Impact of Crosstalk on the Performance of Multi-Wavelength Optical Cross-connected Networks using Deflection Routing

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Abstract— BER performance of multi-hop transparent optical networks in uniform traffic under hot-potato, single-buffer deflection routing schemes is presented. Device-induced crosstalk and ASE noise, limit the characteristics of the network, such as propagation distance, sustainable traffic, and bit-rate.

I. INTRODUCTION

Optical crosstalk imposes a major limit to the practical implementation of multiwavelength optical cross-connected networks. It is therefore important to know how crosstalk scales with network size and traffic load. The traffic performance of multi-hop packet-switching networks such as Manhattan Street Network (MS) and ShuffleNet (SN) has been studied extensively. However, relatively few studies consider the BER performance of these networks. In [2] ultrafast soliton communication is used to evaluate the BER in multi-hop networks with deflection routing, but the impact of crosstalk is not considered. In [3] the BER is analyzed using a semi-analytical simulation method for estimating the effect of the interference noises on the BER performance of a circuit switching network. However, the impact of *traffic randomness* is not considered in the analysis.

This paper presents the first complete BER analysis based on the traffic randomness of multi-hop packet-switched transparent multiwavelength networks. It is shown that the BER performance strongly depends on the traffic load of the network. We present the limit of operation based on a uniform traffic scenario. The main impairments considered in the analysis are intra-band crosstalk and ASE noise.

II. ANALYSIS

Fig. 1 shows the node composed of a stack of submodules, one per wavelength. The wavelengths from the input fibers are spatially demultiplexed and sent to the appropriate submodule for add/drop operations and switching. Packets from the submodules are finally re-multiplexed onto the output fibers. The submodule is described in [2].

The intra-band crosstalk generated by the 2x2 space switch and the one produced by the combination of the demultiplexer (DEMUX) and multiplexer (MUX) [3] are considered. The DEMUX/MUX crosstalk can be reduced by placing narrow-band optical filters before multiplexing. The amount of suppression of the inter-band components will depend on the transfer function $T(\Delta\lambda)$ of the filters.

Crosstalk varies with the traffic parameters of the network; i.e., generation (g), absorption, link utilization probabilities, probability mass function of the age of the packets, architecture of the submodules and routing algorithm [4].

III. RESULTS

We analyzed a network with four 2.5 Gb/s channels in the range of 1550 nm to 1556 nm, with 2 nm channel separation. DEMUX with adjacent signal inter-band crosstalk of -30 dB, and a 2x2 crossbar optical switch with coupling power coefficient α between -25 dB and -35 dB are assumed. Filters have a transfer function $T(\Delta\lambda) = -17$ dB. We represent each amplifier by using the spectrally resolved numerical model of [5] with a forward pumping scheme. The absorption and gain parameters are the same as those of fiber 2a in [6] with a length of 20 m and a pump power of 50 mW. A bandwidth of 125 GHz is used to resolve the effect of ASE spectrum. The optical filter at the receiver has a 0.2 nm bandwidth and the electrical filter has a 2.5 GHz bandwidth. We assumed a fiber with dispersion coefficient $D_c = 1$ ps/km-nm, a loss coefficient of 0.2 dB/km, an inter-node distance of 15 km, a total node loss of 12.5 dB, for hot-potato and 15.5 dB for single-buffer node architectures. The optical amplifiers are located at the output of each node.

We optimized the performance of the network based on the input power. Thus, Fig. 2 shows the maximum number of nodes n traversed by a signal with a BER(n) $< 10^{-9}$ versus input power at g=1 for the channel at 1556 nm, one with the worst gain. Results are shown for Hot-potato under SN topology with α=-35 dB and -25 dB. For low input power the predominant beat noise is signal-ASE that increases with bit rate and for high input powers the signal-crosstalk beat dominates, a noise that is bit rate independent.

