Dynamic Customer Virtual Network Reconfiguration with QoS Constraints and Bandwidth Guarantees

A. Asensio(1), M. Ruiz(1), L.M. Contreras(2), L. Velasco(1), and G. Junyent(1)

(1) Universitat Politècnica de Catalunya (UPC), Barcelona, Spain. aasensio@ac.upc.edu
(2) Telefónica Investigación y Desarrollo (TID), Madrid, Spain

Abstract An algorithm for Customer Virtual Network (CVN) reconfiguration with QoS constraints and bandwidth guarantees is presented. An MPLS virtual network supporting CVNs is pre-planned or dynamically reconfigured. Exhaustive simulations results show 19% CAPEX savings when the MPLS network is reconfigured.

Introduction

Among the wide range of applications and services over IP networks, those requiring bandwidth-on-demand, e.g. inter-datacenter connectivity [1]-[2] or 5G networks [3], are attracting the interest of the industry as well as the research community.

To deal with applications requests for end-to-end (e2e) connectivity provisioning, the IETF has standardized the Application Based Network Operations (ABNO) [4] that can be complemented with an Application Service Orchestrator (ASO) [5] on the top. Aiming at facilitating network resources virtualization, the IETF is working on the Abstraction and Control of Transport Networks (ACTN) framework [6]. The business model in the ACTN framework defines three key entities: customers, service providers and network providers. Customers can request on-demand connectivity between their end-points (EPs) using a Customer Network Controller (CNC), to modify their virtual topology to satisfy service requirements.

In this paper, we focus on providing on-demand reconfiguration of Customer Virtual Networks (CVN) with Quality of Service (QoS) constraints and bandwidth guarantees. Impacts on performance and CAPEX, in terms of amount of Bandwidth-Variable Transponders (BVT) to be installed, are studied.

CVN provisioning

Based on the ACTN model, let us assume a generic landscape with two main actors: *i*) a network operator, which owns the network infrastructure. Since the network operator controls the network infrastructure, is aware of resource availability and is able to collect performance monitoring data, such as effective throughput and delay, and correlate them into QoS indicators; *ii*) a set of customers requiring virtual network services connecting EPs in geographically disperse locations, e.g. a Virtual Network Functions (VNFs) orchestrator requiring on-demand connectivity between DCs to implement service chaining among VNFs.

In this scenario, the layered network depicted in Fig. 1 is considered, where three layers can be identified; from top to bottom: 1) the customer layer with CVNs connecting customer's EPs. Every CVN's link is supported by one or more MPLS paths; 2) the network operator's IP/MPLS network layer consisting in a number of IP/MPLS routers connected through virtual links supported by optical connections; 3) the network operator's optical core network consisting in a number of OXCs and optical links.

Regarding the management architecture, the one in Fig. 2, based on ASO and ABNO, is considered. The ASO module maintains service-related databases (e.g. service and CVN DBs), whereas ABNO maintains network-related databases, i.e. TED and LSP-DB.

In the considered scenario, customers can request CVN reconfigurations to ASO to adapt their CVN to their current needs. CVN reconfiguration requests include set-up or tear-down CVN links and increase or decrease their capacity. Fig. 3 presents an example of how a CVN is modified with the time.

In addition to dynamic reconfiguration, Service Level Agreements between customers and the network operator can include QoS constraints and bandwidth guarantees; QoS can be based on maximum delay permitted between EPs, whereas minimum bandwidth could be requested under failure conditions.

A way to implement bandwidth guarantees is by using spatial diversity i.e., when bandwidth guarantee is requested two or more Shared Risk Link Group (SRLG) -disjoint MPLS paths are established to simultaneously support a CVN link. An example is depicted in Fig. 1, where every optical link is associated with a different SRLG identifier. The SRLG identifier of a MPLS virtual link is the union of the SRLGs supporting that link. Finally, the represented CVN link is supported by two SRLG disjoint MPLS paths: one supported by SRLGs {1, 2, 3} and the other by SRLGs {4, 5}. Therefore, in the event of an optical link failure, the CVN link capacity is squeezed to the bandwidth of the remaining MPLS path. Note that, since only two SRLG disjoint MPLS paths

