can be supported by specific hardware (e.g., spectrum converters) or by optimization algorithms (e.g., spectrum defragmentation).

When a computation is requested, the broker collects intra-AS abstracted connectivity and spectrum availability (Fig. 2b). Observe that, each AS advertises an abstracted intra-AS link information to the broker that depends on both, internal AS policies and the specific agreement with the broker. Details of the AS intra-domain topology remains concealed from the rest ASes and the broker.

A solution might entail applying a capability in an AS. For example, using spectrum converters or performing defragmentation to release a set of slices so that an end-to-end lightpath can be established. In the example in Fig. 2c, the AS200 SDN controller is requested to use conversion from slot 1 to slot 2, while in Fig. 2d the controller applies defragmentation in its domain to release frequency slots 1 or 6. Note that by doing so, end-to-end lightpaths can be established.

The broker has a global view of the virtualized network topology, including information on inter-AS links and abstracted intra-AS link status gathered from each AS. To represent the underlying data plane, we use a graph $G(\mathcal{N}_O, \mathcal{E}_O)$, where $\mathcal{N}_O$ is the set of optical nodes and $\mathcal{E}_O$ is the set of optical links connecting two nodes. Graph $G$ is structured as a set $A$ of ASes. Every AS $a \in A$ consists of three differentiated subsets of nodes:

- $\mathcal{N}_e(a)$ subset of edge nodes belonging to AS $a$, end-points of demands.
- $\mathcal{N}_t(a)$ subset of AS $a$ transit (internal) nodes.
- $\mathcal{N}_i(a)$ subset of AS $a$ border nodes.

Then, $\mathcal{N}_o = \bigcup_{a \in A} \mathcal{N}_e(a)$, and $\mathcal{N}_O = \mathcal{N}_e \cup \mathcal{N}_t \cup \mathcal{N}_i$, with $\mathcal{N}_t \cap \mathcal{N}_i = \emptyset$. For instance, $\mathcal{N}_i(AS100) = \{1.1, 1.2\}$ and $\mathcal{N}_e(AS100) = \{1.3\}$ in Fig. 1.

Regarding the links, two subsets are considered:

![Fig. 1. Multi-AS network architecture.](image1)

![Fig. 2. An example of path computation. a) Initial AS advertisement and inter-AS link updating. b) Abstracted intra-AS and end-nodes advertisement. c) Path computation using the conversion capability and d) using the defragmentation capabilities.](image2)
The proposed scheme sets a new dawn for the optical layer. In OTN, the broker tries to compute a transparent end-to-end lightpath. When a multi-domain connection request is received, the broker tries to compute a transparent end-to-end lightpath, and when no feasible lightpath can be found, it proposes a solution possibly applying some of the capabilities announced by the domains. The MultiAS RMSA with defragmentation algorithm was devised to solve the problem. The proposed scheme was experimentally validated on an inter-continental distributed field trial set-up. Two SDN controllers and an ABNO controller were in charge of the opaque-domains. The broker on top of them was responsible for the domain orchestration, and the spectrum defragmentation capability was enabled in the ABNO-controlled domain.

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6. References


