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Benefits of wavelength translation in datagram all-optical networks

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Indexing term: Optical communication

It is shown that wavelength translation mitigates the blocking of cells substantialy in cross-connected networks. By increasing the number of wavelengths and employing wavelength translation, the probability of deflection can be reduced, which in turn leads to a significant improvement in the teletraffic performance of the network.

Introduction: One of the major problems in multi-wavelength, two connected mesh networks is the blocking of cells at the nodes. Blocking occurs when two competing cells at the input of the node desire the same output. Store and forward, deflection routing and wavelength translation are some techniques which can be used to resolve the conflicts. The teletraffic performance of circuit-switched all-optical and electronic (regenerative) wavelength translation has recently been reported [1, 2]. However, the benefits of using wavelength translation in cell-switched cross-connected networks with deflection routing have not been reported yet. This Letter compares Manhattan Street (MS) and ShuffleNet (SN) networks under wavelength translation in terms of average propagation delay and throughput. We present the limit of operation based on a uniform traffic scenario. It is shown that wavelength translation significantly solves the blocking of cells. Results indicate that the probability of deflection can be reduced substantially by increasing the number of wavelengths and employing wavelength translation which, in turn, significantly improves the teletraffic performance of the network.

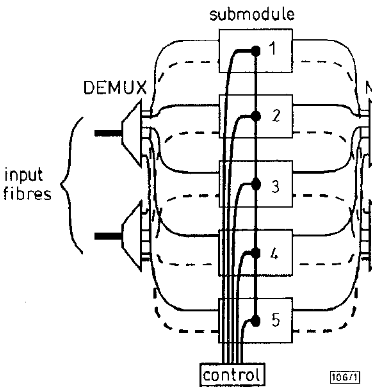

Fig. 1 *Architecture of wavelength translation node*

All submodules are interconnected and there is a central control unit which decides transmission operations

Principle of operation: The node under consideration is composed of a stack of submodules, one per wavelength as shown is Fig. 1. All the submodules are interconnected and there is a central control unit which decides the routing operations. The wavelengths from the input fibres are spatially demultiplexed and sent to the appropriate submodule. Cells from the submodules are finally remultiplexed onto the output fibres. The logical flow of submodule operations is *absorption*, *translation* of flow-through cells, electronic *translation/injection* of new generated cells, and *routing* [3]. The absorption operation removes cells destined for the node. It is assumed that there is one receiver per input wavelength, so that all cells destined for the node can be removed. The wavelength translation operation has the task of rearranging the cells on the various wavelengths so as to eliminate as many wavelength conflicts as possible at its output. Wavelength translation priority is given to cells in transit in order to minimise deflections of flow-through cells. Then, electronic wavelength translation and injection of newly generated cells occurs. Finally, the routing operation is performed by 2×2 switches, one per wavelength, that routes cells out with a simple hot-potato, random contention-resolution algorithm.

Basically, slots can be empty (E), or they can carry a cell for the node (FN), or a cell that cares to exit at output 1 (C1) or at output 2 (C2), or they can carry a don't care (DC) cell. A conflict occurs in a submodule when there are two care cells with the same output preference, for example (C1, C1) or (C2, C2). A conflict selected at random from the pool of conflicts is resolved by taking one of the cells and translating it to a suitable non-conflictive *empty* or *non-empty* slot of a neighbouring submodule randomly selected. Therefore, there are many possibilities to resolve a conflict [3], but the most important is that which resolves conflict of kind (C1,C1) in one submodule by using another conflict of kind (C2, C2) in another submodule, possibly as a result of the translation (C1, C2) and (C1, C2). In the case of a local conflict, where there are no available alternative slots, one of the cells in conflict is randomly chosen for deflection.

The decision for transmission is taken after the absorption operation; then, a new cell per submodule will be injected into the network if there is at least one empty slot and a cell ready for transmission. If there is a conflict between the newly generated cell and the cell in transit, the new cell migrates randomly to a submodule where there is an available non-conflictive empty slot, and is then transmitted by the corresponding submodule. If the new cell cannot find an empty non-conflictive slot, then it is transmitted even though a deflection will occur. Something could be gained by using a hold-up technique [4]; i.e. avoid injecting a new cell whenever such injection causes a deflection.

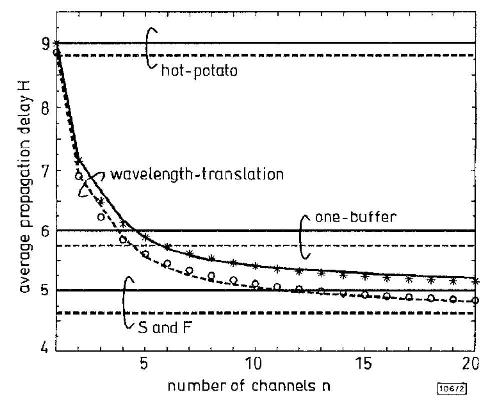

Fig. 2 *Results of average propagation delay H in number of hops against number of channels n for hot-potato, single-buffer, store-and-forward (SandF) and wavelength translation at g = 1*