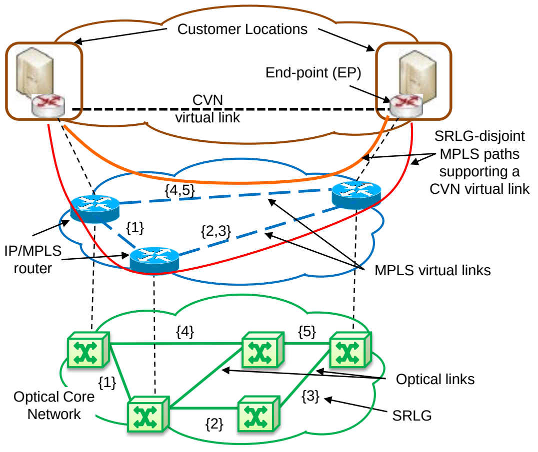

Fig. 1. 3-layered network topology

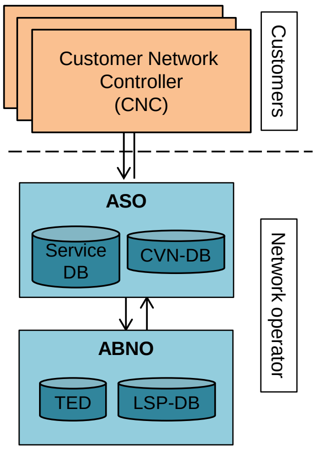

Fig. 2. Management architecture

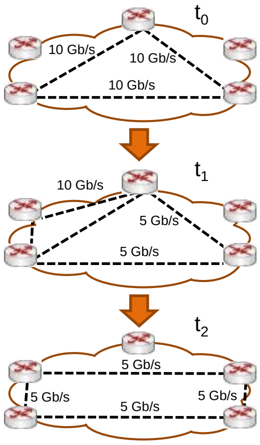

Fig. 3. CNV evolution

where set up, only half of the total CVN link capacity can be guaranteed. For the sake of simplicity, in this paper we assume that condition. To support CVNs, the network operator might either plan and deploy a MPLS virtual network with enough capacity or allow the MPLS virtual network to be dynamically adapted by creating or releasing MPLS virtual links.

CVN-QBG Problem

The CVN reconfiguration with QoS constraints and Bandwidth Guarantees (CVN-QBG) problem can be formally stated as follows:

Given:

- a multilayer network represented by the graph $G_o(V_o, E_o)$; being V_o the set of optical nodes and E_o the set optical of links;
- a MPLS network represented by a graph $G_v(V_v, E_v)$; being V_v the set of MPLS nodes and E_v the set of MPLS virtual links.
- a set of customers C; each $c \in C$ manages its own CVN, which topology is represented by a fully meshed graph $G_c(V_c, E_c)$; being V_c the set of EPs and E_c the set of CVN virtual links.
- a CVN reconfiguration request from customer c, is represented by the tuple $\{c, B^r, Q^r, W^r\}$; where c identifies the customer, B^r is the capacity matrix of the CVN links between EPs, Q^r is the QoS matrix, and W^r is a matrix with CVN links capacity to be guaranteed ($w^r \le 0.5 * b^r$).
- the *MPLSreconf* parameter indicating whether MPLS reconfiguration is allowed or not.
- the *MPLSreopt* parameter specifying whether MPLS reoptimization is allowed or not.

Output: the set L of MPLS paths over G_v and lightpaths (if MPLS reconfiguration is allowed) over G_o that need to be established to serve the CVN reconfiguration request.

Objective: minimize the used resources.

Aiming to solve the CVN-QBG problem in dynamic scenarios, we propose the algorithm in Table 1. Those CVN links with unchanged or decreased requirements are first updated to release resources that can be afterwards reused (lines 2-4 in Table 1). The rest of the CVN links are de-allocated from G_c (lines 5-7) and set up again (lines 8-11) using the *setupCVNLink* algorithm described in Table 2. Note that a CVN reconfiguration request is blocked if one of the CVN links could not be updated.

