Analysis of dynamic traffic grooming in realistic scenarios

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ABSTRACT

IP over Optical networks are emerging as one of the future architectures to support the growth of the Internet by simplifying the the network structure and layering. Many evaluation works on these architectures, however, simply neglect the possible effects of a real network environment. In this paper we compare some overlay dynamic grooming algorithms in realistic scenarios from both the topology and traffic pattern point of view. As reference we present results where IP traffic is considered as constant bitrate sessions and highlight the differences between the models. Results show that the traffic model, scenario, and topology may have a larger effect than expected in grooming algorithms, specially when dynamic, reactive protocols are deployed.

Categories and Subject Descriptors

C.2.5 [**Computer-Communication Networks**]: Local and Wide-Area Networks—*High-speed, Internet*

General Terms

Performance

Keywords

IP over Optical, Grooming, Traffic model, Realistic scenario, Simulations

1. INTRODUCTION

IP over Optical networks leverage the advantages of the IP protocol flexibility and the huge transport capacity of networks based on optical links and optical or opto-electronic switching. Traffic grooming is the multiplexing capability aimed at optimizing the capacity utilization in transport systems by means of the combination of low-speed traffic streams onto high-speed optical channels. Although new services (e.g., IPTV) may require large per-user bandwidth, a large fraction of the traffic volume is still based on rather low rate applications using for instance TCP sessions. Thus, the huge gap between the end-user bandwidth requirements and the huge availability of it at the core-network advocate the use of grooming techniques.

Recent evolution of the optical devices provides the option to set up and tear down the connections dynamically. Assuming the use of suitable signaling and control as GMPLS, the dynamic reconfiguration of the overlay IP network topology can be considered technologically feasible, opening opportunities for the coordinated management of the optical and IP levels. The goal is to dynamically follow, by modifying and tuning the IP topology based on the changes of traffic amounts and patterns.

The traffic grooming problem is a variant of the virtual topology design problem and has received a lot of attention, see for instance [1] for a review. Optimal solutions based on ILP techniques were presented for the static case with different assumptions, e.g. in [2, 3]. However, these methods are too time consuming to use them in the dynamic case and thus heuristics were presented, e.g. in [4, 5, 6, 7, 8]. The solutions can be grouped by their assumption on the information exchange capabilities of the IP and Optical layers: IETF [9] defines three architectures.

Although the publications proposed effective grooming heuristics to reduce ports consumption and request blocking, nearly all of them neglected some important aspects of analysis. On the one hand, the solutions were tested in non-realistic topologies and traffic patterns. On the other hand, the authors have not considered the real behavior of the IP traffic and model it as simple constant bitrate traffic. In [10] elastic traffic models were proposed for the analysis of grooming algorithms and the results were compared from different points of view by defining suitable analysis parameters.

In this paper we perform simulations on a hypothetical backbone network of Hungary using a traffic pattern that is derived from the available public statistics, and then on three scenarios of its future changes. We investigate the differences between the widely used CBR approach and the more realistic elastic model by comparing the results achieved with known dynamic grooming algorithms.

Since the analysis of network solutions means many times a preparation of the network planning process, it is indispensable to consider realistic traffic models in planning algorithms. Our research group is developing a tool named FLEXPLANET, that is based on a flexible, layer-based and technology independent descriptive network model. The properties of the descriptive model make it possible to sup-

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port also the option of elastic traffic in planning.

The remaining of the paper is structured as follows. Sect. 2 defines the network and traffic models assumend in the study and the analyzed algorithms. In Sect. 3 the topology and the traffic pattern is presented. In the same Section we also identify the analysis scenarios and the characteristics that are the basis of comparison. Sect. 4 contains the simulation results and their discussion. Sect. 5 concludes the work.

2. ENVIRONMENT AND MODELS

2.1 IP over Optical Networks

IP over Optical networks are based on two layers: the *optical-* and the *data-layer*. The optical-layer is built up of OXCs interconnected by fiber links, and can provide point-to-point connectivity between IP routers through lightpaths with fixed bandwidth. We assume that this layer uses Wavelength Division Multiplexing, thus the capacity of a lightpath is equal to that of one wavelength channel. The optical layer is incapable of processing directly packets, bursts or any sub-wavelength capacity.

