Routing Strategies for Photonic Networks under Dynamic Traffic Conditions

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Abstract. This paper investigates several routing methods for WDM (Wavelength Division Multiplexing) networks under dynamic traffic load. We evaluate the impact of wavelength conversion (including partial conversion) on the network blocking probability. Moreover, the influence on network performance of priority scheduling for various routing parameters is investigated.

1. Introduction

In the future, WDM technology will be widely used in transport networks. The evolution of WDM networks will probably go from point-to-point links to ring networks and finally to cross-connect (CC) networks with an increasing degree of flexibility [3]. Up to now, a big concern has been the optimal design and dimensioning of such networks [1]. In general, static traffic demands have been used. The main goal has been to minimise the required resources (fibres,...) while achieving a certain network performance. For the operation of WDM networks however, also the dynamic behaviour has to be considered. This dynamic has physical aspects such as power considerations when switching on/off wavelength channels. But there are also network performance aspects from a traffic point of view. Multiple reasons for dynamic can be distinguished, among which we are concentrating on the following two.

- Long-term variations of traffic demands and traffic patterns occur resulting in a rearrangement (and also new installation) of transport paths.
- There also will be short-term variations due to the increasing bitrates of user connections and the increasing use of leased wavelength services (e.g. for service providers or companies).

Since the influence of single blocking events in the optical layer will increase, these dynamic aspects have to be considered. One important task necessary to handle dynamic traffic requests is to route them through the network.

2. Routing in WDM Networks

There is a great variety of routing methods for circuit-switched (CS) as well as for packet switched (PS) communication networks and also many different classification schemes exist [2]. Many analogies between routing in photonic networks and routing in classical CS transport networks can be observed. In both cases, circuit switching will be applied to establish transport paths with a fixed bitrate for a certain time without allowing re-routing of existing connections. Especially a VWP network (Virtual Wavelength Path, i.e. full conversion capabilities are available) with no additional restrictions is absolutely equivalent to a classical CS network with the number of circuits (e.g. time slots or transmission lines) on each link equalling the number of wavelength channels per link.

We will extend later the following well-known routing strategies for the use in a WDM network. Fixed source routing (*FSR*) is based on the paths determined during network dimensioning without alternatives. With *OOC* (Originating-Office Control) only the originating node is able to choose an alternative path whereas all other nodes have to choose the first routing possibility towards the end node. With *SOC* (Sequential-Office Control), each node is able to choose between a number of alternatives. If a node is not able to find any way for the next path section, the call is blocked. If *SOC with* *crankback* (*SOCc*) is used, in such a case routing control may be returned to the predecessor. Therefore, this is the most powerful method of the considered ones whereas FSR is the most restricted one.

However, there are also many differences between classical and WDM networks such as the different dynamics, the importance of single events, or additional constraints (e.g. path length limitations). Moreover, the wavelength domain represents an additional degree of freedom for the routing choices. The last point significantly increases the complexity of routing methods.

As an example we look at a WP (Wavelength Path) network, i.e. a network without any wavelength conversion. Therefore, a continuous wavelength between source and destination is needed. Two basic schemes of finding a valid path can be distinguished:

- First, choose a route and look for any continuous wavelength. If no one is available, try the next route. If all routes are investigated without success, the call is blocked (we call this scheme *Path Priority* or *PP* scheme in the following).
- First, choose a wavelength and test for all possible routes if this wavelength is available. If not, repeat this search for the next wavelength. If all wavelengths fail, the call is blocked (we call this scheme *Wavelength Priority* or *WLP* scheme in the following).

Further complexity is added when the use of limited wavelength conversion is considered. In this case, a decision has to be made between "shorter routes with higher converter requirements" or "longer routes with less converter requirements".

3. Problem Complexity and Modelling Approach

The routing problem is a very complex problem which depends on many input parameters such as network topology and dimensioning, wavelength conversion capabilities, or other technological aspects. Moreover, the offered traffic load (i.e. size and distribution of traffic demands) as well as the traffic characteristics play an important role. Several searching strategies for resource allocation exist. Furthermore, the routing strategy plays an important role. This includes also priority scheduling of routing parameters (e.g., minimisation of either path lengths or conversion requirements).

