Dynamic bandwidth adaptation in NG SDH/WDM transport networks using LCAS

S. Gunreben, C. M. Gauger

University of Stuttgart
Institute of Communication Networks and Computer Engineering
Pfaffenwaldring 47, D 70569 Stuttgart, Germany
{gunreben, gauger}@ikr.uni-stuttgart.de

Abstract

Traffic patterns of data services are known to be highly dynamic and have been characterized as self-similar caused by long-range dependent transfer times and file size distributions [8]. This burstiness appears on various time scales and makes link and network dimensioning more difficult compared to classical voice traffic.

In this paper, we adopt dynamic bandwidth adaptation to transport networks, using new features of next generation SDH/SONET known as virtual concatenation (VCAT) and link capacity adjustment scheme (LCAS), which can flexibly provision subwavelength granularities. We quantify the principal interrelation of dynamic bandwidth adaptation and changing traffic characteristics as well as the impact of operational and technical constraints on achievable service quality in depth.

1 Introduction

Quality of service within metro and core networks is mainly provided by additional capacity to cover both short-term traffic changes and mid-term traffic variations. This overprovisioning leads to a waste of capacity and inefficient usage of resources. An alternative approach to static overdimensioning is to provide capacity dynamically using automatic bandwidth adaptation exactly where and when needed.

In this paper we study the feasibility of dynamic bandwidth adaptation in SDH/WDM transport networks with next generation SDH features such as VCAT and LCAS. We identify technical and operational requirements and constraints, and discuss their impact on network performance and service quality. Also we analyse the impact of network traffic characteristics.

In detailed simulation studies, we use a fluid flow model of aggregate traffic, different adaptation control algorithms, and system dimensionings. As a reference scenario, we also consider the case of static overprovisioning. The performance metrics are volume of traffic lost and time between two successive bandwidth changes.

1.1 Related work

The idea of dynamic bandwidth adaptation motivated extensive studies in the field of ATM. One of the main tasks was to derive algorithms for an efficient transport of variable bit rate traffic streams, e.g, [1], [2], [9], [10], [11], [12]. The applied algorithms are classified in [14] in loss/no-loss and delay classes.

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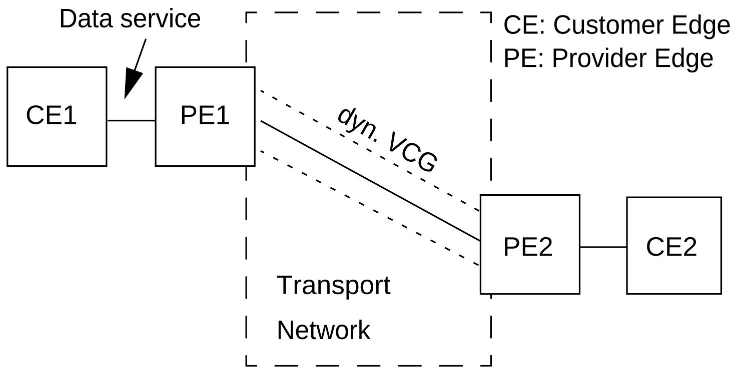

Figure 1 Transport network with point-to-point connection

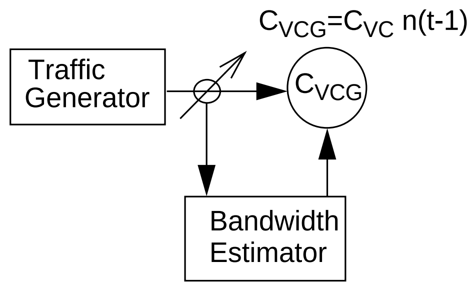

Figure 2 Simulation model

Automatic bandwidth control (ABC) was also proposed in automatic switched optical networks (ASON) in an IP/GMPLS over ASON scenario [15]. On basis of two different service classes they proposed an automatic switching and resource sharing of wavelengths based on predicted traffic using a daily traffic profile.

In [16], a possible realization of automatic switched transport networks was considered using the SDH/VCAT/LCAS scenario. In a lab experiment several nodes forming a core network and fed by Ethernet traffic adapt the capacity of links using LCAS, according to the bandwidth needs. While this work showed principal feasibility, different estimation algorithms or traffic related timing constraints where not presented in detail.

1.2 Next generation transport services

Todays transport networks are often built on a SDH/SONET grooming layer on top of a WDM layer. Transport network services provide connectivity across the transport network, e.g. to establish a point-to-point interconnection of two customer sites. In this scenario the carrier is faced with the problem of transporting typical customer protocols like Ethernet or Fibre Channel. A common solution to transport both over SDH, packet and byte-stream traffic, is the generic framing procedure (GFP, [6]) standardized by the ITU-T.