G-OXCs, which support the multiplexing of sub-wavelength traffic onto wavelength channels, are the bridges between the optical-layer and data-layer. A G-OXC is *also* an IP router, hence at such a node the transit traffic (not terminated in the router) can be groomed with incoming traffic. The data-layer consists of routers interconnected by a virtual topology made of all the lightpaths which have been set up in the optical-layer.

Our assumption is, that the devices of the optical-layer are able to work dynamically and also the lightpaths will be established and torn down dynamically. Every time a new lightpath is added or removed from the network, the virtual topology of the data-layer changes. The IP traffic is then transferred over this dynamic topology.

From the IP network point of view we consider only the backbone segment since it is a natural assumption to have an automatically switched optical infrastructure only there. The access network segments are considered as entry channels, which, on the one hand, model the aggregation of the traffic, and on the other hand, play a bandwidth restrictive role.

The network accepts also traditional CBR calls. In this study these calls are also established on the IP architecture, i.e., they use the resources of the virtual topology and mean a background traffic from the analysis point of view.

2.2 Traffic models

Most of the present Internet applications have the capacity to adapt the rate to changing network conditions (elasticity) and the need to transfer a given amount of data . We suggest to model IP traffic with finite elastic flows that perform the transfer of the data of an application with or without applying a dedicated channel via MPLS for instance. The holding time of a flow becomes a *consequence* of the network conditions and not a property of the flow. This concept is significantly different from the fix duration case, that is a valid model when, for instance, conversational applications are considered.

[10] discussed in detail the differences between the two possible traffic models, highlighting also the impact on the overall performance of dynamic grooming. It also showed the inherent interaction between the IP and the optical layer. In this paper we use the realistic model called *data-based*, that derives the holding time of a flow from the data amount to be transferred *and* from the dynamically changing assigned bandwidth. Traffic flows in this model shares the resources on a virtual topology path following the max-min fairness criterion, thus mimicking the ideal behavior of a bundle of TCP connections. Due to the bandwidth restriction on the access link or to the characteristic of the modelled applications, each flow has a peak bandwidth B_M, that can not be exceeded.

When elastic traffic is considered, no admission control is enforced and no backpressure on traffic sources is available, the network can become instable as the number of flows within the network grows to infinity and their individual throughput goes to zero. To avoid this risk, and to build a more realistic scenario, the mechanism of impatience or *starvation* is introduced. The starvation threshold th_s expressed as a fraction of B_M is assigned to each flow. If at some time instant some flows are assigned a bandwidth smaller than their $th_s * B_M$, the elastic flow with the highest backlog is closed. Note that this rate implicitly defines a minimum bandwidth acceptable for the flow.

Since the simulation of each single TCP session that uses the resources of the backbone network would be very time-consuming, we introduced a simple aggregation in the traffic model. The flow represents a set of user sessions coming from the same source and going to the same destination in the same time period. The round-trip times of the sessions that compose such a flow are similar. Thus we assume that they show synchronous behavior regarding the changes of their instantaneous rate influenced by the network state. Also the starvation effect is synchronized and the entire aggregation is supposed to starve and close.

In some sense, starvation is for elastic traffic models what blocking is for traditional CBR traffic models. However, the starvation and blocking actions are not equivalent, because: i) the arriving flow may not be a starved one; ii) blocking is not influenced by the flow dimension, while the starvation is higher for larger flows; iii) blocking is influenced by the required (maximal) bandwidth of the flow, while starvation is not; iv) starved flows waste network resources and may influence overall throughput, which is computed only on completed flows.