The modelling approach (described in more detail in [4]) uses one traffic generator to characterise the traffic between one pair of source and sink with appropriate distribution functions for the interarrival times of call requests and the call holding time, respectively. The discrete event simulation tool based on this modelling is realised in an object-oriented way in C++. The tool allows a flexible definition of traffic characteristics. The topology and dimensioning of the investigated network can be chosen arbitrarily. Various routing strategies including available alternatives can be defined freely. The tool provides a variety of results. Examples are link load or blocking probabilities for every link, every node, every source-destination node pair, or the whole network, as well as converter occupancies or path lengths. The results are available as mean values with confidence intervals or - where appropriate - as histograms.

4. Case Studies and Results

In the following, we present some results derived for a nine node network example which could represent a German backbone network (Fig. 1). It was dimensioned according to simple rules for symmetrical traffic demands depending on the population of each area and the distance between two nodes. This demand is called *static traffic demand* in the following. The interarrival and service holding times are negative-exponentially distributed.

In [4], it was already shown that the performance of the routing strategies depends on the network load. In general, for low load strategies that use many alternatives are better, while with high load, strategies using few alternatives achieve lower blocking. Moreover, it was shown that the blocking improvements by using wavelength conversion also depends on the routing strategy. The results in [4] were derived for the WLP scheme. Fig. 2 compares now the PP scheme (favouring shorter routes) to the WLP scheme for selected routing strategies (FSR, OOC, SOCc) in the WP case. First, we see that for the same routing strategy the PP scheme performs better than the WLP scheme over the whole load range because in general shorter routes are found leading to lower total resource usage. Obviously, for the FSR strategy there can be no difference between the two schemes.

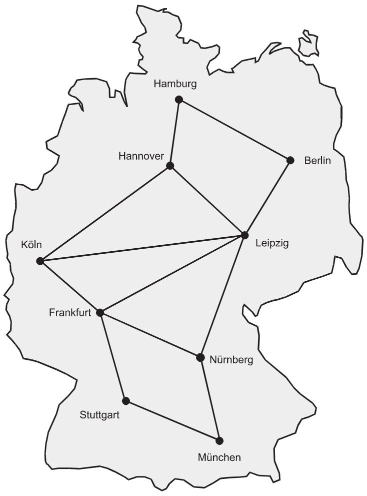

Figure 1: Example network for case studies

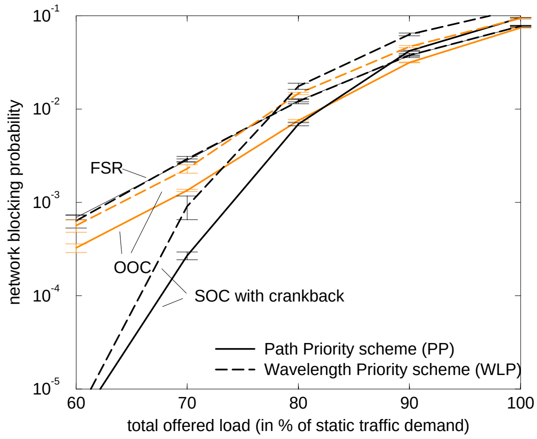

Figure 2: Comparison of PP and WLP scheme (WP concept)

In the following, we consider only the PP scheme. Fig. 3 shows a comparison between the WP and the VWP concept. Two different schemes for the allocation of wavelength converters are considered. One scheme tries to minimise the number of used converters while the other scheme uses converters arbitrarily. Over a wide range of loads, blocking probabilities are lower with the VWP scheme. However, it can be seen that the difference is rather small, especially for the FSR strategy. This shows that converters are especially useful in combination with more sophisticated routing strategies.

An explanation of the effects can be found in Fig. 4 which shows the mean number of links per connection (i.e. the path lengths) versus the network load. For the FSR scheme, it can be seen that the average length decreases with high load because longer paths suffer from higher blocking. Furthermore, the decrease is faster with the WP concept due to additional wavelength blocking. For the SOCc strategy, we see however that with higher load also the link lengths increase because rather long alternative routes are also accepted. Of interest is the difference between the two VWP schemes for converter usage. The figure shows that minimising the converter usage leads to longer routes which explains the higher blockings observed in Fig. 3.