Fig. 3 shows results for the conditional BER(n) versus number of nodes n traversed by a packet when g=0.1 and g=1 for all the submodules of a network

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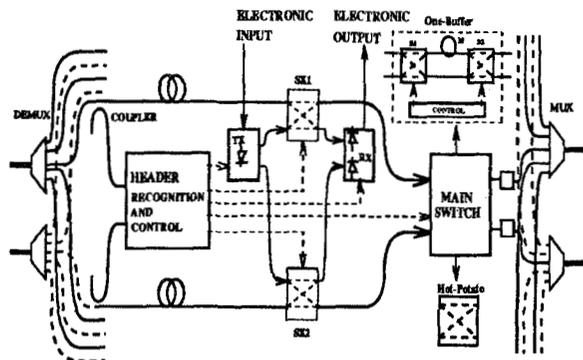
Figure 1: Node block diagram, Hot-potato switch, and One-buffer switch, M is the memory, S1 and S2 are exchange-bypass switches.
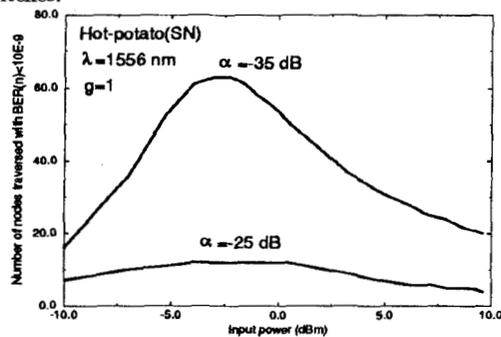

Figure 2: Maximum number of nodes traversed by a signal with a BER(n) $< 10^{-9}$ versus input power at g=1.

Figure 3: BER(n) versus number of nodes for g=0.1 and g=1. Curves are for wavelength 1556 nm
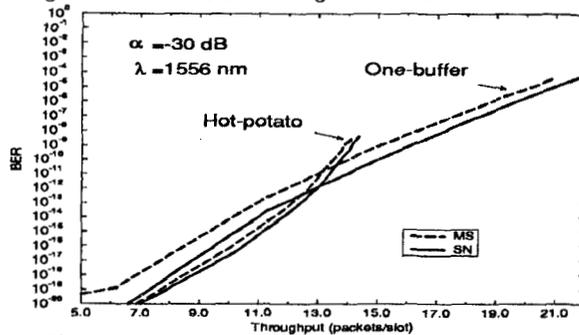
Figure 4: BER versus throughput for networks with 64 nodes for g=1 and α= -30 dB.

with 64 nodes. Observe that SN and MS have a very similar BER(n) performance. The reason is that the link utilization probability and the average age of the packets of both topologies are similar [4]. Observe that the BER(n) degrades at full load (g=1). This is because there are more packets in the network and the crosstalk probability increases. The two main reasons why single-buffer performs worse than hot-potato are: Single-buffer has two optical switches to route the packets, therefore more intra-band crosstalk; the second is that ASE noise increases because the EDFA's gain increases trying to compensate the loss introduced by the the addition of optical switches. Although using optical buffers deteriorates the conditional BER(n), a fair comparison should give curves of average BER vs throughput, as in Fig. 4. Observe that at BER=10^{-9} single-buffer has a higher throughput [1] than hot-potato. Also, observe that under the same throughput SN has a better BER performance than MS due to the fact that SN has less traffic congestion.

IV. CONCLUSIONS

Crosstalk and ASE noise limit the propagation distance, traffic load and bit rate performance of the network. Results show that hot-potato deflection routing has a better BER performance than single-buffer
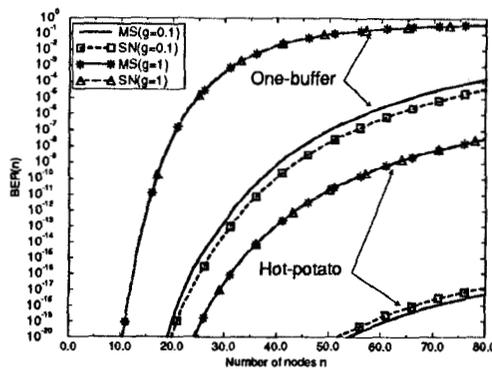
under low throughput. However, at BER=10^{-9} single-buffer has a higher throughput than hot-potato due to the fact that single-buffer has less traffic congestion. If the bit rate increases the BER performance is worse than the shown, but if it decreases the BER improves making possible the operation of single-buffer at high throughput. The feasibility of deflection routing transparent networks will depend on the isolation characteristics of the optical switching elements. The most crucial component is the routing space switch. A high coupling power coefficient α limits the operation of the network, while a low α will make its operation possible with good performance.

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