With the CBR model we are faced with several issues:

- The request blocking is hard to be interpreted as QoS property of the IP traffic.
- The aggregation concept is cumbersome to be adopted here. It is not that realistic to have a set of users that want to start and stop their traffic synchronously. We find the same modelling difficulties for the blocking of the whole set of requests.
- How the appropriate constant bitrate can be selected? The maximum B_M, the minimum $th_s * B_M$ and the average bandwidth are reasonable choices, but note that the latter is not known in advance and the other two may differ by more than one order of magnitude.

In the case of modelling the classic CBR traffic we still have the second issue of the above list, but we may neglect it since we focus on IP application traffic. CBR and phone traffic is considered only as a background guaranteed traffic, that has priority to IP traffic in the scenarios when the latter is modelled with the elastic model.

2.3 Dynamic grooming

Considering the structure of the *control plane*, different architectures can be envisioned according to the amount of information exchanged between the IP and optical layer. RFC 3717 [9] defines three interconnection models: overlay, augmented and peer. In the *peer* model, IP routers and OXC are considered peer network elements, thus the topology and other network information are completely shared in a unified control plane. In the *overlay* model, each layer performs its own routing functions because no information is exchanged between them. An intermediate architecture is the *augmented* model, where some aggregated information from one routing instance is passed to the other, in general only from the optical to the IP layer.

Although many works propose algorithms for the *peer* architecture, it is rather unlikely today to have a network environment where such a cooperation could be realized. Since the providers of the two layers may be different, the normal model of their information exchange is one of the other two architecture. In this work we apply solutions of the *overlay* model.

In this model routing functions are separate in each layer and the dynamic grooming realizes only the decisions whether the virtual topology has to be modified. The investigated algorithms are two extremes of the *HopCons* family introduced in [11]:

OptFirst attempts to open a new direct lightpath, i.e., between the source and destination of the currently arrived IP traffic request and if it does not succeed, the original virtual topology is used for routing.

VirtFirst uses first the original virtual topology for IP routing and if the estimated bandwidth of the transmission would be too poor, the setup of a new direct virtual link is attempted.

In both cases the lightpaths are torn down when there is no traffic on them. With this mechanism the flow reroute can be avoided in the data-layer and QoS properties can be controlled better. On the other hand, the dynamics in the optical-layer may be reduced.

3. ANALYSIS OF A REALISTIC NETWORK CASE

To build a rather realistic scenario we choose a topology and traffic pattern, whose scale accords to the core network of the main telecommunication provider of our country. Neither the topology, nor the pattern is generic at all, but our aim was to study traffic grooming in special, but realistic networking situations.

3.1 Topology

The network topology is a hypothetic version of the Hungarian core network and it is shown on figure 1. It contains 9 nodes and 16 optical links. Since it is suited to the geometry and the distribution of people in the country, the structure is symmetric and has the central node in the capitol Budapest. This node is also the entry and exit point of the international traffic.

Each link contains one optical fiber with 4 wavelengths each of them with 2.5 Gbps capacity. The nodes are G-OXCs with no limits on the number of grooming ports and no wavelength conversion capabilities.

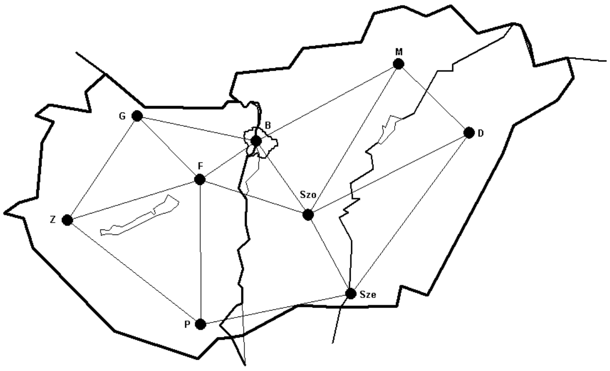

Figure 1: Hypothetic Hungarian backbone topology

3.2 Traffic pattern

To catch the real situation we created a traffic pattern based in part on data items that are available in public statistics. These contain subscriber numbers for each services (IP, mobile, phone, etc.), aggregated for regions. The distribution of traffic sources does not need to correspond to the distribution of inhabitants.

