Big Data Analytics for the Virtual Network Topology Reconfiguration Use Case

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ABSTRACT

ABNO's OAM Handler is extended with big data analytics capabilities to anticipate traffic changes in volume and direction. Predicted traffic is used to trigger virtual network topology re-optimization. When the virtual topology needs to be reconfigured, predicted and current traffic matrices are used to find the optimal topology. A heuristic algorithm to adapt current virtual topology to meet both actual demands and expected traffic matrix is proposed. Experimental assessment is carried out on UPC's SYNERGY testbed.

Keywords: VNT reconfiguration, ABNO, traffic monitoring, Big Data analytics

1. INTRODUCTION

Static network topologies, where large packet nodes (e.g., IP routers) connected through virtual links (*vlinks*) supported by static connections in the optical layer, were commonly designed to cope with the traffic forecast. However, the introduction of new type of services requiring large bitrate connectivity (e.g., datacenter interconnection, CDN for live-TV and video distribution, etc.) together with the traffic increment that operators' networks are needing to deal with year after year entails that static packet network topologies were largely overprovisioned thus, increasing network total cost of ownership (TCO). In view of that, network operators are looking for more efficient architectures able to reduce TCO, while providing the required grade of service. To that end, virtual network topologies (VNT) need to be dynamically adapted not only to variations in traffic volume, but also to changes in the direction of the traffic.

To support connectivity dynamicity, the IETF has recently standardized the ABNO architecture [1], which includes among others: i) the ABNO controller as the entrance point to the network for provisioning and advanced network coordination. It acts as a system orchestrator invoking its inner components according to a specific workflow; ii) a virtual network topology manager (VNTM) in charge of reconfiguring the on demand VNT; iii) a Path Computation Element (PCE) to compute the path for new label switched paths (LSP); iv) a provisioning manager (e.g., a SDN controller) responsible for managing LSPs, both at the optical layer (Lambda Switch Capable, LSC) and at the packet layer (Packet Switch Capable PSC); and v) the Operations, Administration, and Maintenance (OAM) Handler to receive notifications and monitored counters.

To automate VNT adaptability, traffic needs to be monitored in the packet nodes and counters to be accessible by the OAM Handler. In particular, the disaggregated traffic volume forwarded by each packet node to every other destination node should be available. In addition, notification can be also triggered when the used vlink capacity reach some configured threshold (e.g., 90%). In fact, threshold triggered VNT reconfiguration where the OAM Handler receives notifications from the control plane and reroutes individual PSC LSPs was proposed in [2]. Nonetheless, VNT adaptation requires from powerful architectures and algorithms to analyze large amounts of monitored traffic data, so as to anticipate, when possible, to traffic changes targeting at optimizing resource utilization. In this regard, authors in [3] proposed a method for reducing errors in traffic estimations, while authors in [4] used estimated traffic to predict pre-defined scenarios.

In this paper, we propose a big data network manager architecture to support VNT adaptability based on traffic prediction from applying data analytics on the monitored traffic data. When the VNT needs to be reconfigured, predicted and current traffic matrices are used to find the optimal topology.

2. BIG DATA NETWORK MANAGER: ARCHITECTURE AND WORKFLOW

To automate VNT adaptability, traffic needs to be monitored in the IP routers. As already mentioned, one simple architecture would consists in configuring some vlink capacity usage threshold (e.g., 90%) such that the network controller increases the capacity of vlinks by establishing a parallel lightpath when their capacity threshold is exceeded. Notwithstanding the VNT adaptability provided by this kind of reconfiguration, the introduction of new types of service requiring large bitrate causes changes in the direction of the traffic along the day. This is illustrated in Fig. 1, where a 3-node network is depicted and the daily patterns of origin-destination (OD) traffic from node A are plotted. The OD pair A->C registers its maximum at 4 a.m. due to the large volume of inter-datacenter (DC2DC) traffic. As the day goes by, the traffic is gradually shifted towards A->B pair due to the high presence of business and CDN services on that pair. Thus, A->B traffic reaches the top bitrate around 5 p.m. which in turn becomes the valley hour for A->C traffic. Consequently, as traffic matrix changes along time the optimal topology needs to be adjusted to optimize the use of capacity resources, e.g. transponders.

