

# Core VNT Adaptation Based on the Aggregated Metro-Flow Traffic Model Prediction

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**Abstract:** Aggregation of metro-flow traffic models is proposed to obtain valid core traffic predictive models for core VNT reconfiguration when metro and core networks are independently controlled. Exhaustive simulation results reveal large optical transponders usage savings.

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## 1. Introduction

The mismatch between the capacity that connectivity services are requiring and the huge capacity that optical connections are nowadays offering forces to keep differentiated metro and core network segments and to deploy multilayer networks in the core to perform the required grooming/aggregation functionality [1].

To properly dimensioning the capacity and the topology of the MPLS-over-optical virtual network topology (VNT) during the network planning phase, traffic matrices containing maximum traffic values between every origin-destination (OD) pairs are commonly used as input of planning problems. However, that approach entails large overprovisioning thus remarkably increasing Capital Expenditures (CAPEX) as a result of the large variability of traffic in terms of volume and directionality along the day.

From the network control perspective, many network operators are deploying independent software-defined networking (SDN) controllers for the different segments (metro and core) and technologies (MPLS and optical) in the network. That domain-managed network scenario might present problems related to local (not end-to-end) resource optimization, since every domain operates independently.

A new approach to improve resource utilization and reduce overprovisioning was proposed by authors in [2]. Predictive traffic models can be obtained by applying data analytics to monitored traffic data and those predictive traffic models can be used in the process of VNT reconfiguration; the VNT can be proactively adapted for the predicted near future traffic conditions. However, the efficiency of that proposal strongly depends on accurate predictions, which entails long times to produce traffic models (several days). That requirement cannot be achieved in the case that metro controllers re-route metro-flows for metro-scope re-optimization purposes, where some metro-flows firstly entering the core VNT through origin node  $o$  are re-routed in the metro segment and enter the core through node  $o'$ .

In this paper, we propose to create core-flow traffic models based on the aggregation of metro-flow traffic models. For such aggregation, we assume that metro controllers generate traffic models based on monitoring the traffic of the metro-flows and those models are available in a shared repository for the core controller to access them. In addition, we assume metro controllers announce metro-flows re-routing to the core controller, when their core entrance node changes. Based on the aggregated model, we can predict future traffic for the core-flows and use as input for core VNT re-optimization purposes.

## 2. Flow traffic prediction under traffic changes

Let us assume a scenario where a core MPLS-over-optical VNT is used to interconnect a number of metro networks using dual-homing for redundancy purposes. Without loss of generality, let us also assume that all the traffic entering a node in the core VNT towards a common destination node is routed together as a single core-flow; we call this as an OD pair. Those OD pairs might aggregate many metro-flows and hence, re-routing some of the metro-flows in the metro areas might change the aggregated traffic pattern in the ODs in the core network. For illustrative purposes, Fig. 1 presents an example of a metro-flow ( $mf1$ ) routed through the core VNT towards some destination (e.g., a distant metro network or the Internet). Initially,  $mf1$  enters the core VNT from edge node R1 towards destination node R3, so it is aggregated into the R1->R3 OD pair. For metro re-optimization reasons, the metro controller re-routes that  $mf1$  in a way that it now enters the core VNT through edge node R2, being aggregated into R2->R3 OD pair. It is clear that the traffic models for both OD pairs have now changed, so they become invalid for traffic prediction. Without any coordination between metro and core segments, the core controller would continue using the obsolete traffic models for OD traffic prediction, which would lead to inaccurate estimation until prediction errors are detected several hours later and other traffic scenarios are discarded (e.g., traffic anomalies [3]). Depending on the frequency of those metro-wide re-optimizations, a new OD traffic model fitting can be performed, which would need several days for per-hour

models. In any case, it is clear that alternative procedures for OD traffic estimation are needed, so as to keep accurate predictive capabilities over time.

The solution that we propose is based on modelling the metro-flows traffic and compose OD traffic models by combining the models for the actual metro-flow being aggregated into such OD pair in the core network. The next section details the proposed procedure.

### 3. Combining traffic predictive models

To ensure the highest grade of service, traffic prediction can be focused on estimating the OD maximum bitrate for the next period (we call them as MAX models). Notwithstanding the high accuracy of MAX models, they can only be computed by monitoring OD traffic, which would become obsolete in the event of metro-flow re-routing. To avoid that issue, we propose focusing on predictive models for the average ( $\mu$ ) OD traffic and its variance ( $\sigma^2$ ) (AVG models), because they can be computed not only by monitoring OD traffic, but also by combining the AVG traffic models of those metro-flows being aggregated into an OD pair. It is worth noting that combining maximum metro-flow predictions overestimates the real maximum OD traffic, which would entail large VNT overprovisioning.