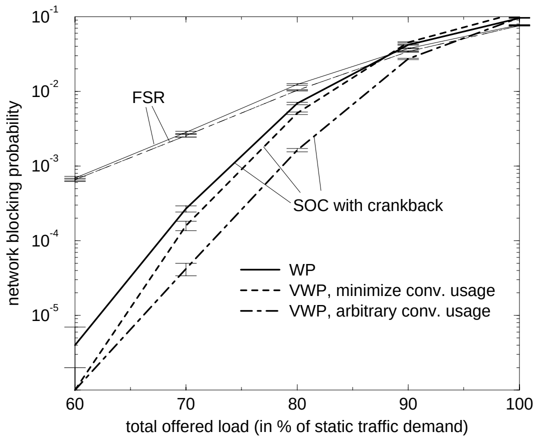

Figure 3: Comparison of WP and VWP (with 2 schemes for converter usage)

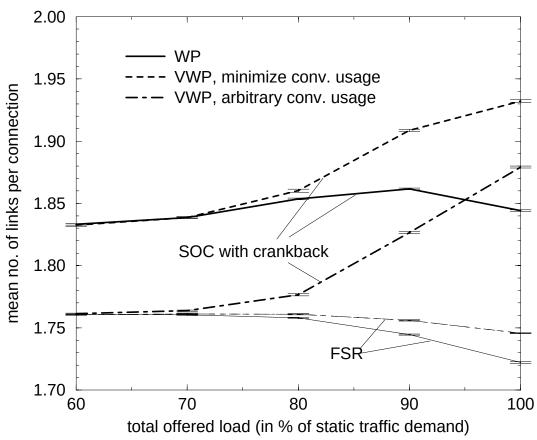

Figure 4: Mean number of links per connection

Another observation from Fig. 3 is that the difference between the WP and the VWP concepts, i.e. the difference between no converters and full conversion in the network is rather small. Therefore the question arises whether partial wavelength conversion could be already sufficient. Fig. 5 shows the results for different routing strategies which all apply the PP scheme with minimising the converter usage. All converters in a node are arranged in a pool for shared use by all connections. The network was loaded with 80% of the static traffic demand. We see that already a relatively small amount of wavelength converters significantly decreases network blocking while more converters have nearly no further impact. For more than two converters per fibre there was no more blocking decrease. Since we assumed 8 wavelength channels per fibre, this equals only 25% of the converters required in the VWP case. Finally, the converter usage in different network nodes is also interesting (Fig. 6). We see a significantly higher occupancy rate in the central network nodes than in border nodes. Moreover, for more than 25% conversion, converter usage reaches very low levels.

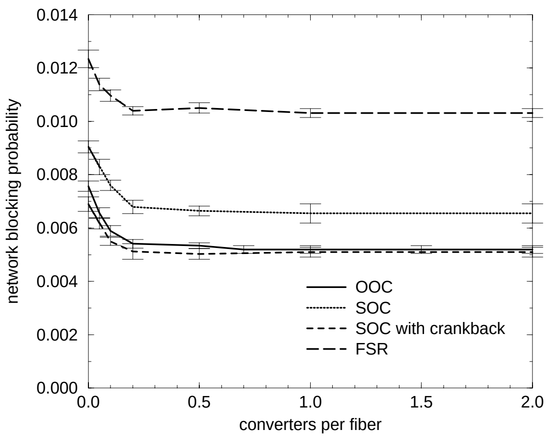

Figure 5: Network blocking probability for partial converter equipment

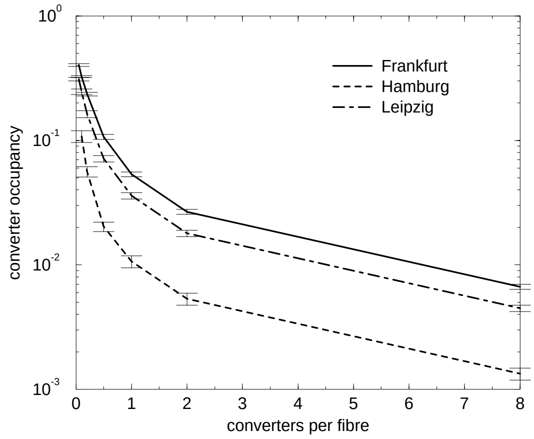

Figure 6: Converter occupancy (SOCc strategy, 80% network load)

5. Conclusions and Outlook

In this paper, we presented several routing strategies for WDM networks considering the additional degree of freedom offered by the wavelength domain. The problem complexity as well as our investigation approach based on discrete event simulation were described. The studies evaluated the achievable performance of various strategies under different load conditions. In particular, we looked at the influence of wavelength conversion on the network performance considering WP and VWP networks as well as partial wavelength conversion showing that already few converters lead to significant improvements. Moreover, the results show that the blocking decrease achievable with conversion strongly depends on the routing strategy.

Further work will consider additional routing strategies and network topologies. Moreover, in addition to the Poisson traffic behaviour assumed in this paper, also other traffic characteristics will be used since first results show that the traffic type also influences blocking probabilities and the efficiency of different routing strategies.

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