Although a considerable portion of IP traffic data is not downloaded from other users, in our studies the source dispersion is the basis of calculation in the case of the destination relations as well. Budapest, the central node of the physical topology becomes thus also a center of traffic: nearly 50% of the IP traffic ends in this node. This rate is rather realistic, because the country is very centralized also from the economical point of view. This induces a high centralization of the information transfer, thus, most of the servers and also the international gateway are located in Budapest.

Beside the distribution of sources we have two other factors of the traffic load computation: the access link speed and the behavior of the subscriber. We distinguished two types of the Internet users:

- A *normal user* uses his connection for general IP applications such as Web browsing, mailing, and file transfer. In average it uses only 10% of its maximal access link speed.
- A *heavy user* generates much more data transfer by performing huge FTP downloads or using P2P applications. These users exploit all their opportunities and download the data at full speed.

In both cases we estimated the time spent with a computer connected to the network and the data amount to transfer was derived from this value. We assumed in every scenario 90% of the users as normal and 10% as heavy users. Using the appropriate data, average users were supposed to generate IP traffic requests. Their average peak bandwidth B_M is calculated from the estimated amount of downloaded data and average time spent with the Internet. With our assumptions we came to a realistic situation, where the scale of the total amount of the traffic that passes the node Budapest accorded to the available statistics of the BIX (Budapest Internet Exchange) system. This networking system provides the connection between the ISPs in Hungary.

As mentioned before, background telephone traffic is also inserted. It is modelled as constant bitrate traffic with suitable bandwidth and estimated time of duration.

To simplify the simulation aggregation is employed in the traffic models. In the case of the elastic IP traffic we applied an *aggregation factor* of average 1000, i.e., a flow request represents the aggregated requests of 1000 users in average. A call of the phone traffic model is for the aggregation of 4000 to 6000 users, i.e., 5000 in average.

One can easily suppose that the Internet user will not transfer all his daily data in a single session, i.e. in a single flow. Thus, we assumed it is partitioning into 1000 smaller pieces. This cut up does not affect the total load, but the duration of a single flow.

3.3 Performance and comparison parameters

Our aim is to compare the realistic elastic model with the classic CBR model of traffic. First, reasonable and comparable properties have to be identified. The behavior of a grooming solution was taken under our scope from two different points of view.

The users are interested in getting a service with acceptable QoS. We considered the two performance meters T and P_s introduced in [10]. They report for the IP flow the average assigned bandwidth and the probability of getting starved. Notice that these two meters are to be analyzed in paralel. In this study we neglect delay issues.

When the service quality of CBR modelled IP traffic has to be given, T is a fixed value because of the constant and guaranteed bandwidth. In this case the admission control substitute the starvation mechanism and thus we can compare the blocking rate with P_s. Blocking and starvation mean for the IP user nearly the same effect, since the transmission is interrupted (at the beginning or in the middle) and the request aborts without success. The difference lays in the reasons mentioned in Sect. 2.2.

The other point of view of the study is that of the network provider(s). The provider's aims are to use its resources efficiently and to serve as many user requests as possible. The average link usage can be evaluated in both layers, while the latter aspect can refer on different measures. Better provisioning quality means on the one hand the decrease of starvation or blocking, and on the other hand the increase of network throughput T_{net}, i.e., higher rate of successfully transmitted traffic.

In order to get a more complete view of the performance we can analyze several other network properties of the two layers, e.g. length of lightpaths in the optical-layer, number of virtual links in the routes assigned to a flow.

The provisioning of the background phone traffic is not analyzed in details. It is prioritized against the elastic IP traffic and no blocking occur in this scenario. In the other case of study we consider only the blocking of CBR modelled IP traffic. The blocking of phone traffic is smaller due to the smaller required bandwidths, but shows a parallel tendency with the blocking of IP traffic.

3.4 Evolution Scenarios

The growth of the Internet traffic is due to several important technical, cultural and economical factors. However, the result has two main aspects: the increasing number of users and the increasing amount of data per user to be transported. For existing services the importance of the first aspect reduces when the market reaches saturation, but new services always open new fast growing fields.