In general, bit rates of customer network technologies, like Ethernet do not match those of SDH, e.g., transporting 100 Mbps Ethernet signal in the next larger VC-4 container leads to a bad utilization of 66% [3]. This disadvantage was solved introducing virtual concatenation (VCAT) in SDH. The transport is realized by several SDH virtual containers (VC) of lower bandwidth forming a virtual concatenated group (VCG). The number of virtual containers within a VCG is variable and chosen to fit the actual bandwidth need.

The signalling protocol within a VCG is called link capacity adjustment scheme (LCAS, [7]). LCAS keeps track of the integrity of a VCG, e.g. in case of a failed VC, LCAS removes this VC and adds it again to the VCG, when the failure is eliminated. Similarly, in case of capacity changes due to customer requirements, LCAS is used for a hitless change of bandwidth by adding or removing VCs. Usually, resizing of a VCG is mostly done according to service level agreements in time-scales of months or years and usually operated manually.

The overall scenario is depicted in Figure 1. A point-to-point connection between two sites is realized by a dynamic VCG. The functionality to measure the bandwidth demand and to resize the VCG is located in the provider edge devices.

The document is structured as follows. Section 2 describes our approach of dynamic bandwidth adaptation in transport networks. Section 3 provides our simulation model and evaluation scenario. Results are given in section 4, while section 5 concludes the paper.

2 Bandwidth adaptation in NG SDH/WDM networks

2.1 System view

When using bandwidth adaptation in transport networks, the special technological and operational environment has to be considered. In contrast to previous work on ABC, our scenario implies discrete bandwidth values. The number of VCs is changed according to traffic demands. The overall bandwidth available in a VCG is the number of active VCs multiplied by the bandwidth of an individual VC, e.g. VC-4-7v = 7 x VC-4 virtual concatenated = 7 x 150 Mbps is well-suited for Gigabit Ethernet.

Signalling of internal VCG changes is done by LCAS. But in this scenario of flexible adaptation, the time scale of adaptation is much smaller than typical provisioning times. Dynamic bandwidth adaptation should operate on time scales of seconds to several minutes or hours, so we assume a control plane taking over the management function of altering the VCG size including path establishment and tear down. When the trigger mechanism suggests a bandwidth change, the processing of this event usually takes some time. Thus, the set-up delay has to be considered. For transport networks, stability is a prior concern. Thus, the frequency of adaptation should be limited and well controlled.

Open loop control bandwidth estimation algorithms mostly assume measurement data to predict future bandwidth demands. Closed loop control algorithms compare measurement data to some target value to gain feedback on the controlling decision. Our scenario is also based on measurement data and open loop controllers. We consider the incoming traffic rate as some data, which could be easily measured in transport networks assuming SNMP sampled data or traffic mean value over an observation interval. We further assume, that these mean values are also available in shorter intervals than the typically SNMP five minute intervals. As this may be possible with a future generation of devices/ protocols, we do not restrict our studies in this dimension to current values.

2.2 Prediction algorithms

For a comprehensive study, we consider three controllers and study their applicability in transport networks. Two of them try to approximate the incoming traffic only by the sampled data rate, while the third one also takes the traffic variance into account and overestimates the traffic on purpose.

- A very simple controller is the maximum controller (*Max*). It stores the last N measurement samples and estimates the bandwidth with the maximum of the obtained values.
- Guerin et al. [4] developed an approximation to estimate the equivalent bandwidth of aggregated traffic. The formula estimates the bandwidth necessary for a given overload probability of less than ε. They proposed the following formula $\hat{C} = m + \alpha'\sigma$ for the equivalent capacity $\hat{C}$ dependent on the traffic mean m and standard deviation σ, where α' is expressed by $\alpha' = \sqrt{-\log\varepsilon - \log 2\pi}$.
  This formula assumes aggregate Gaussian traffic characteristics, which in general does not hold for traffic as considered herein. However, the *Guerin* formula is known to be conservative, so it may give a good estimate also in the case of multifractal traffic. Here, traffic mean and standard deviation are calculated over the last N samples.

