On the Gain of Statistical Multiplexing Over Traffic Grooming

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ABSTRACT
In optical networks that are based on provisioned or switched \( \lambda \)-paths there is no support for sub-\( \lambda \) granularity, and therefore, the network is not efficient for carrying demands of bandwidth requirement significantly smaller than the capacity of a \( \lambda \)-path. Even if we add a layer over the \( \lambda \)-layer to improve granularity and also add grooming capability the network will not be efficiently utilised unless the added upper layer supports statistical multiplexing. The focus of this paper is on showing that in such a two-layer network neither statistical multiplexing in itself nor the traffic grooming with deterministic multiplexing itself can utilise the resources efficiently but only the joint use of both. We perform a simulation study to compare deterministic multiplexing to three different models for statistical multiplexing for two cases, namely, when all nodes are capable of grooming and when no node is capable of grooming at all. The lowest blocking and highest throughput has been achieved for the case of joint use of grooming and statistical multiplexing, particularly when the bandwidth requirements of demands are significantly smaller than the capacity of \( \lambda \)-channels.

Keywords: statistical multiplexing, traffic grooming.

1. INTRODUCTION
The resource management in modern optical transport networks is still based on the allocation of high speed point-to-point channels (lightpaths or (\( \lambda \)-paths) between distant nodes and the traffic flows through these paths. However, using dedicated lightpaths cannot deal well with two important characteristics of the typical traffic. First, the traffic flows — referred to as demands now — usually have bandwidths by orders of magnitude lower than the size of a lightpath. We can achieve much higher network utilization if a lightpath can be shared between more demands instead of dedicating a whole lightpath for a single demand. Traffic grooming allows us to perform this sharing. A further characteristic of the traffic is its fluctuation: its bandwidth changes in both long and short terms. The long term variance can be exploited using different multi hour design schemes, while to deal with short time variance different statistical multiplexing models present efficient solutions.

Here we consider the Wavelength Routing Dense Wavelength Division Multiplexing (WR-DWDM) Network case, where two layers are differentiated. In the lower optical layer the connections between distant nodes can be established via \( \lambda \)-paths. The nodes interconnected by a \( \lambda \)-paths are adjacent in the upper “electronic” layer. The applied technology in this layer is assumed to transmit the traffic using packets. A possible Traffic Engineering goal is to serve as many traffic demands as possible. The static version of the problem, where the traffic demands are given in advance, can be formulated as an optimization task. Vast number of excellent articles elaborates this problem. However, less articles aim with the dynamic version of the problem, where the traffic demands arrive on-line, e.g. [2] and [1].

As far as we know, the effects of joint application of traffic grooming and statistical multiplexing have not been investigated in switched optical network yet. We addressed this problem in our article. The rest of this paper is organised as follows. In Section II we present the applied models and define the exact task while the performance evaluation is discussed in Section III. Finally the paper is concluded in Section IV.

2. NETWORK MODEL
Our work uses a general graph model for performing on-line routing in multilayer networks. This model enables to describe arbitrary topologies and differentiate several switch types. The structure of the graph is discussed and its extension to dynamic grooming is presented in [1]

2.1 Grooming
To decrease the granularity of allocated capacities two or more traffic demands can share a common lightpath. This is multiplexing, it however works only when a common lightpath exists, for instance the endpoints of the demands are the same. Fragmenting the \( \lambda \)-paths into shorter ones may result in higher probability of finding such a common \( \lambda \)-path. Therefore, an intermediate switch can de-multiplex the traffic flows arriving in a \( \lambda \)-channel, and it is able to re-multiplex them on an outgoing \( \lambda \)-channel. This is referred as traffic grooming.

2.2 Statistical Multiplexing Models
Significant part of the traffic in the core network is provided by aggregated packet data traffic, whose bandwidth requirements varies in time. Traditional solution is to allocate resources equal to the sum of maximum

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bandwidths required by each demand. It is called as deterministic multiplexing, which causes an over-dimensioned network. The amount of wasted capacity can be decreased through statistical multiplexing exploiting that more sources likely does not generate traffic at peak rates. Therefore, for the aggregated traffic a limit can be defined for which the probability that the aggregation exceeds the defined limit is a fixed low value. This latter parameter is the overflow (or the packet loss) probability and the limit is the effective bandwidth.

The theoretical principles can be found in F. Kelly’s paper [3]. S. Floyd proposed a simple method [4] for defining the necessary capacity based on the Hoeffding bound. It has two benefits: it is easily calculable and it is a conservative estimation, however this model is rather inaccurate in our case, so not applicable.

Assuming that the arriving traffic is mutually independent and their bandwidths follow the Gaussian distribution results in a model proposed by Guerin [5][6]. This latter assumption can be done, since the demands are the aggregation of a vast number of small basic traffic flows. The allocated bandwidth can be calculated as follows:

\[ BW = \sum_{i=1}^{n} m_i + \alpha \cdot \sigma \]

where \( m_i \) is the average speed of the elemental sources, while \( \sigma \) is the deviation of the aggregated traffic. Since the traffic of the demands is assumed to follow the Gaussian distribution, their aggregations are still following the same distribution. In this case the overflow probability is well characterized by parameter \( \alpha \). For instance, in order to have the overflow probability of 0.01, the value of alpha must be 2.32, and if \( \alpha \) is set to 5.61, this probability will be \( 10^{-9} \).

