4. ITG-Fachtagung *Photonic Networks*, May 5. - 6., 2003, Leipzig, Germany

Dimensioning of SDH/WDM Multilayer Networks

Martin Köhn, Christoph M. Gauger
University of Stuttgart, Institute of Communication Networks and Computer Engineering (IKR),
Pfaffenwaldring 47, 70569 Stuttgart, Germany
e-mail: {koehn, gauger}@ikr.uni-stuttgart.de

Abstract

Integration of SDH and WDM network technology in dynamic multilayer networks is considered one promising option for migrating from rather static SDH networks to the automatically switched transport network (ASTN) with a dynamic photonic layer. This paper investigates dimensioning of SDH/WDM multilayer networks. Two different approaches for dimensioning network links and nodes are compared for different SDH/WDM multilayer routing schemes. While the first derives the dimensioning directly from the mean traffic load on the individual network links, the second considers the dynamic nature of the latter traffic load by employing the Erlang-B formula for dimensioning. Finally, the impact of transponder overdimensioning on the performance of SDH/WDM multilayer routing schemes is investigated.

1 Introduction

The increasing usage of the Internet around the world leads to a massive growth in traffic volume and dynamics to be handled by the network backbones. To cope with this development, several high dynamic solutions like optical burst switching (OBS) and optical packet switching (OPS) have been investigated during the last few years. They all can cover the high dynamics of Internet traffic, but there is no direct migration path from todays static SDH/SONET-based WDM networks towards IP-over-OBS/OPS as these technologies require a completely new infrastructure (nodes etc.) and control systems. This argument is even stronger in presence of the current market downturn.

One feasible solution to cover the dynamics of IP traffic is the concept of enhanced automatically switched SDH/SONET-WDM multilayer networks. The mayor reason for this approach is the fact that dynamics can be covered and at the same time an evolution path for todays SDH-centric networks exists.

SDH/SONET-WDM multilayer networks provide dynamics on both layers and consist of multilayer nodes with crossconnects on the SDH/SONET layer as well as on the WDM layer (**Fig. 1**). Dimensioning of multilayer networks for dynamic traffic requests is a key problem that has to be solved.

The objective of the dimensioning process is to minimize the network infrastructure cost and the blocking probability for arriving connections at the same time. The performance of mulitlayer networks is significantly influenced by routing strategies and assignment of different lower bandwidth SDH connections to wavelengths, often referred to as grooming.

In general, static networks are dimensioned by assigning given connection demands to dedicated resources. In the case of WDM networks, this process is referred to as the routing and wavelength assignment problem (RWA). Several solutions to the static RWA problem have been investigated which minimize the total number of wavelength hops in the network.

However, in dynamic networks connection requests arrive and terminate statistically. Mean values of utilized end-to-end bandwidth are given in traffic matrices and distributions are used for the inter-arrival and holding time of connections. Although a static dimensioning based on mean values of connection requests could be used for dynamic networks this dimensioning may not be appropriate. The law of the economy of scales states that a small channel trunk requires more resources for reaching the same blocking probability than a large trunk under the same load per channel.

Also, the adoption of dimensioning methods used in other dynamic multilayer networks (e. g. IP-over-ATM) is no valid solution. These networks are usually operated and dimensioned in a single layer mode without regarding the dynamics of underlying layers. Therefore, new dimensioning schemes are necessary.

The remainder of the paper is structured as follows: Section 2 introduces SDH/WDM multilayer networks. This is followed by a classification of different dimensioning schemes and the description of investigated algorithms in

*This work was partly funded within the MultiTeraNet project (www.multiteranet.de) by the German Bundesministerium für Bildung und Forschung under contract No. 01BP289.