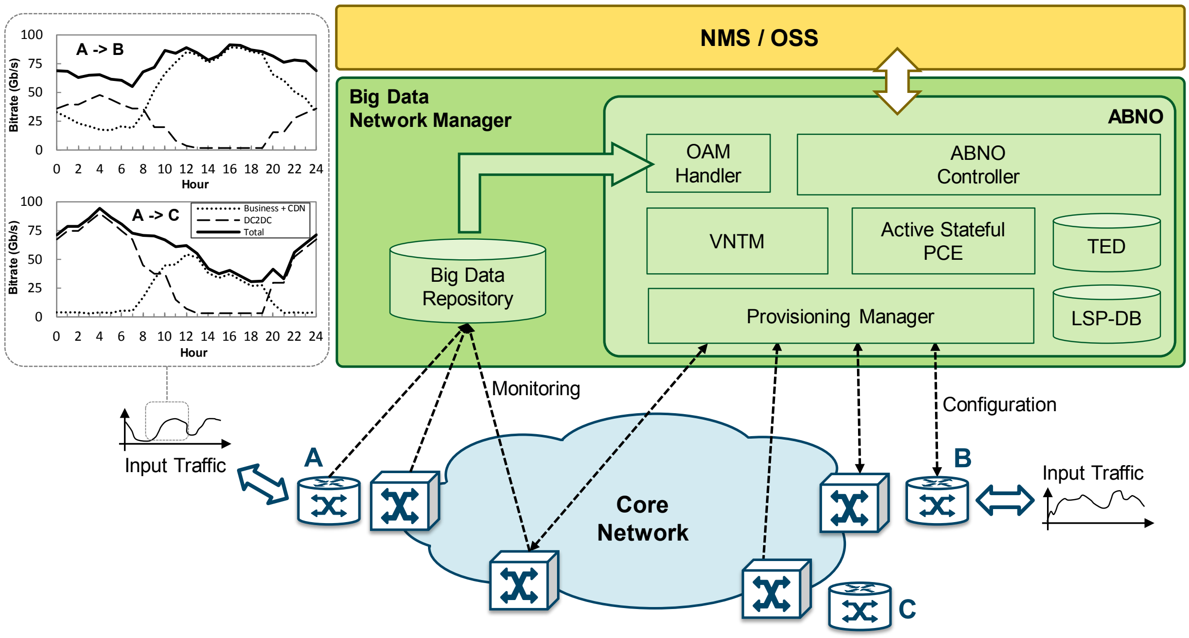


Figure 1. Big data network manager architecture.

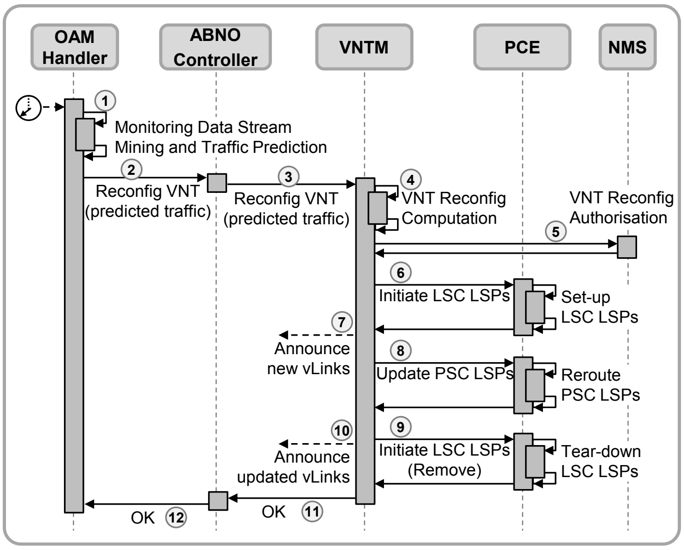


Figure 2. Proposed workflow.

Table 1. VNT reconfiguration algorithm.

