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Comparison of Contention Resolution Strategies in OBS Network Scenarios

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Abstract

Optical burst switching (OBS) has attracted interest as a transport network architecture for the future optical Internet. As OBS relies on statistical multiplexing efficient contention resolution is a key issue in order to achieve a low burst loss probability. Basically, contentions can be resolved by wavelength conversion, deflection routing and delaying the burst in a fiber delay line or a combination of these schemes. This paper compares the basic and combined contention resolution strategies in two reference core network scenarios with respect to burst loss probability and end-to-end transfer delay. We show that the effectiveness of those contention resolution schemes highly depends on the load offered to the network and the dimensioning of specific nodes and links. For high load, contention resolution schemes applying deflection routing have an end-to-end transfer time increase in the order of 10–60 % depending on the scheme.

Keywords: WDM, deflection routing, fibre delay lines, wavelength conversion, performance evaluation

1. Introduction

Optical Burst Switching (OBS) has been proposed as an efficient and flexible switching paradigm for a highly dynamic future optical data plane [1]. In OBS networks, the dynamics of traffic can be supported by edge nodes which aggregate traffic and assemble IP packets into variable length optical bursts as well as by core nodes which asynchronously switch these bursts. A key characteristic is the hybrid approach in which burst control packets are signaled out of band and processed electronically while data bursts stay in the optical domain until they reach their destination node. According to one-pass reservation in OBS, burst transmission is not delayed until an acknowledgment of successful end-to-end path setup is received but is initiated shortly after the burst was assembled and the control packet was sent out. Due to this one-pass reservation strategy and statistical multiplexing burst loss can occur in case of contention and efficient resolution strategies in OBS core nodes are essential in order to achieve a low burst blocking probability as required in transport networks.

This paper discusses the main contention resolution strategies and evaluates their performance in network scenarios. Section 2 introduces the main concepts for contention resolution in OBS. The impact of different contention resolution schemes on the burst loss probability is evaluated in section 3.1 while section 3.2 investigates the influence on the mean transfer time. Section 4 concludes this paper.

2. Contention Resolution in OBS

In principle, contention resolution in OBS networks can be performed in one of the three physical domains wavelength, space and time (c. f. [2] for a more detailed discussion). In this paper, following basic strategies and further assumptions are considered (acronyms in parentheses):

- wavelength conversion without limitations regarding number of converters or tuning range (*Conv*)
- deflection routing selecting an alternative available output interface in each node in the order of shortest path length (*Defl*)
- buffering uses a shared feedback fiber delay line (FDL) buffer with a single FDL employing WDM (*FDL*).

Apart from these basic strategies, also combinations of them can be applied. As the order in which these schemes are applied is essential, they are named by a concatenation of their acronyms. E. g., *ConvFDLDefl* refers to a scheme which tries conversion first, only if this fails it tries to buffer in an FDL and only if this also fails it tries deflection routing. Previous work showed that when combining full wavelength conversion with either FDL buffers or deflection routing conversion should always be used first [2, 3]. Thus, we only compare schemes which apply wavelength conversion first. Also, our previous evaluations showed that for deflection routing improve-

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Fig. 1 Pan-European Network Scenario [4]
total traffic = 1 Tbps,
mean number of λs/link = 5.43

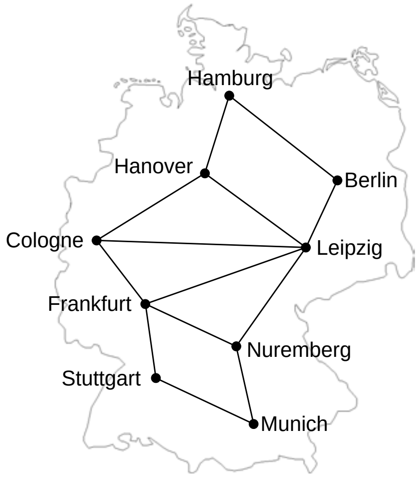

Fig. 2 Germany Network Scenario
total traffic = 1 Tbps,
mean number of λs/link = 6.92

ments and penalties due to limitations regarding the number of deflections, the number of paths and even loops were marginal as long as a reasonable amount of flexibility was allowed. Thus, we do not apply any of these extended strategies in this paper.

So far, OBS research on contention resolution has concentrated either on isolated nodes or on network topologies with uniform traffic and uniform link dimensioning. Especially, deflection routing is commonly evaluated in regular interconnection networks like torus topologies, i. e., in networks with a large number of equal length alternative paths. However, as topology and link dimensioning determine the performance of wavelength conversion and deflection routing irregular networks which are dimensioned tight should be used for a more realistic analysis. In [3], a thorough comparison of different basic and combined contention resolution schemes has been performed for Optical Packet Switching in an irregular, uniform link capacity network under a uniform demand matrix and with IP traffic characteristics.