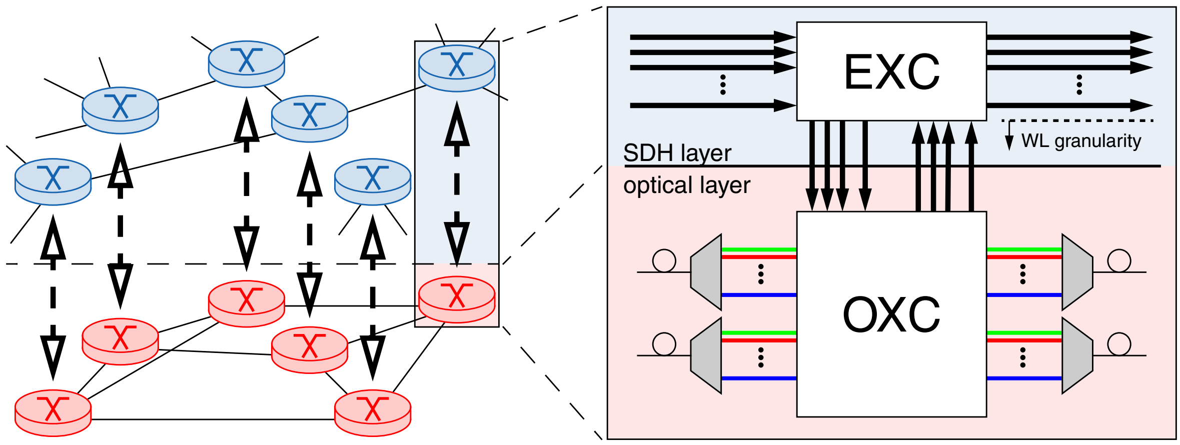

Fig. 1 SDH-over-WDM multilayer network and node

Section 3. In Section 4, we evaluate dimensioning approaches by simulation and present some properties of the algorithms. Finally, Section 5 summarizes our work and provides an outlook.

2 Multilayer Networks

2.1 Multilayer Nodes

A multilayer node (**Fig. 1**) comprises a non-blocking optical crossconnect (OXC) with switching capabilities for wavelength channels as well as a non-blocking electrical crossconnect (EXC) with switching capabilities for all SDH/SONET granularities. OXC and EXC are connected by a limited number of tunable transponders (TP) of a given line-rate. Wavelength converters are not installed. The advantage of such an architecture is the freedom of switching connections through the node.

In general, traffic is generated in the SDH layer with different granularities. Several SDH connections are multiplexed to connections of up to wavelength bandwidth and transmitted through the optical layer. For switching a wavelength channel through a node, there are three mayor possibilities:

1. A incoming wavelength channel can be switched directly to an outgoing fiber on the same wavelength.
2. If wavelength conversion is necessary, this can be emulated by switching the wavelength channel to the EXC and without any SDH processing back to the OXC on another wavelength. The OXC forwards the wavelength to the output fiber.
3. Wavelengths carrying SDH connections for different destinations can be switched through to the electrical layer for demultiplexing as well as additional SDH connections can be multiplexed onto partially used wavelengths.

2.2 Routing and Grooming

Efficient transport of dynamic traffic demands of different granularities from the SONET/SDH hierarchy requires optimized multi layer routing and grooming algorithms. In SDH/SONET-WDM multilayer networks, grooming is closely related to routing on both layers and is an important aspect to be considered for dimensioning. This is due to the fact that the grooming scheme influences the setup of lightpaths, i. e. the load on the optical network.

Four basic grooming options can be identified:

a. single-hop grooming on existing lightpath: The connection is assigned to one existing direct lightpath.
b. multi-hop grooming on existing lightpaths: Routing takes place on the electrical layer by using more than one existing lightpath and switching the connection in the EXCs of intermediate nodes.
c. single-hop grooming on new lightpath: A new lightpath is set up between the source and the destination node. The connection request is routed on the optical layer via this new lightpath.
d. combined multi-hop grooming on new and existing lightpaths: This is a combination of options A and C. The connection request can be routed on both the electrical and optical layer by using a series of existing and new lightpaths.

While non-integrated routing schemes are only capable of grooming on either existing or new lightpaths, integrated routing is able to perform the combined grooming described in D.

In this paper we consider the non-integrated routing schemes PreferOptical and PreferSDH as well as the integrated scheme Weighted Integrated Routing (WIR). In PreferOptical, the options are applied in the order A-C-B, where for PreferSDH the order is A-B-C. WIR [2], [3] has been proposed as an integrated SDH/WDM routing scheme which calculates one or a set of potential paths for a connection request, rates these potential paths and tries to set up the connection. All of these routing schemes apply shortest path-based adaptive routing in the both layers.