On the other hand the improvement of the offered network services and the new applications imply increasing bandwidth needs of users. This way of evolution does not have to be connected to any growth of the traffic, but the behavior of the users may change.

In this paper we study how these factors affect the network performance. We defined three scenarios for separate analysis of the three direction of evolution. The independent study aims to set the focus on the clean effects of each factors. The scenarios are:

A : the network load is increased in terms of growing intensity of flow request arrival, while B_M remains untouched,

B : the network load is increased in terms of growing amounts of data to be transported by a single flow, while B_M remains untouched,

C : B_M is increased, while the network load remains untouched.

In every scenarios the starting situation corresponds to the actual characteristics of the traffic, that is derived from the statistics and the assumptions given in Sect. 3.2. The total network load in this case is about 18.5 Gbps.

En every scenarios we analyzed three possible models for the IP traffic:

fC : constant bitrate requests are generated, each with a required bandwidth equal to the average peak rate B_M calculated for a general user. We assume a fix aggregation factor 1000.

vC : the concept of using CBR calls is the same as in the case of ***fC***, but the aggregation factor varies between 500 and 1500 with uniform distribution.

dE : finite, data based elastic flows are generated and the aggregation factor is set between 500 and 1500 with uniform distribution.

In each model cases we determined the basic parameters as described in Sect. 3.2. For the current data the maximal bandwidth calculation for a single general user resulted in 210 kbps. A reasonable value for the period (year 2006) in which the statistical data were taken from. The estimation of the daily average of the data amount to be transported resulted in 300 Mbyte per user.

4. NUMERICAL RESULTS

The performance of the algorithms in different networking scenarios was evaluated with the Gancles simulator presented in [12]. This tool can simulate traffic according to many different network models, and for both traffic models introduced in Sect. 2. It provides the implementation of several dynamic grooming algorithms too.

Traffic sources are connected to each G-OXCs and generate flow requests following a Poisson process and according to the traffic pattern. Starvation threshold th_s was set to 0.1 in simulations where IP traffic was modelled with ***dE*** elastic flows.

Since in this work we analyze overlay architecture grooming algorithms, the routing function is defined separated for the two layers of the network. The applied routing in the optical-layer is the FPLC algorithm described in [13] with first-fit wavelength assignment. This algorithm sets up the lightpath on the route with the widest capabilities in terms of available wavelengths. In the data-layer the simple alternate path algorithm is applied for the current virtual topology, with alternatives ordered by length. Note that in the case of the elastic traffic model this algorithm selects always the shortest path.

For an initial full connectivity of the data-layer a one hop lightpath is set up on each optical link at the start of the simulation.

All simulations are run until performance indices reach a 99% confidence level over a ±1% confidence interval around the point estimate. Estimations are carried out with the *batch means* technique.

4.1 Increasing the number of users

In scenario A the network load increases because of the user population growth. The x axis of the figures is for the absolute network load that increases up to 2.7 times the initial load; loads and results are in Gbps.

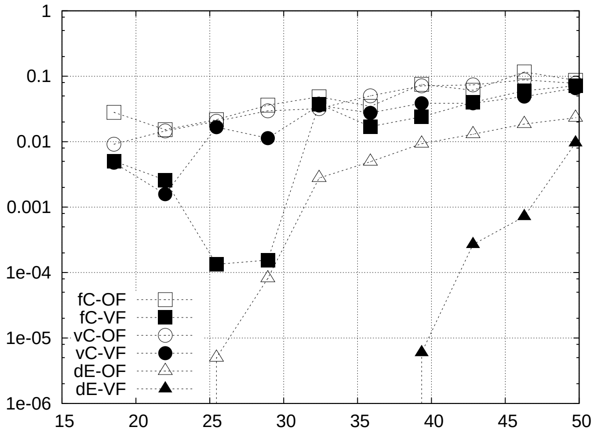

Figure 2: Scenario A: blocking rate

In Fig. 2 the blocking rate is compared for the different models and algorithms. For each models the *VirtFirst* algorithm performs better than *OptFirst*. The greedy behavior of the latter causes the opening of as many direct virtual links as possible even when the load is low. This ends up early in the exhaustion of optical links on the shortest paths between the nodes with major traffic load ratio and the central node, while neglecting the other available resources. When the direct virtual links become full, the traffic gets blocked, since not enough alternative paths are available in the data-layer. This is due to the fact, that between the pairs of nodes with lower traffic load not enough lightpaths are open.

