Node Optimisation of a Multirate Upgradeable OADM Network Based on a Parallel Waveband-switching Architecture

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Abstract *We optimise the design of a new parallel waveband-switching OADM to significantly reduce the node complexity. Case studies are provided for an 8-node network operated at 10 Gb/s and then upgraded to 40 Gb/s.*

Introduction

In next-generation high-capacity wavelength division multiplexed (WDM) transport networks, switching each individual wavelength at each node could result in tremendous increase in the complexity and cost of the network. Waveband switching [1][2] has been proposed to effectively reduce the connection ports in the network nodes and therefore the cost. The key idea is to group multiple wavelengths to a waveband so that switching can be performed at the waveband level. Previous proposals of waveband switching are based on a cascade architecture that employs waveband and wavelength demultiplexers together with fibre switches in a serial configuration. Recently a blocker-based parallel architecture was proposed and experimentally demonstrated [3]. The parallel waveband switching architecture shows some significant advantages: it does not require any space switches thus saving node size and cost; the parallel architecture reduces loss and filtering penalties as seen in the cascade architecture; and the blocker-based device supports data rate upgrade *without* the need for replacing any optical components, which is not possible with previous proposals.

Fig. 1 shows the hierarchical optical add-drop multiplexing (OADM) node architecture in a parallel configuration that consists of waveband and wavelength levels to provide different granularities. Incoming signals are power-split and fed into the waveband and wavelength OADMs, which operate in a broadcast and select manner based on blocker filters. The wavelength OADMs handle traffic at the wavelength level. Once bundled traffic streams fill a waveband, they are directed through the waveband OADM. The coarse granularity in the waveband OADM helps reduce the node complexity, while the blocker-based wavelength OADM provides flexible bandwidths for different data rates without the upgrade cost in optics. Such an OADM network was experimentally shown [3] to be capable of supporting 10- and 40-Gb/s data rates. However, a problem that remains to be solved is the optimisation of the node design to minimize the number of wavelength OADMs needed and the associated control complexity.

In this paper we study the node optimisation by proposing an efficient heuristic algorithm. The results show that the required number of wavelength OADMs is at most one in the case studies using the proposed algorithm, which outperforms a sequential waveband assignment algorithm. As an example, we investigate an 8-node ring network operated at 10 Gb/s and then upgraded to 40 Gb/s.

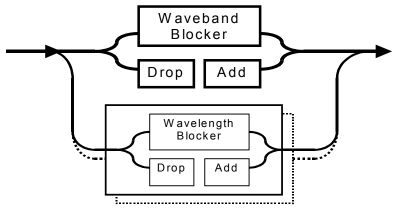

Fig. 1: The hierarchical OADM consisting of wavelength and waveband levels to reduce the complexity.

Node optimisation

As shown in Fig. 1, there could be one or more wavelength OADMs attached with a waveband OADM depending on the traffic pattern and the wavelength assignment algorithm used. The goal of this study is to minimize the number of wavelength OADMs in each node, and the corresponding total control elements since they translate to the device size and cost in most cases. The number of control elements in a node is defined as the number of wavebands plus the product of the number of wavelengths per waveband and the number of wavelength OADMs.

The bandwidth status of a node can be modelled as in Fig. 2. The total bandwidth is C in the number of wavelengths, which can be divided to N wavebands. Each waveband contains C/N wavelengths. A wavelength OADM is assigned to a node if there are wavelengths to drop. However once the aggregated wavelengths fill a waveband they are dropped by the waveband OADM. Add function is simply realized by using passive combiners. Therefore we focus on destination grouping of wavelengths as the wavelength OADMs are only required where there is traffic to drop. In the following analysis we do not consider space reuse of the wavelengths, since with the recent advance of high-spectral efficiency techniques the number of available wavelengths can

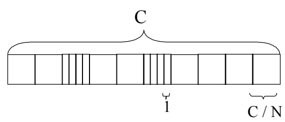

Fig. 2: Bandwidth modeling in the simulation. In this case there are two wavelength OADMs in the node.

be significantly increased to 320 for example [4].