Results are for ShuffleNet (SN64) and Manhattan Street (MS64) networks with 64 nodes
* MS simulation, O SN simulation
——— MS theory, - - - - - SN theory

Results and discussion: Monte Carlo simulation results are presented to validate the accuracy of an analytical model [5] using *uniform* traffic according to the routing method for *regular* cross-connected networks presented in [6], which we have extended to wavelength translation. Fig. 2 shows propagation delay H in number of hops against number of wavelengths n for ShuffleNet (SN) and Manhattan Street (MS) networks with 64 nodes. We can observe that the propagation delay for hot-potato, single-buffer [7], and ideal store-and-forward (S&F) [3] remain constant because channels are independent of each other, whereas the propagation delay for wavelength translation routing improves with the number of channels. The reason for this is that cells in conflict have the possibility of being translated to an available non-conflictive slot on another wavelength. The probability of deflection then decreases and the propagation delay improves. Simulations use uniform traffic conditions for each channel. Full load is used for each channel in the network. SN64 performs better than MS64 due to the fact that SN has a smaller diameter [7] and thus the link load is lower. Simulation statistics were collected for 30,000 clock cycles, after discarding 10,000 initial cycles to allow transients to die out.

Fig. 3*a* and *b* shows results (for MS and SN, respectively) for the average propagation delay against throughput per channel *S*, i.e. the average number of cells inserted/absorbed per slot per

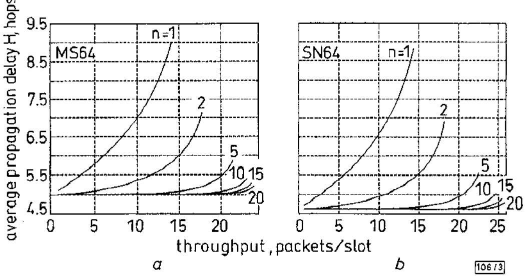

Fig. 3 *Results of average propagation delay H against throughput*

a For MS
b For SN
Parameter *n*: number of channels

wavelength. Wavelength translation in *cell 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 (*n*) in the network. Observe how quickly throughput and propagation delay improve with the number of channels used. As in [1], as a measure of the benefit of wavelength translation for cell switching, we define the *gain* as the increase in throughput for the same average propagation delay:

$$Gain = \left| \frac{S(n>1)}{S(n=1)} \right|_{H>H_{min}} \quad (1)$$

where $S(n = 1)$ represents the throughput per channel of a network without wavelength translation, and $S(n > 1)$ represents the throughput per channel of a network with wavelength translation.

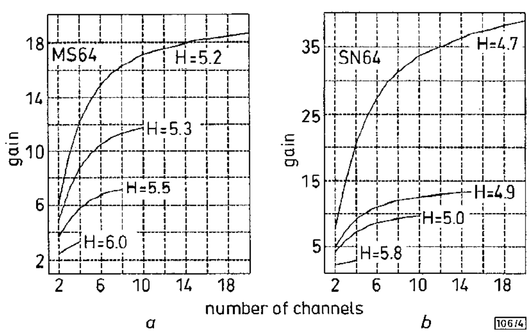

Fig. 4 *Results of gain against number of channels n*

a For values of H = 5.2, 5.3, 5.5, 6.0
b For values of H = 4.7, 4.9, 5.0, 5.8

H_{min} is the minimum propagation delay. Fig. 4*a* and *b* shows curves of *gain* for fixed values of H = 5.2, 5.3, 5.5, 6.0 for MS, and H = 4.7, 4.9, 5.0, 5.8 for SN. As H decreases, the *gain* increases depending on the number of channels used, but this comes at the expense of increased hardware. As a practical example, note that when the number of wavelengths increases from 1 to 10 in an MS64 network, the throughput per wavelength increases from 14.1 to 23.5 at full load, which is a significant improvement. The largest relative improvement is obtained when increasing from one to two wavelengths, as is the case when considering buffering in deflection routing [7].

Conclusion: One of the major problems in multi-wavelength two connected mesh networks is the blocking of cells at the nodes. Blocking occurs when two competing cells target the same output. This Letter shows that wavelength translation significantly mitigates the blocking of cells, reduces the probability of deflection substantially by increasing the number of wavelengths, improves significantly the teletraffic performance of the network and, therefore, the cell inter-arrival time jitter (delay jitter) can be reduced. Results indicate that at full load, the use of wavelength translation recovers > 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.

 2 July 1997
Electronics Letters Online No: 19971040

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Investigation into the robustness of 100Gbit/s (5×20Gbit/s) regenerated WDM soliton transoceanic transmission to line breaks and repairs

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Indexing terms: Solitons, Optical communication, Wavelength division multiplexing

The authors analyse the effect of line repairs after cable breaks in transoceanic regenerated WDM soliton systems. A theoretical 5×20Gbit/s WDM system with 50km/350km amplifier/regenerator spacing is used as a test example. The system robustness to the insertion of up to 10km of repair fibre jumper corresponding to high-depth breaks is numerically demonstrated.

So far, two solutions for combining the advantages of wavelength-division multiplexing (WDM) with optical regeneration by synchronous modulation in undersea transmission systems [1] have been proposed: either regenerate the channels separately within a