Teletraffic Performance of Multi-Wavelength Optical Cross-connected Networks using Wavelength Translation

G. A. Castañón, O. K. Tonguz and A. Bononi[1]

Abstract— The teletraffic performance of regular two-connected multi-hop datagram optical networks in uniform traffic under hot-potato routing and wavelength translation is presented. Manhattan Street (MS) Network and ShuffleNet (SN) are compared in terms of average propagation delay and throughput. We analyze a wavelength translation (WT) node architecture. Such an architecture decreases packet deflection by providing the possibility of an optimized wavelength translation routing. Packets are wavelength translated in the case of local conflict at a node to avoid deflection; otherwise they transparently traverse the node.

1. INTRODUCTION

The major advantage of cross-connected optical networks is that they achieve higher throughput than linear topologies like buses and rings [1], [2]. If routing buffers are not available at a node, the packets can be temporarily deflected to an undesired link. Thus, deflection routing allows the use of fiber links as optical buffers [1]-[3] while *bit-rate non-regenerative transparency* is maintained. Such an advantage in traffic management causes a major weakness in transmission [4]. It has been shown [5] that the quality of signals decreases with traffic load due to accumulation of weak noises such as the amplifier spontaneous emission (ASE) noise and device-induced crosstalk in high-speed transparent optical networks. Thus, node architectures that reduce the propagation delay to a minimum average number of hops and keep a certain bit-rate transparency are ideal for cross-connected networks. We analyze a wavelength translation (WT) node architecture. Such an architecture decreases packet deflection, and thus throughput and propagation delay improve.

We introduce an optimized wavelength translation routing algorithm that minimizes the probability of packet deflection. We analyze wavelength translation assuming that packets in transit have translation priority over new locally generated packets. Packets are wavelength translated in the case of local conflict and an available slot in a output wavelength to avoid deflection, otherwise packets will transparently traverse the node. In case of local conflict, but no available alternative receptive slots, one packet is randomly chosen for deflection instead of being dropped.

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The teletraffic performance of *circuit-switched* all-optical [6], [7], [8],[9] and electronic (regenerative) [10] wavelength translation has recently been reported . However, the teletraffic performance of *packet-switched* wavelength translation with deflection routing has not been reported yet.

This paper analyzes the steady-state behavior of two connected mesh *packet-switched* optical networks under wavelength translation. We present the limit of operation based on a uniform traffic scenario. We present results of simulation studies and compare the network performance with and without wavelength translation.

Section II presents the structure of the node and provides the necessary traffic parameters. Section III presents the wavelength translation algorithm. Section IV presents the results for MS and SN. Finally, section V contains the conclusions of the study.

2. NODE STRUCTURE

The node is composed of a stack of submodules, one per wavelength. Fig 1 shows the architecture of the wavelength translation node. All the submodules are interconnected and there is a central control unit which decides absorption, translation, injection of a new packet, and routing operations. The wavelengths from the input fibers are spatially demultiplexed and sent to the appropriate submodule. Packets from the submodules are finally re-multiplexed onto the output fibers. The submodule consists of a header recognition block, two crossbar switches for add/drop operations followed by a crossbar routing switch as Fig. 2a shows. The header recognition block taps power off to electronically read the packet header and make routing/control decisions. There is one transmitter (TX) and one translator (WT) per submodule. The WT acts like a lift, translating a packet that would get deflected to a new submodule (wavelength) where it can be properly routed. Packets are aligned at each node by tunable optical delays before the routing switch. We will assume that the packet detection-transmission delay is compensated by the tunable optical delays. Also, we will assume that the header of the packets is at one common bit-rate. The logical flow of node operations is *absorption, translation* to a receiving wavelength, electronic *translation/injection* of a new generated packet, and *routing*, as depicted in Fig. 2b.

When a packet is routed through a node, one of the two outputs is chosen according to a shortest path algorithm [11]. Based on the position of the intermediate node and the packet's destination node, one or both outputs may be suitable for minimizing the number of hops a packet has to

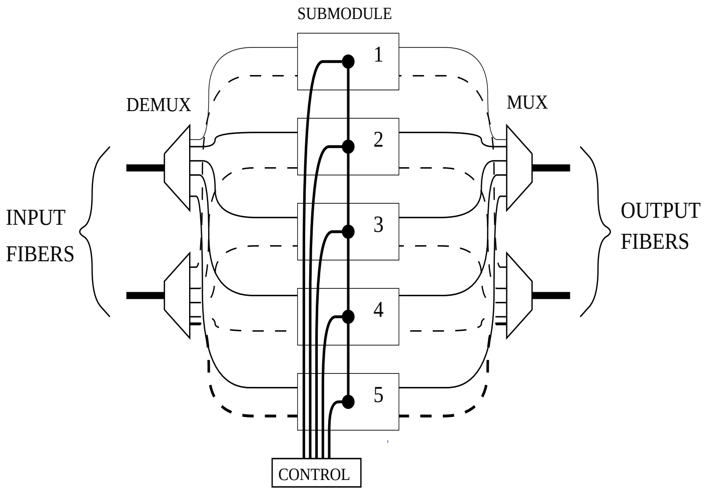


Figure 1: Architecture of the wavelength translation node. All the submodules are interconnected and there is a central control unit which decides transmission operations.