INPUT: $G_O(V,L)$, $G_V(N,E')$, P, D, OD, α, k
OUTPUT: E^*,P^*

$resetNetwork(G_V, G_O);G_V^* \leftarrow \emptyset$;
$OD \leftarrow phaseI(G_V,OD,\alpha)$
if $OD==\emptyset$ **then** $G_V^* \leftarrow G_V$
else
  $OD_{aux} \leftarrow OD$; $G_{Vaux} \leftarrow G_V$
  if $|OD| \leq k$ **then** $maxIte==1$
  for i in 1..$maxIte$ **do**
    $OD \leftarrow OD_{aux}$; $G_V \leftarrow G_{Vaux}$
    $OD \leftarrow phaseII(OD,G_V,k)$
    if $OD \neq \emptyset$ **then**
      $OD \leftarrow phaseIII(OD,G_V)$
      if $OD \neq \emptyset$ **then continue**
    if G_V.cost <= cost(G_V^*)
    then $G_V^* \leftarrow G_V$
if $G_V^*==\emptyset$ **then return infeasible**
cleanAndRouteCurrentDemands(G_V^*,D)
return Gv^*

In view of the above, the VNT should be changed by adding and releasing vlinks rather than just adapting the capacity of existing vlinks. Such VNT reconfiguration entails that, instead of monitoring vlink capacity usage, end-to-end traffic should be monitored so as to reconfigure the current VNT based on OD traffic. That could be even refined by classifying flows into services enabling Deep Packet Inspection monitoring in edge routers.

In the proposed architecture in Fig. 1, monitoring traffic data is sent periodically to a big data repository consisting of a distributed database and a data collector. Periodically, e.g., every minute, the OAM Handler retrieves aggregated monitored data, which is stored into a big data system ready to be analyzed. The big data OAM Handler is in charge of several functions related with data processing and transformation, as well as for the decision making process. Regarding data pre-processing, it applies data stream mining techniques on the received data and periodically (e.g., every hour) transforms monitored data into modelled data. Modelled data is used by a prediction module, running machine learning algorithms to anticipate next period traffic conditions (labelled as 1 in Fig. 2). Based on the predicted traffic, a decision maker module decides whether the VNT should be updated. In case of VNT reconfiguration, the VNTM is in charge of computing the new VNT. To that end, the OAM Handler issues a request to the ABNO controller including the predicted traffic together with some other parameters required for VNT reconfiguration (2) and the ABNO controller initiates the workflow forwarding a request to the VNTM (3).

The VNTM computes a new VNT with the predicted traffic matrix received from the OAM Handler (4). Continuing with our seven-node VNT example, let us assume that the new VNT consists on adding the new virtual link 6-7 and reducing the capacity of some other vlinks. The solution is first notified to the NMS (5) and then, its implementation is divided into a sequence of steps to avoid traffic disruption as anticipated above: firstly, LSC LSP 6-7 is created (6) and the new vlink is advertised (7); next, PSC LSPs are rerouted (8) (a make-before-brake strategy to avoid disruption can be implemented) and unused capacity in vlinks 1-3 and 1-4 removed by tearing down the underlying LSC LSPs (9); new vlinks' capacity is advertised (10). Upon VNT reconfiguration completion, VNTM replies to the ABNO controller (11), which eventually replies to the OAM Handler (12).

3. DATA ANALYTICS-BASED VNT RECONFIGURATION

As stated above, the predicted OD traffic matrix for the next period is used to decide whether a VNT reconfiguration is needed or not. Thus, predicted ODs are individually inspected to find when the estimated bitrate of those ODs without a direct vlink in the current VNT exceeds a given threshold; in such case, the VNT reconfiguration is triggered since it is clear that current VNT does not fit with expected OD pair flows distribution. In case of VNT reconfiguration, both the predicted OD matrix and the current set of connections are required as input of an optimization algorithm that finds a target VNT. This is mandatory to ensure that the new VNT fits with expected traffic conditions as well as for current traffic needs.

The VNT reconfiguration based on traffic prediction problem can then be stated as follows:

Given:

- An optical network represented by graph $G_O(N, L)$, being N the set of OXC nodes and L the set of fiber links.
- The current VNT represented by graph $G_V(V, E')$, being $V \subseteq N$ the subset of IP/MPLS routers and $E' \subseteq E$ the subset of current vlinks. Set E is the set of all possible vlinks among the IP/MPLS nodes.
- The set P of current lightpaths supporting E'.
- The set and the capacity $Q(v)$ of available transponder for each node v in V.
  The set D of demands currently set-up, specifying source, destination, and requested bitrate.
- The predicted OD traffic matrix specifying the predicted bitrate.
- The maximum number k of new vlinks to be added to the VNT.