3 Network Dimensioning

In this section, we discuss design parameter, classify different dimensioning approaches and describe the algorithms applied.

3.1 Dimensioning parameters

Depending on the initial scenario and constraints, different network dimensioning tasks have to be performed:

1. *Topology, node positions and fiber ducts*
   These tasks mainly have to be dealt with in a greenfield network planning scenario.
2. *Link dimensioning*
   Assuming multi-fiber links and a fixed number of wavelengths per fiber n, the number of fibers per link remains the only parameter to be determined.
3. *Node dimensioning*
   For multilayer nodes like in **Fig. 1**, the number of optical interfaces follows from link dimensioning. While the number of transponders is especially interesting in the multilayer scenario, the number of tributary can be assumed the same as in an overlay scenario and is therefore not considered here.

As dynamic SDH/WDM multilayer networks will most likely be deployed on current network infrastructure, we assume a given topology. Thus, only the number of fibers per link and the number of transponders have to be determined and are focused on in the following sections.

3.2 Dimensioning Approaches

For an end-to-end lightpath, two kinds of resources have to be provided—transponders at the source and destination node as well as wavelength channels along the path. As described in Section 2, transponders in multilayer nodes can be used for

1. termination of end-to-end lightpaths
2. emulated wavelength conversion and
3. multi-hop grooming.

While the load generated by the first application can be derived from the traffic matrix, the contributions of the latter two applications strongly depend on the dynamics of routing and grooming and therefore cannot be determined in advance. If these contributions are neglected, both kinds of resources can be treated in a consistent way.

In order to map end-to-end traffic requirements into offered load on transponders and network links we translate connection requests of arbitrary granularity into wavelength granularity and route them through the network on a shortest path. For individual resources we calculate the sum A_i of traffic routed over them and neglect path blocking for dimensioning.

Based on these values for the offered traffic, each individual resource is dimensioned independent of all the others by applying one of the following two mappings:

- **linear dimensioning**: For an offered traffic A_i, $n_i = \lceil A_i \rceil$ describes the number of transponders or the number of wavelength channels respectively.
- **Erlang dimensioning**: Here, each resource is modelled as a loss system with n_i servers and general service time distribution to which an offered traffic A_i arrives according to a Poisson process. A target blocking probability B is specified for all resources and the number of transponders or wavelength channels n_i is calculated from the Erlang-B formula

$$B(A, n) = \frac{A^n / n!}{\sum_{i=0}^{n} A^i / i!} .$$

For both approaches, he number of fibers on a network link is calculated by dividing the number of wavelength channels n_i obtained in the previous step by the number of wavelengths per fiber w and rounding it up to the next greater integer $\lceil n_i / w \rceil$.

In order to scale the dimensioning of a network for overprovisioning the number of transponders and wavelength channels can simply be multiplied by a scaling factor in the case of linear dimensioning or be controlled by the target blocking probability B in the case of Erlang dimensioning. Overprovisioning can be used to account for the dynamics of connection requests as well as for emulated wavelength conversion and multi-hop grooming in the case of transponders.

4 Simulation Studies

In this section, we first compare the performance of networks dimensioned according to the linear and Erlang approaches for different degrees of overprovisioning. Then, we analyze the impact of overprovisioning transponders while keeping the network dimensioning fixed.

All presented simulation studies were performed using a fictitious 9-node network of Germany [4] with 8 wavelengths on each fiber. The bandwidth of a wavelength was chosen to be STM16. The traffic mix used in this case study was of 80% STM1, 15% Gigabit-Ethernet (transported as VC-4-7v in SDH [6]) and 5% STM16 connection requests corresponding to a mixture of approx. 30%