Similar causes can explain the very strange behavior of *VirtFirst* for the models ***fC*** and ***vC***: in the lower load area the blocking decreases with the growth of load. Our hypothesis is that, when the load increases lightly, more virtual resources will be set up between also the nodes that generate lower traffic load. This provides also more path alternatives when the request is routed on the current virtual topology.

The starvation rate for the ***dE*** model remains far below the blocking rates. It proves, that conclusions about algorithms behavior based on the rate of refused requests can be misleading when the IP traffic is modelled with CBR calls.

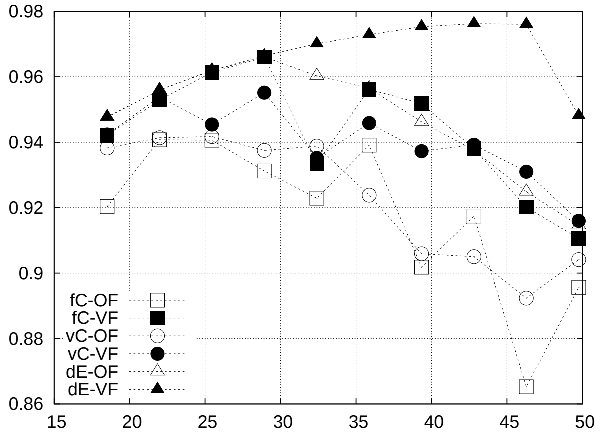

Figure 3: Scenario A: relative network throughput

Results presented in Fig. 3 are also relative to the scenario discussed above. To have a common perspective in different load situations we divided the network throughput T_{net} by the actual value of load. The effect of the blocking on this measure is evident when the traffic is CBR. A wide range oscillation of the *OptFirst* performance can be seen for ***fC*** in the upper load region[1]. This effect can be derived again from the highly centralized traffic pattern and the behavior of the grooming algorithm in such situations. The increase of load causes, that more virtual resources will be set up between also the nodes that generate lower traffic load. This provides also more path alternatives in high load cases when the request is routed on the current virtual topology. However, a further increase of load may not induce the opening of further virtual links if the yet available resources are enough for the traffic of nodes with low traffic. For the ***vC*** model the effect is not that critical, since the required bandwidth varies from call to call and the existing virtual links can be utilized better.

In the elastic traffic case the starvation mechanism affects rather the flows with larger amount to transport and thus the relative network throughput results can not be derived evidently from the blocking. The relative network throughput increases and starts to decrease when the starvation (blocking) rate is about 0.005. The throughput of this model overrides that of guaranteed ones. This comes from the lower blocking rate, not from the partially transported data of interrupted flows, that are excluded from the calculation.

Fig. 4 stands here as reference to an other QoS factor that the users experience. The average bandwidth of a single flow is an important measure when elasticity is assumed, since the duration of transporting the required data amount

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[1] The oscillation is present also in the blocking plots, but here the linear scale of axis y makes it more visible.