Let us consider a particular OD pair  $od$  and the set of aggregated metro-flows  $F(od)$ . From theory on convolution in statistics [4], it turns out that the average traffic resulting from the sum of metro-flows is equivalent to the sum of the average traffic requested by every single metro-flow (eq. (1)). This also works for the variance ( $\sigma^2$ ) under the assumption of uncorrelated metro-flow traffic (eq. (2)).

$$\mu_{t,t+1}(od) = \sum_{f \in F(od)} \mu_{t,t+1}(f) \quad (1) \quad \sigma_{t,t+1}^2(od) = \sum_{f \in F(od)} \sigma_{t,t+1}^2(f) \quad (2)$$

To estimate the maximum OD traffic  $max(od)$ , a multiplicative factor ( $k$ ) of the standard deviation ( $\sigma$ ) can be added to  $\mu$  (eq. (3)).

$$max(od) \approx \mu_{t,t+1}(od) + k \sqrt{\sigma_{t,t+1}^2(od)} \quad (3)$$

Table 1 presents the proposed algorithm to re-compute OD traffic models after a metro-flow re-routing event. It receives the set  $Q$  of all ODs with its model and set of aggregated metro-flows. First, the set of obsolete models is found by inspecting the current aggregation of the metro-flows (line 1 in Table 1). For each obsolete OD model, the type of the model determines whether a new AVG model needs to be computed (lines 4-5) since the current one is a MAX model, or it can be updated by including the new metro-flows entering the OD pair and excluding those ones leaving it from the prediction (lines 6-7). For the updating process, we can take advantage of the linearity of the average and variance aggregation to produce fast updates applying equations (4) and (5). The set of updated models is eventually returned (line 9).

$$\mu_{t,t+1}(od)+ = \sum_{f \in F_{IN}(od)} \mu_{t,t+1}(f) - \sum_{f \in F_{OUT}(od)} \mu_{t,t+1}(f) \quad (4) \quad \sigma_{t,t+1}^2(od)+ = \sum_{f \in F_{IN}(od)} \sigma_{t,t+1}^2(f) - \sum_{f \in F_{OUT}(od)} \sigma_{t,t+1}^2(f) \quad (5)$$

Table 1. Predictive OD traffic model update algorithm

INPUT:	$Q = \{ \langle od, m, F(od) \rangle \}$
OUTPUT:	$S = \{ \langle od, m' \rangle \}$
1:	$Q_{obs} \leftarrow getObsoleteModels(Q)$
2:	$S \leftarrow \emptyset$
3:	<b>for each</b> $q = \langle od, m, F(od) \rangle$ <b>in</b> $Q_{obs}$ <b>do</b>
4:	<b>if</b> $type(m) == MAX$ <b>then</b>
5:	$m' \leftarrow newAggregate(F(od))$ (eqs. (3), (1), (2))
6:	<b>else if</b> $type(m) == AVG$ <b>then</b>
7:	$m' \leftarrow updateAggregate(m, F(od))$ (eqs. (3), (4), (5))
8:	$S \leftarrow S \cup \{ \langle od, m' \rangle \}$
9:	<b>return</b> $S$

## 4. Results

To provide AVG models with a similar accuracy than that provided by the MAX models, the value of parameter  $k$  must be properly tuned. In order to evaluate the impact of this parameter in the traffic prediction, we ran simulations generating metro-flow with traffic following different profiles (*business*, *CDN* and *DC2DC* [5]) and aggregating those metro-flows in OD pairs. The quality of the prediction between AVG and MAX models was compared for different values of  $k$ .

Fig. 2 presents the overall difference between the values obtained with both predictive models. We can observe that a value of  $k=4$  provides the best

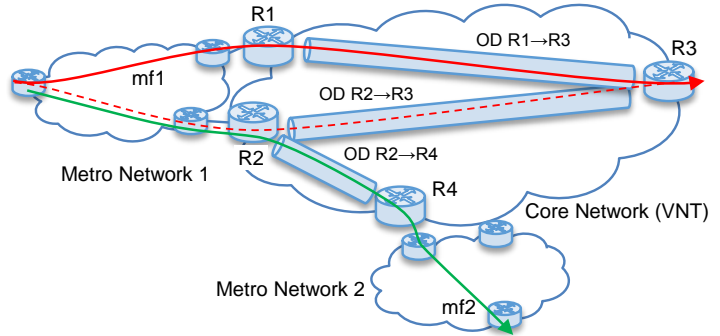


Fig. 1. Metro-flow re-routing might change traffic in the core.

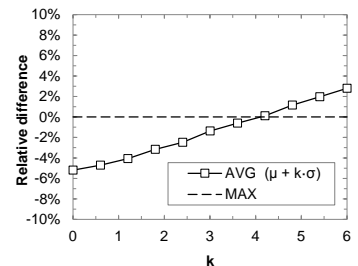


Fig. 2. Max OD traffic estimation vs. k.