The principle of Lindberger’s formula [7] defines the required bandwidth for each elemental traffic flows. Summarising it the following formula is obtained, which is the direct proportional to the average bandwidth requirement, and the variance, as well as reciprocally proportional to the capacity of the channel (C).

\[ BW = \sum_{i=1}^{n} a \cdot m_i + b \cdot \frac{\sigma^2}{C} \]

where \( a \) and \( b \) are depending only on the packet loss probability:

\[ a = -\frac{\log P_{\text{loss}}}{50} \quad \text{and} \quad b = -6 \cdot \log P_{\text{loss}}. \]

In our examination we used the \((a=1.18, b=63)\) pair, with which the overflow probability of \( P_{\text{loss}} = 10^{-9} \).

With the following capacity estimation formula the allocated capacity equal to the sum of the average bandwidth requirement of demands, and this amount have to be increased with the maximum among the difference of maximum and average bandwidth requirements.

\[ \sum_{i=1}^{n} m_i + \max_{i=1,n} \{ p_i - m_i \} \]

All three detailed models are selected based on their benefits: they need only a few descriptors of the traffic (mean rate and the peak rate or the variance) and they can be evaluated that becomes crucial when on-line routing is considered.

3. NUMERICAL RESULTS

The simulations were performed using a C++ simulation software developed at our Department. This tool implements the graph model and performs on demand routing. It applies a Discrete Event Driven (DES) simulation framework: the traffic demands arrive one-by-one and the proper paths for them are searched using Diskstra’s shortest path finder algorithm. If a path, with enough available capacity is found the required amount of bandwidth is allocated for the demand. Otherwise the demand is blocked. When a demand is terminated its connection is released freeing all its capacity.

Network Topology: We have considered the reference network of the COST 266 Project [8] which consists of 25 nodes and 32 physical link. For each physical link 4-channels are defined each having 1000 Mbps capacity.

The traffic demands are described by six parameters: the source and destination nodes, the time when the demand is invoked, the holding time, and finally, the bandwidth requirement of the demand defined by its peak and its mean rates. The demands to be routed are generated randomly in advance to make possible the investigation of the different models over the same traffic sample. These samples are defined as follows. The arrivals are modeled as a Poisson process: the intensity is the inverse of the average interarrival time of consequent demands. The average of the holding time of the demands is also defined. The two descriptors of the bandwidths of demands are calculated as follows: The average peak rate is calculated from the link capacity and
it is described with the peak-rate to channel capacity ratio (PCR/CH ratio). The mean rate is derived from the peak rate via multiplying the peak rate with the peak-to-mean ratio (PCR/SCR ratio).

3.1 Numerical Results

With the application of statistical multiplexing in the network, not only lower network load is experimented, but also more traffic demands can be served through lower blocking ratios. Nevertheless, the amount of decrease of the blocking ratio (blocking gain) remains an open question. On Figures 1a and 1b the measured blocking ratios are presented at different levels of demand arrival rates. Here, two major observations can be made: if all the nodes have grooming capability the gain is high: the blocking ratio is almost zero in all statistic multiplexing cases, even when the deterministic case produce 40% blocking ratio (Fig. 1b). On the contrary, if all the nodes are OXCs the multiplexing gain is negligible (Fig. 1a), since the λ-paths can be shared only among those demands that have common source and destination. Therefore much less demands are multiplexed into a λ-path, thus, the multiplexing gain is much lower.

We have shown that the blocking gain increases as more demands are served. Now, on Figures 1c and 1d the measured blocking ratios for different peak-rate-to-link capacity ratios can be seen. In the OXC case, there is no blocking gain of statistical multiplexing for smaller ratios. However, from 0.5 PCR/CH ratio a small gain appears because the bandwidth allocated for the demands between the same ingress-egress node pair becomes comparable to the link capacity. Then, the statistic multiplexing models shares the λ-path between more demands, since less capacity is dedicated to each demand. Therefore, the blocking ratio will be smaller than in the deterministic case.

However, in the case of grooming, the deterministic model the blocking steadily increases, while the statistic models provide zero blocking ratios until a certain bound of PCR/CH ratio is reached. After that it also starts to increase, while the difference between the blocking remains roughly the same. This means that considering the statistical models larger demands can be served that the deterministic model on the same blocking level. For instance blocking ratio 0.1 is reached by the deterministic method when the PCR/CH ratio is 0.1 while it is roughly 0.3 in the statistic case.

![Figure 1](image.png)

**Figure 1.** Blocking Probabilities measured on COST 266 basic topology.
4. CONCLUSION

The aim of this paper was to investigate the joint application of statistical multiplexing models and traffic grooming. We have selected three multiplexing models those can be easily calculated and implemented them to our simulation tool. We have conducted simulations their results show that the statistical multiplexing gain can be exploited only if grooming nodes are assumed, in the OXC case the decreased load was in vain: the blocking probabilities did not decrease at all. On the other hand, applying traffic grooming much more traffic can be served to achieve the same blocking probability as with the deterministic multiplexing case.

REFERENCES