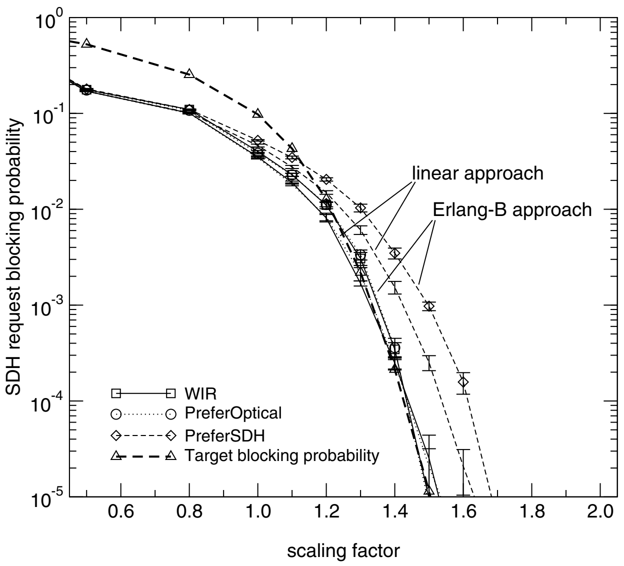

Fig. 2 Linear and Erlang-B-based dimensioning

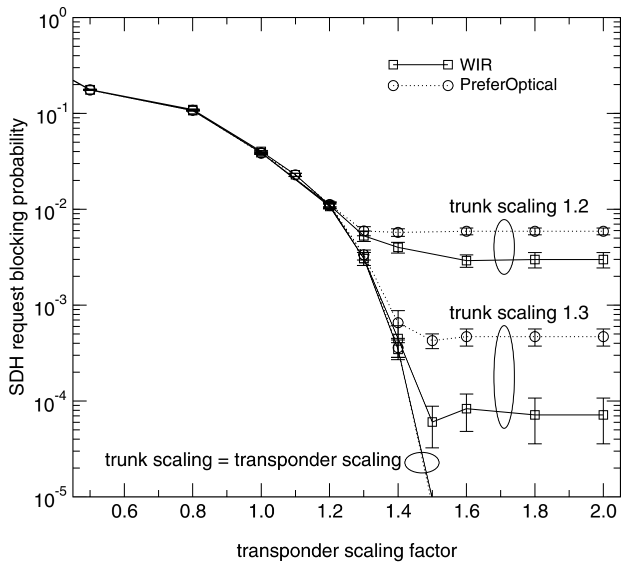

Fig. 3 Scaled transponder dimensioning

STM1, 40% GbE and 30% STM16 by traffic volume. Unless stated differently, all connection requests arrive according to a Poisson process and holding times are negative exponentially distributed.

4.1 Comparison of dimensioning approaches

The influence of the different dimensioning approaches is depicted in **Fig. 2**. The SDH request blocking probability is plotted versus the scaling factor for different routing schemes. In case of Erlang dimensioning, the scaling factor is calculated by dividing the sum of all wavelength channels and transponders by linear dimensioning with scaling factor 1.0.

First, it can be seen that WIR and PreferOptical outperform PreferSDH in both cases by up to an order of magnitude. This is reasonable due to the fact, that PreferSDH occupies a higher number of optical links per end-to-end connection than WIR and PreferOptical whereby virtual traffic is introduced into the network.

Comparing the example networks dimensioned by the two approaches for different scaling factors it can be seen that the dimensioning of single links differ by at most 10 %. As in **Fig. 2** depicted the SDH request blocking probability is nearly equal for the two dimensioning approaches.

The target request blocking probability is also depicted in **Fig. 2**. It is shown that for scaling factors higher than 1.0 the SDH blocking probability for the routing schemes WIR and PreferOptical fit the target blocking probability used in the Erlang dimensioning very well.

4.2 Impact of transponder overprovisioning

Fig. 3. depicts the SDH request blocking probability versus the transponder scaling factor for WIR and PreferOptical and different network link dimensionings. For reference, the performance of the network dimensioned by the Erlang-B approach is depicted again.

While PreferOptical and WIR have shown the same performance for the case in which the target blocking probability for network links and transponders was the same, WIR performs significantly better when increasing the number of transponders while keeping the network unchanged. This can be explained by the fact that WIR allows emulated wavelength conversion and multi-hop grooming which reduce blocking probability but consume additional transponders. Also, it can be seen that WIR can reach the same SDH request blocking probability with less transponders than PreferOptical for the same network dimensioning—for network scaling factor 1.3 this accounts for a 12 % saving in transponders.