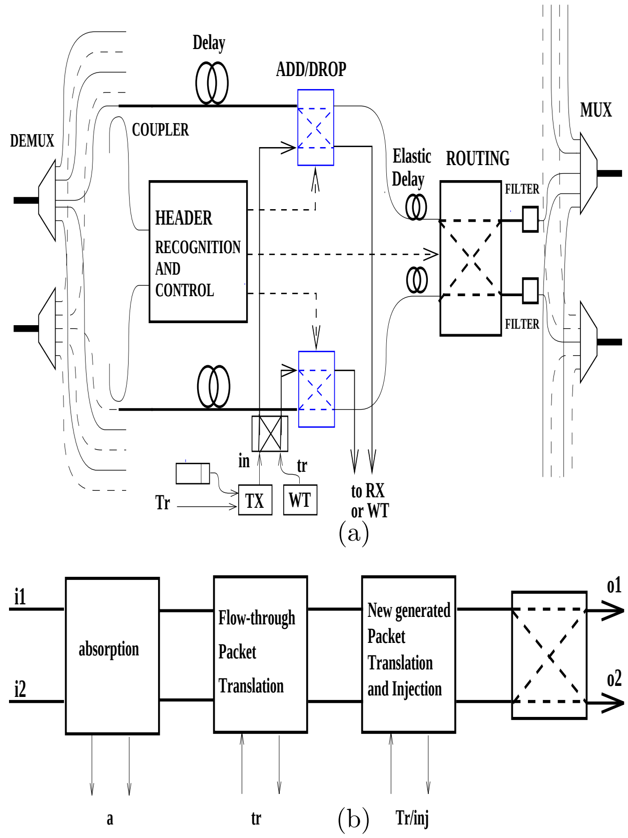


Figure 2: a) Physical and b) logical submodule structure.

traverse for reaching destination. A packet that can take both outputs is called a *don't care packet*, while a packet that has only one preferred output is called a *care packet*. Basically, slots arrive aligned at the submodule's input i_1 and i_2. They can be empty (E), can carry a packet for the node (FN), or a packet that cares to exit on output 1 (C1) or output 2 (C2), or a don't care (DC) packet.

2.1 Traffic Parameters

There are important parameters that determine the teletraffic performance of packet-switched two-connected networks, we briefly mention them.

i) The probability of packet generation g_i [12]. This is the probability of having a new packet ready for transmission. We will assume that the transmitters (TX_i) have no local input queue. New packets arrive in each time slot with probability g_i. The subindex **i** indicates an arbitrary optical channel.

ii) Average number of hops H_i that packets experience before absorption. The probability of packet absorption a_i is related to H_i as: $a_i = 1/H_i$ [3].

iii) The slot utilization u_i, i.e., the probability of finding a packet at the input links of a node at each slot.

iv) Probability of don't care packet, $P_{dc,i}$ represents the probability that a packet entering a node is in a don't care state. Thus, $(1 - P_{dc,i})$ is the probability that the packet is in care state.

v) Network throughput S_i. It is the average number of packets inserted/absorbed per slot in the network at equilibrium on λ_i.

3. Wavelength Translation Routing

In this section we will present the wavelength translation routing we are using for the simulations. We present Monte Carlo simulations results using *uniform* traffic according to the routing method for *regular* cross-connected networks presented in [12] which we extended to wavelength translation. The traffic is said to be *uniform* when 1) all nodes are equally active, generating a new packet at each time slot with the same probability g_i, and 2) the destinations of the packets generated at each node are chosen uniformly among all nodes (except the source) in the network, and independently slot by slot. A network is said to be *regular* when all nodes are topologically equivalent. Regularity and uniform traffic ensure that the traffic flowing through a node is statistically the same for every node [13].

3.1 Translation priority to packets in transit

In this section we consider the case in which packets in transit have translation priority over new generated packets.