Find: a reconfigured VNT $G_V*(V, E*)$, where $E* \subseteq E$, and a set $P*$of lightpaths supporting $E*$.
Objective: Minimize the overall resource utilization to serve both, D and OD sets.

Table 1 presents the proposed heuristic algorithm. After releasing the current demands and lightpaths supporting the current VNT (lines 1-2), the heuristic goes for three sequential phases. Each phase allocates a subset of OD pairs and modifies the topology and the capacity of the VNT. Phase I (line 4) is a deterministic procedure where large OD pairs that can be routed through direct vlinks are processed. If not all OD pairs were processed, Phase II and Phase III are executed for a given number of iterations in the hope of finding the minimum cost VNT (lines 9-16). In Phase II (line 11), a set of at most k new vlinks to serve an OD pair in one single hop are created. Phase III (line 13) extends the connectivity of current VNT before solving the minimum cost routing for each remaining OD. If a feasible VNT is obtained, the current set of demands is allocated back in this new VNT (lines 18-19). Recall that ODs used for the new VNT might be different than current demands. Thus, a randomized algorithm is applied to allocate current demands fitting OD pairs.

4. EXPERIMENTAL ASSESSMENT

Experiments have been carried out on the UPC's SYNERGY test-bed. Apache Cassandra database [5] was used as a big data repository and the data collector module was implemented to offer an UDP- based interface to the monitors, storing the received data in Cassandra. Apache Spark [6] was used to implement data stream mining and machine learning techniques. Finally, ABNO modules in Fig. 1 were implemented using UPC's iONE software [7]. A HTTP REST API interface was implemented between the OAM Handler and the ABNO controller and from it to VNTM, so as to convey the predicted traffic matrix. PCEP was used between VNTM, PCE, and Provision Manager. Finally, BGP-LS was used to synchronize traffic engineering databases (TED). In particular, VNTM is in charge of advertising topological changes in the VNT, including vlink creation and releasing, as well as updating vlink capacity.

Figure 3 illustrates monitored traffic data periodically being send by the packet nodes to the data collector, as well as the request that the OAM Handler issues to Cassandra's REST API to collect monitored data. UDP monitoring messages contain, among others, the source node and the timestamp of the sample, and for each aggregated flow leaving the node to a destination, its destination node and bitrate. After selecting and aggregating monitored data between the selected times t_i and t_j, Cassandra replies with a JSON-encoded matrix specifying for each pair of source-destination the average, maximum, and minimum bitrate.

Figure 4 shows the meaningful messages exchanged between ABNO modules. For the sake of clarity, messages are identified following the workflow in Fig. 2. The OAM handler sends a REST API request to the ABNO controller (message 2 in Fig. 4) containing the predicted traffic matrix for the next period. The details of that message are presented in Fig. 5. After receiving the predicted traffic matrix, the VNT computes the optimal VNT