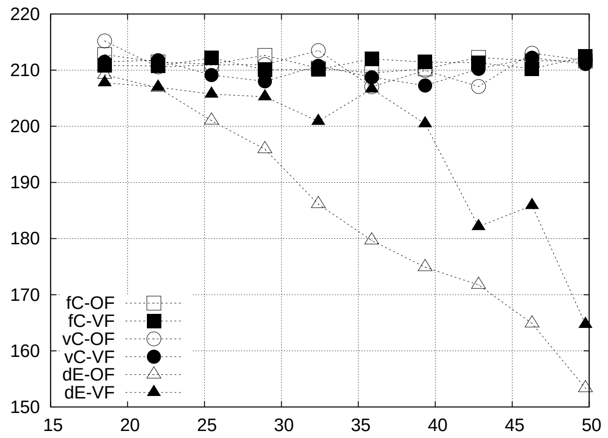

Figure 4: Scenario A: average bandwidth

strictly depends on it. We plotted this measure in kbps units. [10] focuses on the discussion of this performance meter presenting detailed results with the model ***dE***. Here we only mention the reason of the strange jump-back in the curve of *VirtFirst*. Since this algorithm tries to route the flows first on the current virtual topology, the increase of the load first induces the narrowing of the average bandwidth without opening new resources. At a certain point the flows should become too thin and new virtual links will be set up. This extension of available resources let the flows have bigger bandwidths again.

In the case of ***fC*** no changes of the average assigned bandwidth (multiplied by the fix aggregation factor) should be observed. The small differences come from the error of our measurement method. A rather surprising result is, that the average remains nearly fix for the model ***vC*** too. This means, that for this case the blocking is not sensitive on the requested bandwidth.

4.2 Increasing the download amounts

In this scenario the network load was increased up to 3.8 times of the initial value. In general we can see similar behavior of the algorithms and models as in scenario A.

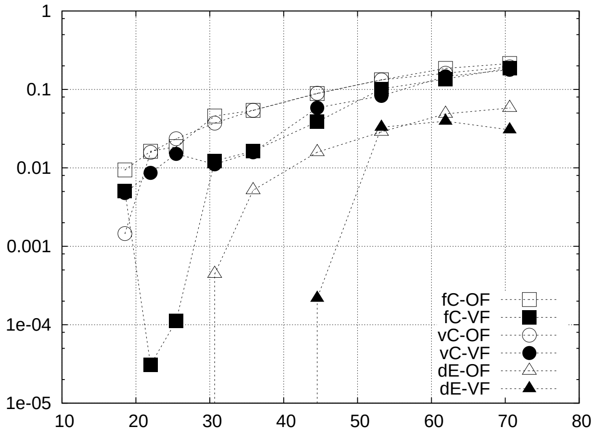

Figure 5: Scenario B: blocking rate

In Fig. 5 the same decrease of blocking can be observed for the algorithm *VirtFirst* when CBR model is applied for the traffic. This algorithm performs better than *OptFirst* also in this case. We can observe again, that the values achieved with CBR traffic models considerably override the values of starvation and may mislead the characterization of the algorithms.

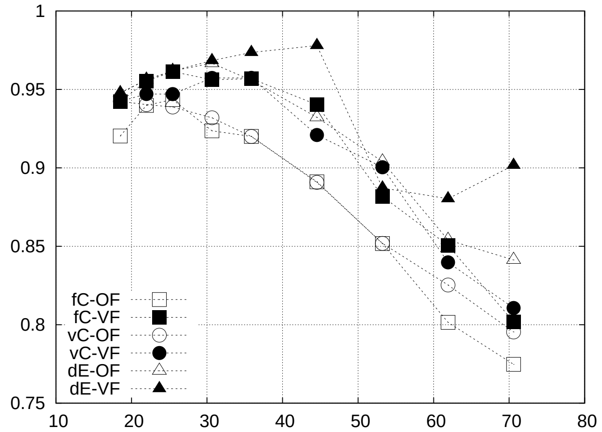

Figure 6: Scenario B: relative network throughput

Analyzing Fig. 6 we find that the relative throughput oscillation of *OptFirst* is missing for both CBR traffic models. This difference originates in the way of increasing the load. Since in scenario B the data amount is in growth, the duration of a flow increases. This affects the dynamics of the modification of the virtual topology. When the virtual links are torn down less often, the possibility to open new ones decreases too and hence, the indicator for having better performance is missing.

4.3 Increasing the bandwidth

A different situation is studied in scenario C, the peak bandwidth of the flows gets increased up to 4 times the initial values, while the load remains the same.