We will assume that incoming packets are wavelength translated when there is a local conflict and there is at least one available slot in the remaining submodules. A conflict occurs in a submodule when there are two care packets with the same output preference, for example (C1,C1) or (C2,C2). To solve a conflict, one of the packets in conflict (taken randomly) can be translated to a suitable non-conflictive *empty* or *non-empty* slot of a neighbor submodule as Fig. 3a shows. In case the slot is *empty*, the cell in con-

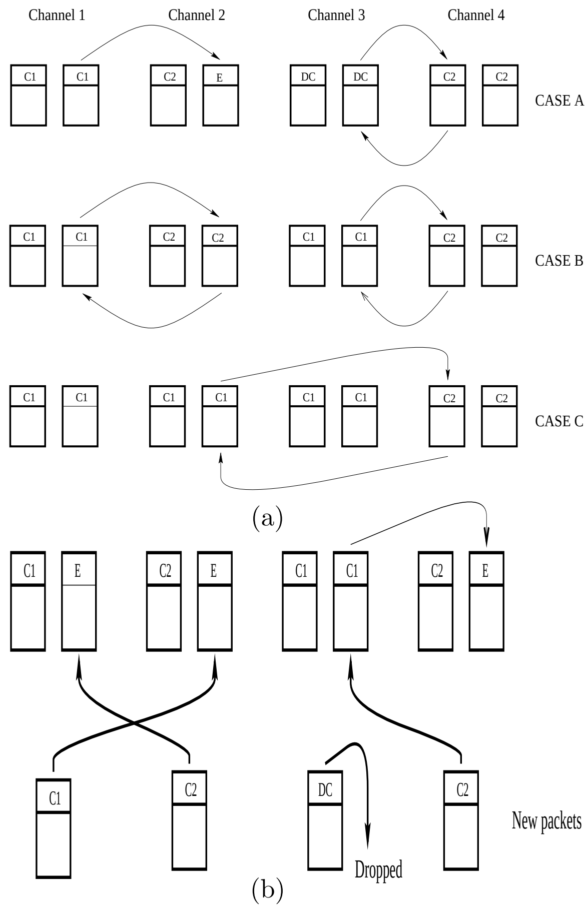


Figure 3: a) Wavelength translation routing of packets in transit; b) Wavelength translation routing of new packets

flict just takes the empty slot as the translation of channel 1 to channel 2 of case A. In case the slot is *non-empty* but can help solve the conflict, of a neighbor submodule, both cells are translated. For example in case A, channel 4 has a conflict and channel 3 has not, however channel 3 can help to solve the conflict, and translation occurs between channel 3 and 4. The result of this translation on channel 3 and 4 is (DC,C2) and (DC,C2) respectively. In case B all the submodules have cells in conflict, however all the conflicts can be solved. Also, in case C all the submodules have cells in conflict, two conflicts can be solved and two conflicts can not, then two packets are deflected (one packet per channel) using the non-priority hot-potato routing algorithm that assigns one at random to the desired output, and deflects the second.

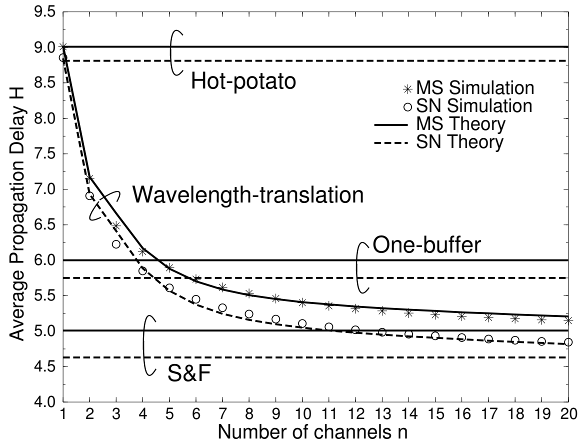
The way one submodule with packet conflict is selected for translation among all the remaining submodules with packet conflict is equally likely. Also, the way one receptive submodule is selected for translation among all the remaining receptive submodules is equally likely. This is to distribute uniformly the packet translations and ensure that the traffic flowing through each node is statistically the same for each wavelength. If one submodule refuses to receive a packet, the submodule with a conflict keeps requesting for translation to the remaining submodules until the packet in conflict is accepted by one submodule. If the conflictive packet is not accepted among all the submodules, then the packet is deflected. Observe that there is no submodule translation priority. Also, each submodule can translate one packet per time slot since there is only one translator per submodule.