The *setupCVNLink* algorithm starts finding a MPLS path with capacity *w* on G_v ensuring *q* (line 2 in Table 2). In the case that no route is found and MPLS reoptimization is allowed, reoptimization on the shortest path for *d* in G_v is

Table 1. Algorithm for CVN-QBG.

```
INPUT: $G_c$, $B^r$, $Q^r$, $W^r$          OUTPUT: $L$
1:  $D \leftarrow \emptyset$, $L \leftarrow \emptyset$
2:  for each $e \in E_c$ do
3:    if $B^r(e) \le B(e)$ AND $Q^r(e) \le Q(e)$
                    AND $W^r(e) \le W(e)$ then
4:        update ($e$, $B^r(e)$, $Q^r(e)$, $W^r(e)$)
5:    else
6:        dealloc (e, $G_c$)
7:        $D \leftarrow D \cup \{e\}$
8:  for each $d \in D$ do
9:    l ← setupCVNLink ($d$, $B^r(d)$, $Q^r(d)$, $W^r(d)$, $G_c$)
10:   if $l = \emptyset$ then return $\emptyset$
11:   $L \leftarrow L \cup \{l\}$
12: return $L$
```

Table 2. *setupCVNLink* algorithm.

```
INPUT: $d, b, q, w, G_c$                 OUTPUT: $L$
1:  $L \leftarrow \emptyset$
2:  $R \leftarrow$ findPath($d$, $w$, $q$)
3:  if $R = \emptyset$ then
4:    if MPLSreopt then
5:      reoptimize(shortestPath($d$, $q$), $w$)
6:      $R \leftarrow$ findPath($d$, $w$, $q$)
7:    if $R = \emptyset$ AND MPLSreconf then
8:      $L \leftarrow L \cup$ setupMPLSLinks ($d$, $w$, $q$)
9:      $R \leftarrow$ findPath($d$, $w$, $q$)
10:   if $R = \emptyset$ then return $\emptyset$
11: $L \leftarrow L \cup$ allocate($G_c$, $d$, $R$, $w$)
12: $b_{pend} \leftarrow b - w$; $subpaths \leftarrow 0$
13: while $b_{pend} > 0$ AND $subpaths < k$ do
14:   $S \leftarrow$ findDisjointPath ($d$, $1$, $q$, $R$)
15:   if $S = \emptyset$ then (procedure similar to lines 4-10)
16:   $b_S \leftarrow$ min ($b_{pend}$, getMaxBandwidth ($S$))
17:   $L \leftarrow L \cup$ allocate($G_c$, $d$, $S$, $b_S$)
18:   $b_{pend} \leftarrow b_{pend} - b_S$; $subpaths$++
19: return $L$
```

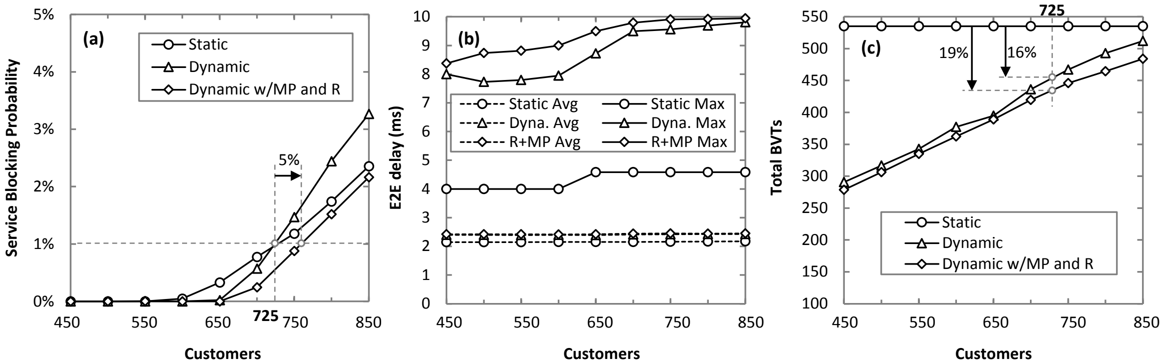

Fig. 4. Service blocking (a), end-to-end delay (b), and total number of BVTs (c) against number of clients