In this paper, in contrast, we use tightly dimensioned Pan-European and German reference networks (**Fig. 1** and **2**) for our evaluation. Also, we incorporate the specifics of OBS, e. g., the FDL buffer and the output wavelength are both reserved according to just-enough-time (JET) *before* the burst enters the buffer which prioritizes buffered bursts over newly arriving bursts—this is called *PriorRes* in [5]. We show how the different strategies can be optimally combined in order to achieve low burst loss probabilities and to overcome the reduced flexibility of the optical layer compared to the electronic layer like the lack of inexpensive random access memory.

3. Performance Evaluation

Performance of the different basic and combined schemes is evaluated by event-driven simulation. Bursts are generated based on a Poisson process and burst length is exponentially distributed with mean 100 kbit, i. e., a mean burst duration of h = 10 μs for 10 Gbps line-rate.

The number of add/drop ports in OBS nodes is not limited and the delay for burst control packet processing is compensated by a short extra FDL of appropriate length at the input of the node. Thus, neither effects of offset reduction along the path nor offset violation due to excessive deflections are considered. The delay of the buffer FDLs is $2h$ = 20 μs and there are 8 wavelengths in the FDL.

Link capacities in both networks are dimensioned according to a static traffic demand matrix obtained from a population model based on shortest path routing such that blocking probabilities on all links are equal in the Erlang model [6]. In order to allow for a systematic analysis, fiber length on all links is 200 km which translates into a propagation delay of 1 ms. Thus, FDL delay is small compared to link delay which is realistic in WAN scenarios [7].

3.1 Principle Behavior

Fig. 3 and **4** depict burst loss probability versus relative offered load for both networks. It can be seen that the results are very similar for both scenarios. For high loads, the schemes employing deflection routing after conversion are inefficient as they produce additional load in an already highly loaded network. For medium loads *ConvDefl* outperforms *Conv* and *ConvDeflFDL* which are all outperformed by *ConvFDL* and *ConvFDLDefl*. For low

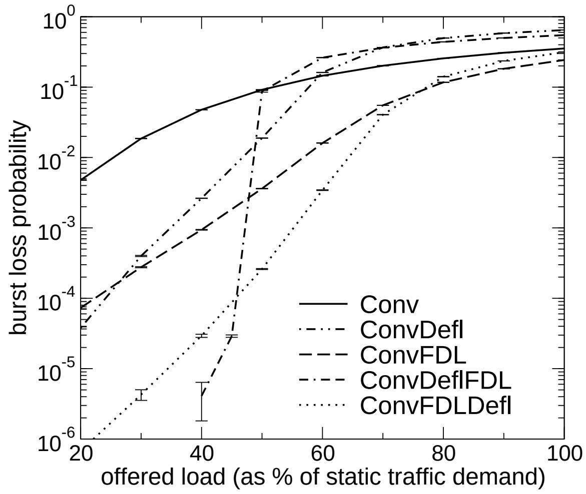

Fig. 3 Results for Pan-European Network

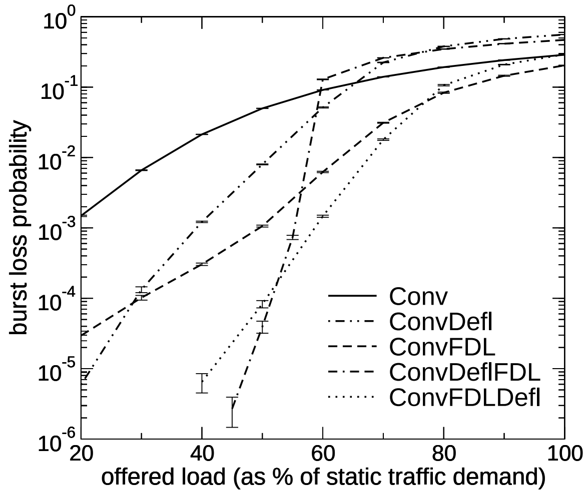

Fig. 4 Results for Germany Network

loads, the performance is directly related to the amout of flexibility provided, i. e. the number of domains available for contention resolution. *Conv* is outperformed by *ConvFDL* and *ConvDefl* while *ConvFDLDefl* and *ConvDeflFDL* finally have the best performance.

Burst loss probability for *ConvFDL* does not decrease as fast as all other schemes for low loads. For the Germany network, this can be explained by comparing the loss probabilities in **Fig. 4** and **5**: the node Stuttgart dominates the network performance for low loads as it is attached to the link to Munich with only 2 wavelengths which only yields minimal multiplexing gain. This effect can be greatly reduced by additional deflection routing (*ConvFDLDefl*) due to the detour route via Frankfurt and Nuremberg. **Fig. 5** also shows how the node Leipzig which is connected to 5 neighbor nodes by links with several wavelengths greatly benefits from the FDL buffer as its output links are less frequently congested. Additional deflection routing for low to medium loads can improve performance even more due to the large number of alternative paths. This could motivate the application of different schemes for different nodes depending on topology, link dimensioning and node degree.