Independent of the routing scheme, the same blocking probability can be achieved by a relatively larger network and less transponders and vice versa. Thus, the total network cost can be optimized considering the individual costs for transponders and fiber hops.

4.3 Dependence on the arrival process

The influence of the coefficient of variation is depicted in **Fig. 4**. It is plotted the SDH request blocking probability versus the scaling factor for three coefficients of variation

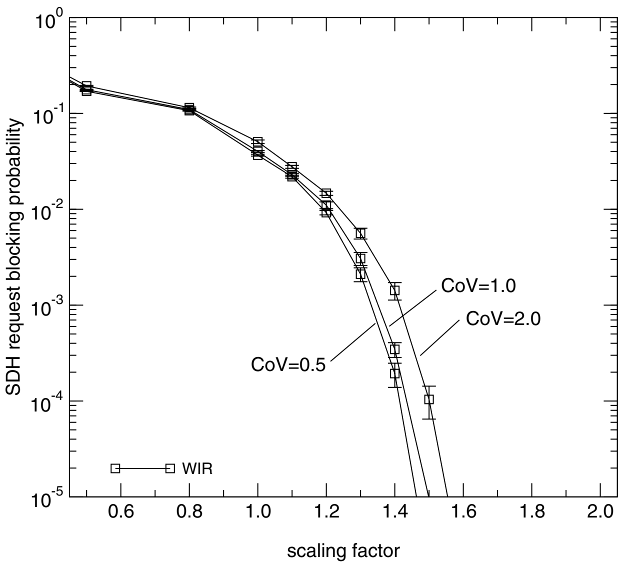

Fig. 4 Influence of coefficient of variation

from 0.5 to 2. The results for the routing schemes PreferOptical and PreferSDH are omitted as they perform similarly.

It is shown that the higher the variation the higher the blocking probability is. From this we can see that the estimation of traffic has to be done very precisely.

5 Conclusions

After introducing into SDH-WDM multilayer networks, we presented two dimensioning approaches for dynamic SDH/WDM multilayer networks using a shortest path based scheme for mapping traffic to network links and transponders followed by an either linear or Erlang-B-based dimensioning.

Case studies investigated several properties of these dimensionings in cooperation with three different routing schemes. It can be stated that networks dimensioned by the introduced approaches perform as expected with respect to the SDH request blocking probability.

As the future work, the further characteristics of the dimensioning schemes have to be investigated. Also, the model has to be extended for fixed transponders which have no wavelength tunability due to the fact that tunable lasers are one of the mayor cost factors of line cards.

Acknowledgments

The authors would like to thank Stefan Bodamer and Marc Necker for invaluable discussions.

References

[1] E. HENANDEZ-VALENCIA: “Hybrid transport solutions for TDM/data networking services.” *IEEE Communications Magazine*, Vol. 40, No. 5, May 2002, pp. 104-112.

[2] M.C. NECKER, C.M. GAUGER, S. BODAMER: “A new efficient integrated routing scheme for SDH/SONET-WDM multilayer networks.” *Proceedings of the Optical Fiber Communication Conference (OFC 2003)*, Atlanta, March 2003.

[3] M.C. NECKER: “Improving performance of SDH/SONET-WDM multilayer networks using Weighted Integrated Routing.” *Beiträge zur 13. GI/ITG Fachtagung Kommunikation in Verteilten Systemen (KiVS 2003)*, Leipzig, February 2003, pp. 421-432.

[4] J. SPÄTH: “Dynamic routing and resource allocation in WDM transport networks.” *Computer Networks*, Vol. 32, No. 5, May 2000, pp. 519-538.

[5] J. SPÄTH: “Entwurf und Bewertung von Verfahren zur Verkehrslenkung in WDM-Netzen” *82. Bericht über verkehrstheoretische Arbeiten*, Dissertation, Stuttgart, 2002.

[6] ITU-T Rec. G.707/clause 11, “Network Node Interface for the Synchronous Digital Hierarchy (SDH)”, 2000