performed (line 5). The reoptimization algorithm tries to make room for the requested bandwidth by reallocating MPLS paths established on the selected path. If no route is found for *d* and MPLS reconfiguration is allowed, new MPLS virtual links are set-up adding enough capacity to G_v so as to serve *d* (lines 7-9). If a path is not found CVN link *d* cannot be served. Otherwise, it is allocated in G_v. Next, a number of MPLS paths, limited by the *k* parameter, disjoint with the MPLS path guaranteeing *w*, are established to convey the remaining bandwidth to be served.

Illustrative results

The performance of the proposed algorithm for the CVN-QBG problem is studied considering three incremental approaches: *i*) a *static* MPLS network approach in which the IP/MPLS virtual network is pre-planned beforehand, *k* is fixed to 1 (no multipath), and *MPLSreconf* is fixed to 0 (re-optimization is not allowed); *ii*) a MPLS *dynamic* approach allowing MPLS network reconfiguration; and *iii*) a MPLS *dynamic* approach allowing multipath and reoptimization.

For evaluation purposes, a MPLS virtual network topology was pre-planned so as to provide the same performance than that of the MPLS dynamic approach at 1% of blocking probability (BP). To that end, an off-line planning algorithm, not shown in this paper because of space limitation, was developed.

A 30-location network topology based on the Telefonica's national network was considered, where each location is equipped with an optical node and an IP/MPLS router with 100Gb/s BVTs. The management architecture in Fig. 2 and the proposed algorithm have been implemented in an OMNeT++-based network simulator.

Regarding customers, two differentiated services have been considered: one requiring regional CVN topologies during office hours and 50% bandwidth guaranteed; the other requiring nation-wide CVN topologies during off-peak periods. EPs are connected to the closest IP/MPLS router. The maximum delay allowed between EPs is 10 ms. CVN reconfiguration requests arrive during service-defined periods, where the capacity requested between EPs is randomly chosen in the range [1-10] Gb/s. The offered load is related to the number of customers being served. Finally, CVN reconfiguration requests arrive to ASO following an exponential distribution with mean 1 hour.

Fig. 4a plots CVN service blocking probability as a function of the load. As commented above, the MPLS static and dynamic approaches perform the same for 1% blocking. When reoptimization and multipath options are applied, a small gain of 5% in terms of more traffic is observed.

Fig. 4b focuses on QoS. As shown, the MPLS preplanning approach provides the best QoS for both average and maximum delay. However, dynamic approaches provide QoS under the specified maximum, being on-average delay comparable to the static approach.

Finally, Fig. 4c concentrates on the total number of BVTs to equip. As observed, the required number of BVTs increases with the load in the dynamic approaches, in contrast to the static one. CAPEX savings as high as 16% for the dynamic MPLS and 19% the dynamic with reoptimization approaches are shown.

Conclusions

An algorithm for dynamic CVN reconfiguration with QoS and bandwidth guarantees has been proposed and evaluated through exhaustive simulations. Results show remarkable CAPEX savings under different dynamic strategies.

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References

[1] L. Velasco et al.. "Cross-Stratum Orchestration and Flexgrid Optical Networks for Datacenter Federations," IEEE Network Magazine, vol. 27, pp. 23-30, 2013.

[2] A. Asensio et al., "Orchestrating Connectivity Services to support Elastic Operations in Datacenter Federations," Springer Photonic Network Communications, 2015.

[3] M. Fiorani et al., "Challenges for 5G Transport Networks," in proc. IEEE ANTS, 2014.

[4] D. King, A. Farrel, "A PCE-Based Architecture for App.-Based Netw. Operations," IETF RFC 7491, 2015.

[5] L. Velasco et al., "Towards a Carrier SDN: An example for Elastic Inter-Datacenter Connectivity," OSA Optics Express, vol. 22, pp. 55-61, 2014.

[6] D. Ceccarelli and Y. Lee, "Framework for Abstraction and Control of Transport Networks," IETF draft, 2015.