The decision for transmission of locally generated packets can be taken after the absorption block or after the translation block. If the decision is taken after the absorption block, then, a new packet per submodule will be injected into the network if there is at least one empty slot and a packet ready for transmission g. However, the injection of new packets is performed after the translation stage. This is to permit first possible translations, if needed, of the packet in transit and then electronic translation/injection of new packets occurs. Observe that the number of empty slots remains constant after the translation block. If both input links contain a flow-through packet not destined to the node, local blocking occurs and the local packet is discarded as Fig. 3b shows. In case an empty slot is used by a flow-through cell that required translation, one of the remaining slots left empty after the translation block will be used by a new packet. Then, it is possible for a new packet to electronically migrate to another submodule for transmission. Also, if there is a conflict between the new packet and the packet in transit, the new packet migrates randomly to a submodule where there is an available non-conflictive empty slot and is transmitted by the corresponding submodule. If the new packet can not find an empty non-conflictive slot, then it is transmitted even though a deflection will occur. However, the electronic translation of new packets decreases the probability of deflection of locally generated packets.

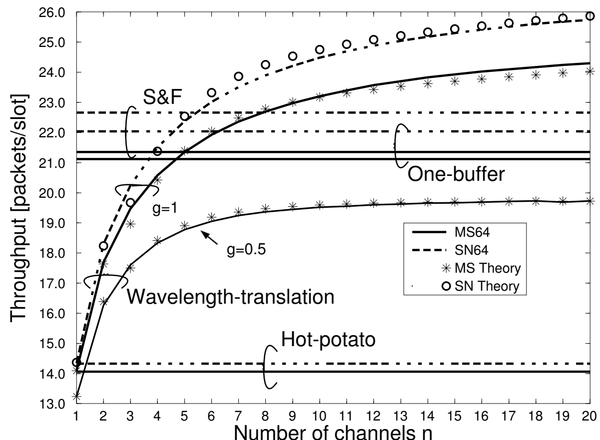
In addition to solving packet conflicts, wavelength translation has the effect of redistributing care packets among the channels used in the network. This redistribution may increase the number of transmissions of locally generated packets if the decision for transmission is taken after the translation block. For example, assume that at the output links of the absorption block of a network with two wavelengths there are (C1,C1) in channel 1 and (E,E) in channel 2. After the translation block the result can be (E,C1) and (C1,E). If the decision for transmission is taken here, two (if any) packets can be transmitted (one per channel) increasing the probability of conflict between locally generated packets and flow through packets. In the case the decision for transmission is taken after the absorption block, just one (if any) locally generated packet can be transmitted and exposed to possible conflict.

4. RESULTS

Fig. 4a shows propagation delay H in number of hops versus number of channels and Fig. 4b shows throughput versus number of channels for ShuffleNet (SN) and Manhattan



(a)



(b)

Figure 4: a) Simulation results of average propagation delay H in number of hops and b) throughput versus number of channels for hot-potato, single-buffer, store-and-forward (S&F) and wavelength translation at g=1. Results are for ShuffleNet (SN64) and Manhattan Street (MS64) networks with 64 nodes.

Street (MS) networks with 64 nodes. Observe that propagation delay and throughput for hot-potato, single-buffer [3], and ideal store-and-forward (S&F [**?**]) keeps constant because channels are independent of each other whereas propagation delay and throughput for wavelength translation routing improves with the number of channels. The reason for this is that packets in conflict have the possibility of being translated to an available non-conflictive slot. The probability of deflection then decreases and the propagation delay improves. Simulations use uniform traffic conditions for each channel. Full load ($g = 1$) is used for each channel in the network, corresponding to the case of a saturated infinite shared input queue at the transmitters (TX_i) [13]. SN64 network performs better than MS64 due to the fact that SN has less traffic congestion because the link load is lower and the packet absorption probability is higher. Simulation statistics were collected for 30000 clock cycles, after discarding 10000 initial cycles to allow for transients to die out.

Results for propagation delay for the case of S&F were obtained computing the average network propagation delay and the average queueing delay for the case when transmission priority is given to the routing buffers [**?**]. If transmission priority is given to the input buffer over the internal buffers, then results of propagation delay are worse than those shown because of saturation of routing buffers at $g = 1$ [**?**].

5. CONCLUSIONS

Wavelength translation in *packet switching* networks with deflection routing has the feature of decreasing the probability of deflection, i.e. improving the throughput and propagation delay depending on the number of channels used in the network. In this paper an optimized wavelength translation routing algorithm has been introduced that minimizes the probability of packet deflection. The average results show that SN has higher throughput and lower propagation delay than MS when wavelength translation is used due to the fact that SN has less traffic congestion. The effectiveness of wavelength translation is quantified. It is verified that under uniform traffic, the use of wavelength translation recovers more than 60% of the propagation delay loss of hot-potato with respect to store-and-forward when five or more channels are used in the network. Also, when five or more channels are used the throughput given by wavelength translation is better than the throughput given by S&F.

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