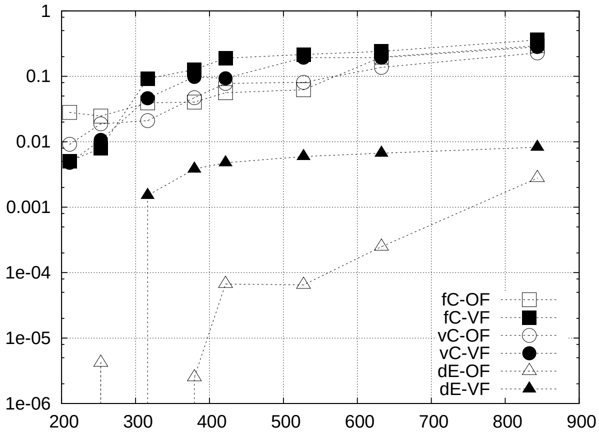

Figure 7: Scenario C: blocking rate

The most important, but quite evident property of each algorithm and model cases, is the monotonous growth of

CBR blocking plotted on Fig. 7. Although the load remains the same we experience this effect due to the sensibility of blocking on the required bandwidth. When the requirements grow, the possibilities to insert a new flow decrease. In the case of the model ***dE*** this effect occurs because of the linear dependence between maximal and the minimal rate of a flow through the fixed th_s threshold.

In this scenario the algorithm *OptFirst* performs better than *VirtFirst*. This behavior corresponds to the very light loads of the previous scenarios. The light load allows more dynamics in the establishment of lightpaths, especially when *OptFirst* is used. The algorithm *VirtFirst* puts the accent on the use of the virtual topology and induces more flows that divide one virtual link. Thus the link gets empty rarely and the dynamics is restricted.

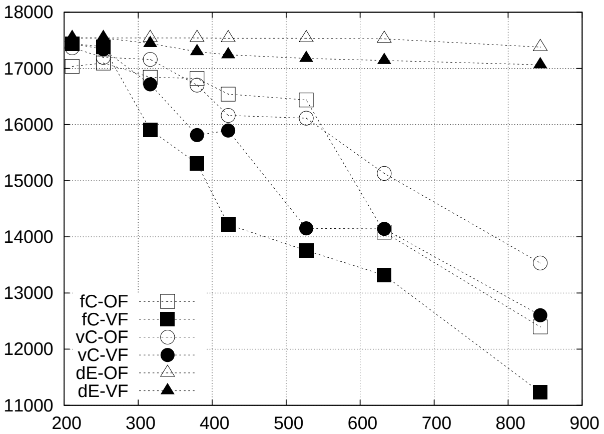

Figure 8: Scenario C: Network throughput

Since the load is untouched we plot the absolute value T_{net} on Fig. 8 in Gbps units. The plot shows again the dependence between the network throughput and the blocking.

5. CONCLUSIONS

In this study we compared two dynamic grooming algorithms: *OptFirst* and *VirtFirst*. They are both studied in an overlay network model with realistic core network topologies and traffic parameters. Starting from actual traffic loads measured on the Hungarian backbone, three evolutionary scenarios for traffic change were considered.

We explored how the algorithms perform when the IP traffic is modelled with a realistic elastic model, and we evaluated the behavior also with a traditional CBR traffic model, since the classic approach to grooming studies assumes IP traffic as constant bitrate flows.

Our results highlight the importance of the choice of traffic model. The choice can induce special effects and can lead to maybe wrong conclusions about the performance of the algorithms. Compared to our previous works on this topic, we analyzed the differences between the traffic modelling approaches both from the user request blocking and the network throughput point of view.

On the other hand, we discussed special effects that originate in the properties of network topology and traffic pattern. The high traffic weight of the central node leads to the oscillations of the blocking rate. This effect is not easily predicable and could not be observed in the rather general scenarios of previous studies.

In the future we will focus on the creation of a theoretical model for the evaluation. One further aim is to tune the elastic traffic model to suit better to the most popular application of today's and future Internet and study dynamic grooming. Experiments will also be run to adopt the models and concepts in the FLEXPLANET planning tool as well.

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