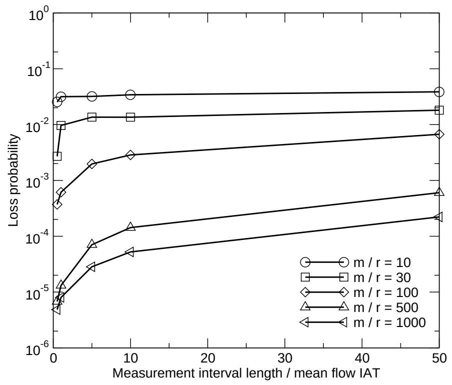

Figure 3 Impact of rising access rates

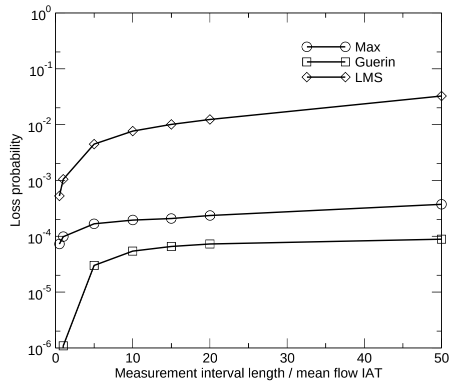

Figure 4 Comparison of different controllers

- The least mean square (*LMS*) controller is a standard filter algorithm. In this context, the weighted N samples of the past estimate the bandwidth for the next interval. The weighting factors are chosen to minimize the squared error of the filter input signal and some target value. For a more detailed description please refer to [5].

3 Simulation and evaluation scenario

<u>3.1 Simulation model</u>

In Figure 2 the simulation model and its components are shown. Synthetic traffic from a generator is measured and its rate (mean value over some interval) is provided to the bandwidth estimator. It estimates the bandwidth according to the past values and estimates the amount of capacity necessary to cover the incoming traffic. The capacity C_{VCG} of a VCG is adjusted to integer multiples of C_{VC} based on the past measurement samples. The estimated bandwidth is rounded up fitting an integer number of containers, $n(t-1) \cdot C_{VC}$.

The server capacity is assumed to be at maximum $C_{max} \geq C_{VCG}$. As can be seen in the figure, the link is modelled by a single server without any buffering. Typical time-scales of a buffer are much smaller than the capacity update intervals we consider here. Thus, we cannot take advantage of the buffer on these time-scales.

<u>3.2 Fluid flow traffic model</u>

As we consider transport networks, the aggregate M/Pareto flow traffic model was chosen according to [13], [17]. A flow is characterized by its constant flow rate r and its duration. A flow could be interpreted by an user session with access rate r and a duration depending on the flow volume. The arrival of flows is characterized by a Poisson process, with mean interarrival time T_{IAT}. The fluid volume of a flow is Pareto distributed. The distribution function $P\{X \leq x\} = 1-(k/x)^{\alpha}$ with $x \geq k$ is characterized by a minimum value k and shape parameter α. The shape parameter is directly related to the Hurst parameter by $H = (3-\alpha)/2$. In all scenarios we assume a Hurst parameter of 0.85.

<u>3.3 System parameters</u>

As we showed above, a key parameter is the measurement interval. Flexibility and more general results can be obtained, when the measurement interval and the traffic parameters are normalized. In our studies, we characterize the measurement interval by the mean number of flow arrivals. The number of flows within a measurement interval is varied from 1 to 50, spanning a time interval of $1 \cdot T_{IAT}$ to $50 \cdot T_{IAT}$.

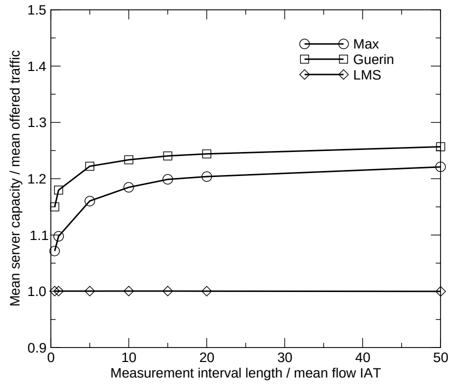

Figure 5 Mean bandwidth provisioned

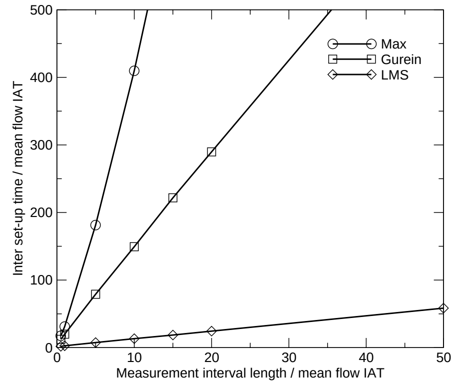

Figure 6 Server update IAT

The other important parameter is the interval between two possible bandwidth changes. Here, the time is expressed by an integer multiple of the measurement interval. In our studies, the inter-update time is between 1 and 10 measurement intervals. While in the former case after obtaining a measurement sample the capacity could be updated, in the latter case the capacity could be changed only after every 10th measurement interval.