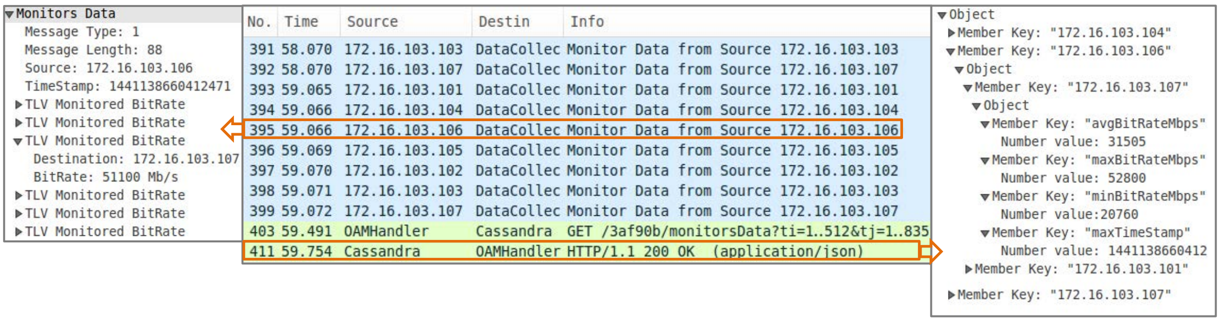
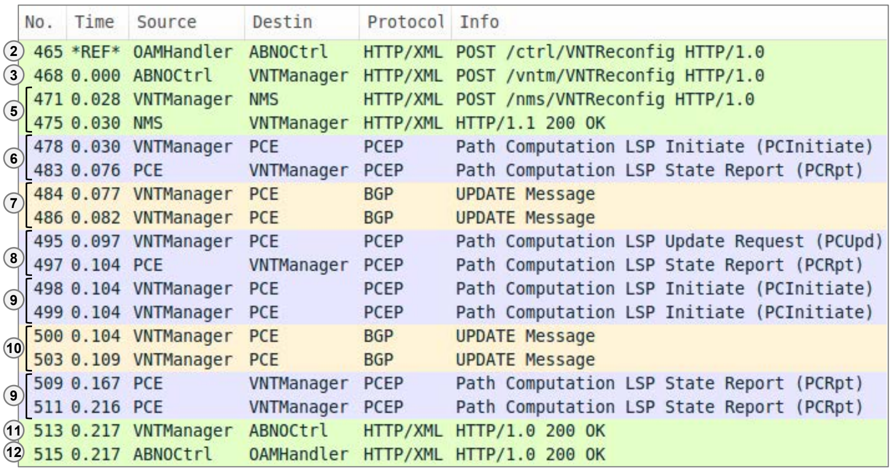


Figure 3. Exchanged messages for monitored traffic collection.



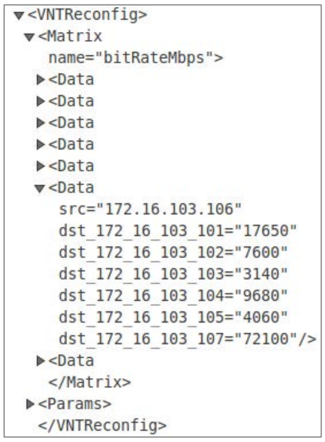


Figure 4. Exchanged messages for VNT reconfiguration. *Figure 5. Message (2) details.*

and issues requests to the PCE to implement the LSC LSPs supporting the new vlinks (6), reroute the selected PSC LSPs (8), and tear down unused LSC LSPs (9). In addition, VNT changes are advertised to the rest of ABNO modules (7 and 10). The total process took 217ms, from the instant the OAM handler triggered the workflow.

5. CONCLUSIONS

A big data analytics OAM handler has been proposed to support VNT adaptability based on traffic prediction. Packet nodes monitor incoming traffic and send monitoring data to a big data repository, based on Cassandra. Monitoring data is collected by the OAM Handler and locally stored. Periodically, e.g., every hour, collected monitoring data is transformed into modelled data and used to predict next period traffic applying machine learning techniques.

A workflow is proposed, where the VNTM module is in charge of adapting the VNT to future conditions. To that end, the VNTM computes a new VNT based on the predicted traffic computed by the OAM handler. An algorithm for VNT reconfiguration has been proposed to deal with expected traffic variations in volume and directionality. Finally, the architecture has been experimentally assessed in UPC's SYNERGY test-bed, where Apache Spark was used as a platform for data stream mining and machine learning purposes.

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REFERENCES

[1] D. King and A. Farrel, "A PCE-based Architecture for Application-based Network Operations," IETF RFC 7491, 2015.
[2] A. Aguado *et al.*, "Dynamic VN reconfiguration over SDN orchestrated multi-technology optical domains," in *Proc. ECOC 2015*.
[3] Y. Ohsita *et al.*, "Gradually reconfiguring VNT based on estimated traffic matrices," *IEEE Transac. on Netw.*, vol. 18, 2010.
[4] N. Fernández *et al.*, "Virtual topology reconfiguration in optical networks by means of cognition," *IEEE J. of Opt. Comms. Netw.*, vol. 7, 2015.
[5] Apache Cassandra: http://cassandra.apache.org/
[6] Apache Spark: http://spark.apache.org/
[7] L. Velasco and Ll. Gifre, "iONE: A workflow-oriented ABNO implementation," in *Proc. Photonics in Switching*, 2015.