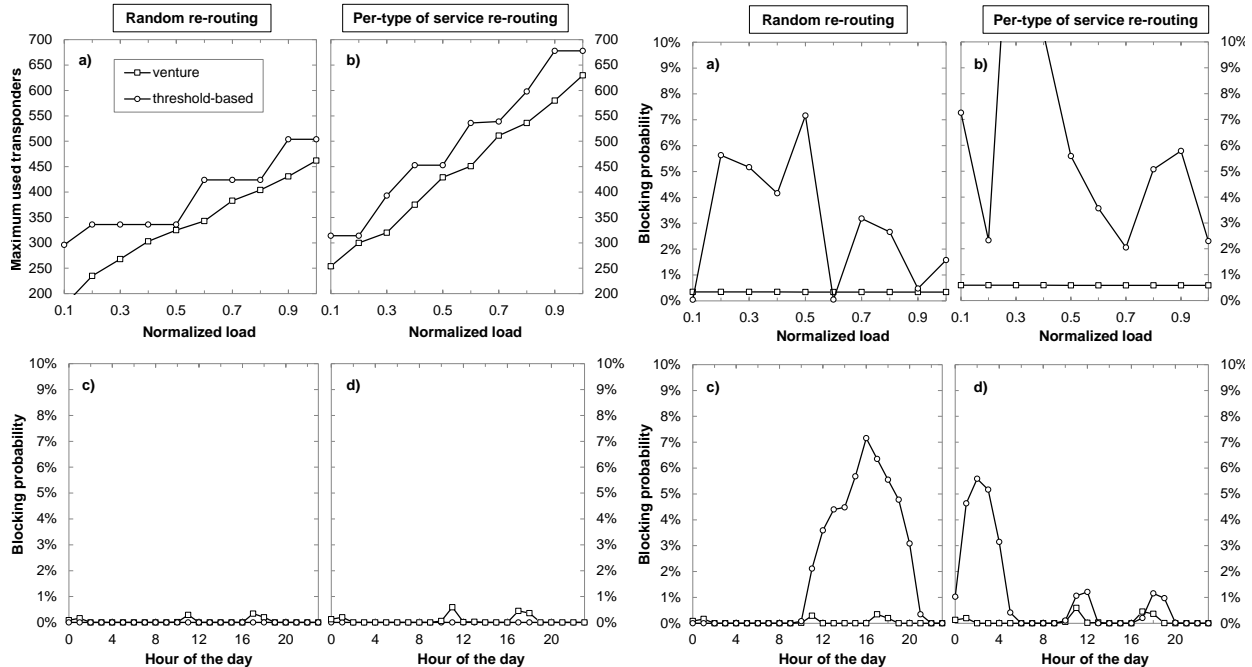


Fig. 3. Maximum used transponders (a)-(b) and daily blocking probability for a normalized load of 0.6 (c)-(d).

Fig. 4. Maximum blocking probability along the day (a)-(b) and daily blocking probability for a normalized load of 0.6 (c)-(d).

approximation to the MAX traffic prediction. This value was used to configure the AVG models used in the following simulation scenarios.

For evaluation purposes, we developed an ad-hoc event-driven simulator in OMNeT and considered a 14-node core VNT interconnecting 7 metro networks using dual-homing. A total of 7000 metro-flows were uniformly injected into the core network following the traffic profiles mentioned above. Finally, two approaches were used to adapt the core VNT: *i*) a threshold-based approach where the capacity of virtual links in the VNT is managed according to the traffic load, and *ii*) the VENTURE algorithm described in [2] to adapt the core VNT topology to OD traffic changes. VENTURE runs periodically every hour.

To study the effect of metro-flow re-routing on the performance of the approaches for managing the core VNT, we evaluate two metro-flow re-routing schemes: *i*) *per-type of service* metro-flow re-routing and *ii*) *random* metro-flow re-routing.

Fig. 3a-b show the amount of transponders to be installed in the nodes of core VNT for each approach and metro-flow re-routing schemes (we left the approaches freedom to add as many transponders as they needed) as a function of the normalized load. We observe savings as high as 40% in the number of transponders when the VENTURE approach is implemented with respect to the threshold-based one. Fig. 3c-d show the daily blocking probability for a fixed normalized load of 0.6 for each re-routing scheme. The threshold-based approach yields zero blocking probability in both scenarios, whereas the VENTURE algorithm produces a maximum blocking probability not higher than 0.6% at certain hours, being virtually zero during most of the time.

Let us now to limit the number of transponders to be used under the threshold-based approach to the number used by the VENTURE algorithm and analyze its performance. Fig. 4a-b show the maximum blocking probability obtained by each approach as a function of the load for each metro-flow re-routing schemes. The threshold-based approach increases noticeable the blocking probability showing a poor performance compared to the VENTURE approach for both re-routing schemes. When the daily blocking probability is analyzed for a fixed normalized load value (Fig. 4c-d), we observe that the threshold-based approach produces a blocking above 5% during long periods.

## 5. Conclusions

OD traffic prediction based on metro-flow model aggregation is proposed to obtain adaptive traffic predictions that can be used to reconfigure the VNT after metro-flow re-routing. We compared the performance of two approaches, VENTURE and threshold-based, to adapt the core VNT to traffic changes when OD traffic models were obsoleted as a result of metro-flow re-routing. VENTURE showed large benefits in terms of optical transponders utilization.

## References

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