As mentioned above, it is necessary to include an extra delay for the estimated bandwidth to become available. This setup delay, is given as a fraction of the time between two possible bandwidth changes. We consider three cases, no set-up delay, 10% and 30% set-up delay related to the time between two control instances.

Other parameters related to the system are its offered load, the server granularity and the bandwidth estimators memory. The systems load is expressed by the ratio of offered traffic in average and the maximum possible link capacity C_{max}. In all scenarios a load of 0.4 is considered. Until further notice, the maximum link capacity is divided up into 100 VCs and the memory of the bandwidth estimators is set to $N = 100$.

3.4 Performance metrices

To quantify our results, metrices regarding quality of service and network stability are applied. As the QoS metric the amount of traffic lost due to bandwidth estimation error is used. When capacity is adapted dynamically, also network stability can be affected. We focused on that aspect by capturing the mean time between two successive bandwidth changes. Because of the bursty nature of traffic overprovisioning cannot be avoided completely, so the amount of extra capacity spent is also studied.

In contrast to the dynamic link model, bandwidth can be provided statically on the outgoing link and never be changed. We compare both scenarios by relating the static overprovisioned bandwidth with the mean capacity in the dynamic case.

4 Simulation results

In this section, our simulation results are presented. In a very first scenario the impact of increasing customer flow data rate on loss performance is studied. The *Max* estimator is used for simplicity reasons and no additional set-up delay is considered, e.g. the control interval is equal to the measurement interval. In Figure 3 the loss probability is shown versus the measurement interval length in mean number of flow arrivals.

When the ratio between mean and access rate decreases, i.e. the access rate increases on the same load level, loss increases significantly due to much larger burstiness. It can also be seen, that increasing the time between capacity changes, also increases loss up

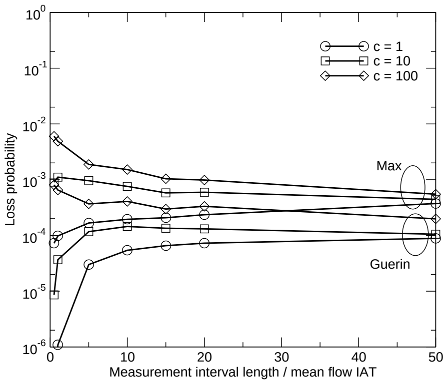

Figure 7 Impact of increasing control interval

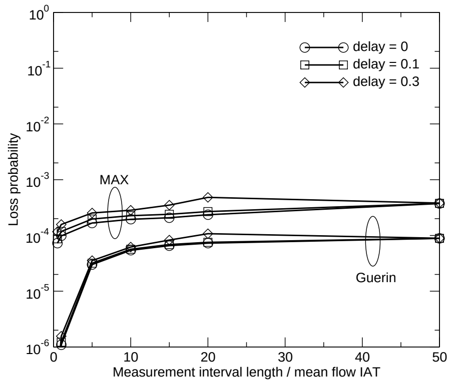

Figure 8 Impact of set-up delay

to some value and remains on this level. Considering a ratio of $m/r = 10$ even the measurement interval has no impact on the loss. From this we can conclude, that bandwidth adaptation only makes sense for less bursty traffic.

In the following, the ratio of mean traffic rate to access rate is chosen to be 100, e.g. assuming 1 Gbps total mean rate in the backbone and 10 Mbps as the mean access rate, which can be assumed to be a relevant scenario for point-to-point interconnection of company sites.

In Figure 4 three different controllers are compared with each other and the impact of different time scales on loss is considered. While the *Max* and *Guerin* estimator perform quite well with loss probabilities smaller than 10^{-4}, the *LMS* estimator curve shows similar behaviour but on a higher loss level up to 10^{-2}. The *Max* estimator remembers the largest value over a long time span, so in most cases the actual incoming traffic is less than the provided outgoing link capacity. The formula according to *Guerin* explicitly takes the traffic variance into account and thus is expected to yield a higher overprovisioning. The *LMS* estimator filters out the traffic variations and does not follow short term traffic trends, so its performance is worst.

This can be verified in Figure 5, where the mean server capacity relative to the mean of offered traffic is depicted against the measurement interval. Again the three estimators are compared. The high loss of the *LMS* estimator (Figure 4) origin in the mean server capacity provided, which is equal to the offered traffic independent of the measurement interval. In contrast, the high traffic variability and large variance forces the bandwidth estimators *Max* and *Guerin* to increase the outgoing link bandwidth up to a mean overprovisioning of approx. 20%.