Noteworthy is a specific of *ConvDeflFDL*. Towards low loads, the loss probability drops rapidly as enough network capacity becomes available. The reason for this can be derived from [8]: The contention resolution scheme *ConvDeflFDL* has a large number of possibilities for deflecting or delaying a burst in case of contention. Below a certain threshold, the probability of contention is very low and almost all bursts traverse the network on a shortest path. Above the threshold, the probability for contention raises very fast due positive feedback. Here, many bursts are deflected while a small number is delayed. In general, deflection leads to increased traffic due to detours in the network and thus a higher contention probability which again increases the number of deflected bursts etc. Concluding, a large number of bursts is not delivered on the shortest path anymore and many bursts have to be dropped despite having travelled over several hops. Both facts lead to an increased load and a highly congested network with a high number bursts dropped.

In *ConvFDLDefl* that has the same number of possibilities for contention resolution, the additional load due to contention resolution in the network is much lower as most of the bursts are delayed in an FDL. Accordingly, the congestion probability is only slightly increased. Although *ConvDefl* also detours the bursts and thus increases the load in the network bursts are usually dropped without excessive deflection as there is no third resolution strategy.

3.2 Impact on Mean Transfer Time

The second important performance measure for an OBS network is the mean transfer time (MTT). It represents the duration for a burst to traverse the network from the source to the destination node. As assembly and disassembly delay are the same for all contention resolution schemes they are not included in the MTT. In **Fig. 6**, the expected MTT is shown for reference. It can be calculated by assuming that all bursts are routed on the shortest path and without any losses.

The behavior of the contention resolution schemes can be divided into two groups: First, for *Conv* and *ConvFDL* the MTT is always below the reference value and decreases slightly for an increase in offered load. This can be explained by the fact that for high load bursts that have to traverse a larger number of hops experience a higher loss probability. As the MTT considers only bursts that reach the destination node the MTT decreases. For *ConvFDL*, the increase in transfer time compared to *Conv* is due to the FDL delay but its contribution is small regarding the MTT.

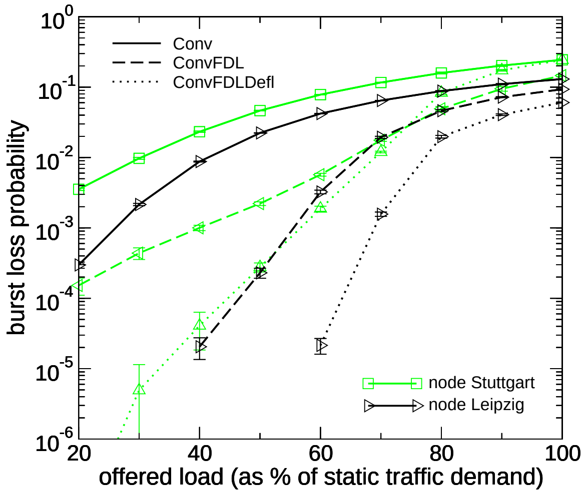

Fig. 5 Results for nodes Stuttgart and Leipzig in Germany Network

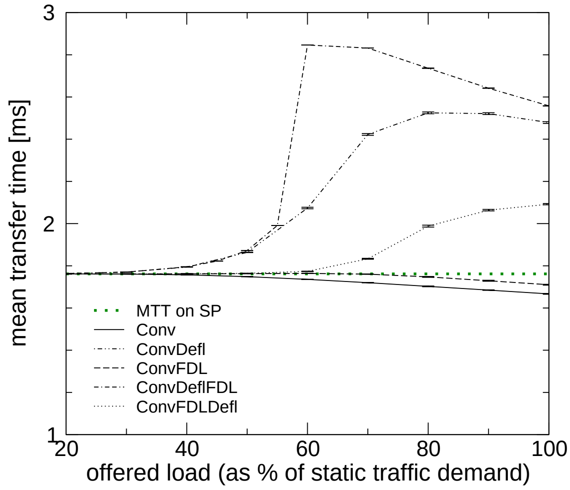

Fig. 6 Further Results for Germany Network

Second, for all the schemes applying deflection, the MTT increases for medium and high load situations compared to the other schemes as well as to the reference curve. This can be explained by the fact that most deflections require at least one more hop which accounts for an additional propagation delay of 1 ms—this is two orders of magnitude greater than the FDL delay. Comparing the deflection schemes, *ConvFDLDefl* has the smallest penalty as most of the contentions can be resolved by using FDL buffers and only a small number of bursts have to be deflected. Finally, the slope of *ConvDeflFDL* has to be pointed out here. While for loads below 55% there is only a small increase of the MTT a almost step-wise increase can be observed between 55% and 60%. Again, this can be explained by the positive feedback inherent to those schemes as discussed above.

4. Conclusions

In this paper we presented a comparison of different basic and combined contention resolution strategies for OBS networks. Performance has been evaluation by simulation for two reference core network topologies.

Concluding, the performance of contention resolution schemes is sensitive to both offered traffic and dimensioning of individual network nodes and links which should be considered in their analysis. Combination of conversion with FDL buffers yields lower losses than conversion with deflection routing in most cases, however at the cost of the additional buffer.

Acknowledgments

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