We propose a heuristic algorithm and compute the required numbers of wavelength OADMs and the control elements in the network given the traffic demand. We then compare the performance of the proposed algorithm with a sequential wavelength assignment algorithm as well as a conventional re-configurable OADM. The proposed algorithm is outlined as follows:

For the node with the maximum traffic to drop
while (the node has one or more waveband traffic to drop, and if there is an empty waveband) **do**
    drop one waveband of traffic to the empty waveband
end while
while (there is remaining traffic to drop in the node, and there is a waveband with minimum capacity that fits the remaining traffic) **do**
    drop the remaining traffic to this minimum waveband and add a wavelength OADM
end while
while (there is still remaining traffic to drop in the current node, find a waveband with the maximum bandwidth available) **do**
    drop traffic to this waveband and add a wavelength OADM
end while
Repeat the above process for the rest of the nodes

In the following section we study the performance of the proposed algorithm and compare it with an algorithm that assigns the drop traffic to wavebands in a sequential manner regardless of the traffic amount.

Case studies

We assume all-to-all traffic in the simulation. To include as many practical scenarios as possible, we assign the node-to-node traffic demand with a random number having an exponential distribution with a mean value of D (wavelengths) for all node pairs. We run the simulation 100 times and average the results. Optimisation of the node design can be achieved by varying the number of wavelengths per waveband (coarse granularity).

We first study an 8-node OADM network with a 320x10Gb/s capacity. The total capacity C in number of wavelengths is 320, and the average D varies from 1 to 4 λs. Fig. 3a and 3b show the proposed algorithm outperforms the sequential algorithm in the average numbers of control elements and the wavelength OADMs required in a node, respectively. Note that the number of control becomes large when the granularity is the finest or the coarsest. This can be explained as such: in one extreme case where the waveband granularity becomes 320, only one wavelength OADM covering the whole bandwidth is needed; while in another extreme case only one waveband OADM is needed that has single-wavelength granularity. Minimum number of control elements is obtained when the waveband granularity is properly chosen. We further note that at most one wavelength OADM is required in a node based on the proposed algorithm, since it only needs to handle the

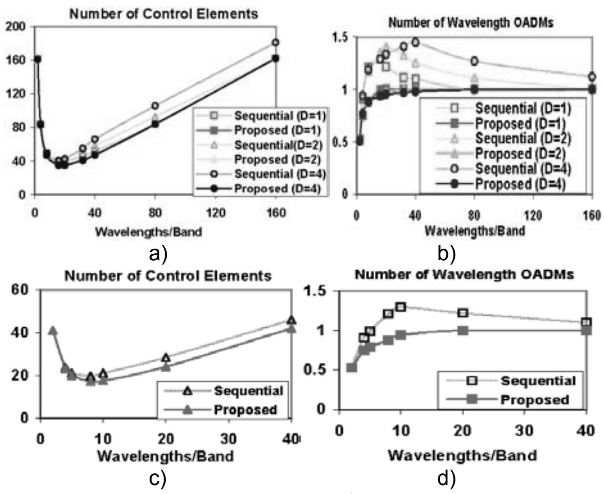

Fig. 3: a) The average number of control elements per node with different traffic demands, b) the number of wavelength OADMs, c) and d) are the corresponding requirements for the network when it is upgraded to 40 Gb/s

remaining traffic of less than a waveband. In Fig. 3b the less requirement on the number of wavelength OADMs at lower wavelength/band regime can be attributed to the higher probability that the drop traffic happens to fill an integer multiple of wavebands, thus the wavelength OADM is not needed.

We also consider the application scenario where the average pair-wise traffic demand increases to 40 Gb/s, and network terminals are upgraded to 40-Gb/s. The number of wavelengths available is 80 based on a previous experimental demonstration [5]. The reduced number of wavelengths helps simplify the node control and network management. In the 40-Gb/s case as shown in Fig. 3c and 3d, similar conclusions can be drawn. Tab. 1 is a comparison of the network configured in the optimum condition based on the two algorithms, and a conventional re-configurable OADM network that does not employ waveband switching. The optimised OADM network possesses a much-reduced complexity, which translates to lower cost and smaller size of the nodes.

Tab. 1 A comparison of the total # of control elements

	10 G (D = 4 λs)	40 G
Proposed Algorithm	280	136
Sequential Algorithm	325	157
No waveband switching	2560	640

Conclusions

We have studied a parallel waveband-switching OADM network that can significantly reduce the node complexity and therefore the cost and size of the device. We propose a heuristic algorithm to obtain the optimum design parameter. Case studies are provided at 10 Gb/s and 40 Gb/s, respectively.

Acknowledgement

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