Also, in Figure 6 the mean time between consecutive bandwidth changes is shown using different measurement intervals. The *Max* estimator leads to longer times between updates, because of its long history to remember large values. The *LMS* estimator calculates the estimated bandwidth with every new sample, which leads to frequent changes in bandwidth and more dynamic bandwidth changes than necessary. The *Guerin* estimator lies between the other two, because of its overprovisioning and the recalculation of the traffic variance and mean with every sample.

Figures 3–6 showed the impact of measurement interval and algorithm on the trade-off between loss rate, overprovisioning and update frequency. In the next three figures the impact of additional delays is shown considering only the controllers *Guerin* and *Max*.

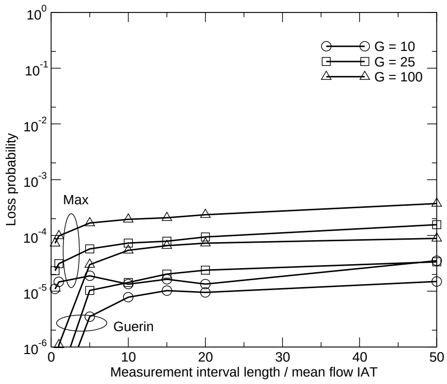

Figure 9 Impact of different granularities

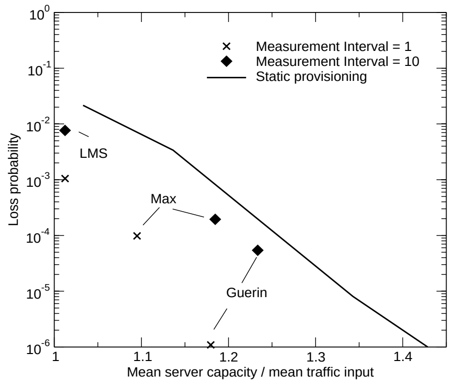

Figure 10 Comparison to static reference scenario

In Figure 7, the impact of an increased adaptation interval is shown. The server capacity is adapted not every measurement interval but only after c intervals. It can be seen, that the impact of larger control intervals has much less impact than the base measurement interval itself.

For $c = 1$ we study the impact of a set-up delay. In Figure 8, the additional set-up time is shown. We consider a delay equalling 0%, 10% and 30% of the controlling interval for a new estimation to be processed. It can be clearly seen, that the additional delay has only minor impact compared to the measurement interval.

In all scenarios up to now, we used a granularity of 100 VCs. The impact of different granularities on loss is studied in Figure 9. There, the number of VCs per VCG for a given total capacity is varied from 10 to 100. Both, *Guerin* and *Max* controller perform better with rougher granularities, i.e. a larger C_{VC}, due to the impact of rounding. The estimated bandwidth is rounded up to an integer number of VCs, which results in more overprovisioning.

Finally, to show the benefit of our dynamic approach, the results are compared to a real system with statically provisioned amount of capacity. The static provisioned bandwidth is usually related to the mean offered traffic. In Figure 10, the loss performance of the static case is shown against the mean offered traffic normalized to the mean input rate. For the dynamic case, the mean server capacity is shown. It can be seen, that when *Max* and *Guerin* estimator in average require the same capacity compared to the static case, loss performance is better. On the other side, to gain a certain level of QoS *Max* and *Guerin* need less capacity. These achievements can only by reached, when the measurement interval is short, otherwise the achievements are smaller.

5 Conclusion

In this paper, we first identified the critical aspects and requirements for dynamic bandwidth adaptation in transport networks to cope with dynamic data traffic patterns. We considered a WDM/SDH network with next generation SDH features. With the benefit of these extensions and the support of a control plane, it is possible to realize dynamic provisioning of capacity.

In our studies we used aggregate traffic using an M/Pareto fluid flow model and three controllers for bandwidth estimation. We showed principal effects of dynamic provisioning in transport networks. Dynamic bandwidth adaptation is not suitable for a stationary highly bursty data traffic. Only, for a smaller burstiness, higher performance improvements compared to the static case can be gained. We also showed that additional delays, have smaller impact on the performance than the basic measurement interval. As a final step we compared the static scenario of overprovisioning with our approach and found, that some bandwidth efficiency can be gained in the mean. We suppose, when the traffic is instationary, e.g. following a daily shape, the estimators can adapt to those changes, while the static case cannot. This is studied in our ongoing research.

Acknowledgement

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