Multi-Granular Optical Path Networking Technologies

Ken-ichi Sato

Nagoya University, EECS, Furo-cho, Chikusa-ku, Nagoya, 464-8603 Japan

Abstract: This paper investigates the prospects and challenges of hierarchical optical path networks. The key enabling technologies are demonstrated that include hierarchical optical path network design algorithms and a newly developed waveband filter.

Keywords: Optical Path, Waveband, Photonic Network

Introduction

Optical path technologies [1] exploit wavelength routing, enhance node throughput and reduce network cost. ROADMs have recently been introduced and a large scale deployment is being conducted in North America and Japan. GMPLS controlled OXCs [2] have also been used to create nation-wide testbeds. New broadband services including IP TV and high definition TV are now imminent and further traffic expansion is expected in the near future. This will result in a significant increase in the number of wavelength paths that should be cross-connected at nodes, and hence optical node throughput must be enhanced. One important technology that can resolve this problem is the introduction of wavebands and hierarchical optical path cross-connects (HOXCs) [3], [4]. This paper explores recent advances in the research and development of hierarchical multi-layer photonic networks [5].

2. Hierarchical Optical Path Network Technologies

2.1 Hierarchical optical path

One of the salient features of optical paths is that switch complexity does not depend on the bit rate carried by an optical path. Hierarchical optical path arrangement is a natural approach when traffic increases. Some optical switches support optical signals with a wide range of wavelengths; this means that the same switches can be used for switching multiple optical paths. Switching multiple optical paths or switching wavebands can reduce total switch size (necessary number of cross-connect switch ports) substantially. This mitigates one of the major present challenges in creating reliable large-scale optical cross-connects. The ratio of total cross-connect switch ports, multi-layer/single layer, is expressed as [6];

$$\frac{(M+(L+1)+M)/\alpha}{M\times(L+1)} \quad [1]$$

where M is the number of optical paths per waveband, L is the number of average hops of each wavelength/waveband path (Fig. 1). The hierarchical path structure can degrade link utilization, and this effect can be strengthened by the additional complexity created by the waveband/wavelength assignment problem. The degree of link utilization degradation is represented by parameter α. This problem can be mitigated by the development of effective network design algorithms as explained in 2.2. When M, L, and α are 16, 6, and 0.9, respectively, the ratio is 0.39; that is, the reduction in total cross-connect switch port number attained by introducing multi-layer optical path cross-connects is about 60 percent.

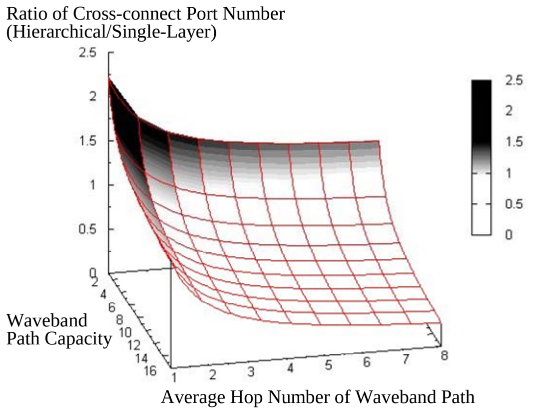

Figure 1 Ratio of required optical ports between hierarchical and single-layer networks

2.2 Hierarchical Optical Path Network Design

The waveband routing and waveband assignment problem of multi-granular optical networks is a generalization of the single-granular optical network design problem. Analogous to the single-granular case [7], the problem is inherently NP-complete and can equivalently be formulated as a combinatorial optimization problem that targets minimizing the total number of optical ports of cross-connect systems [8], [9] or maximizing the utilization of fiber capacity [10]. The number of binary variables in the combinatorial optimization problem explosively increases with network size. This characteristic makes the problem computationally impossible to accurately solve for large networks. Indeed, previous publications that tackled the combinatorial optimization formulation gave up on exact solutions and provided alternative algorithms based on heuristics or relaxation instead.

A heuristic algorithm that is based on a different strategy was recently proposed [11], details and a performance analysis are given in [12]. We must search for a set of wavelength paths that are efficiently carried by a waveband path and can sufficiently occupy the waveband path. A space, named “s-d (source-destination) Cartesian product space,” is newly defined to evaluate ‘closeness’ among wavelength paths. Figure 2 shows the cost reduction possible with the multi-layer optical path network in a comparison against a single layer one for a 9x9 polygrid network with randomly distributed wavelength path demands. The vertical axis of the graph is relative cost normalized by the cost of a single layer optical network designed by locating the shortest paths with re-routing of wavelength paths in sparsely used fibers. End-to-End represents the method that accommodates wavelength paths within a waveband path that has the same source and destination as the wavelength paths. With the proposed method [11], [12], the cost reduction is greatly enhanced even for small traffic demands. The investigation provides not only performance comparisons of different methods, but also clarifies the applicability of the multi-layer optical path network.

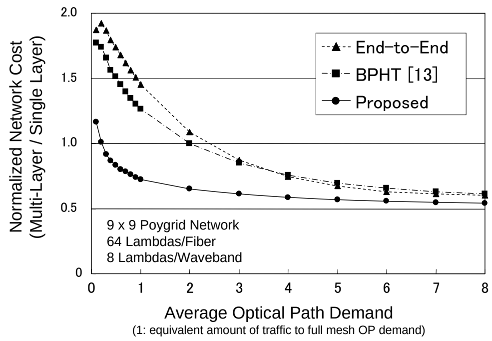

Figure 2 Comparison among proposed and conventional algorithms (end-to-end and BPHT)

2.3 Waveband Multiplexers/Demultiplexers

Waveband multiplexers/demultiplexers (WB MUX/DEMUX) are one of the key components in developing HOXCs. A recent our proposal [14] uses concatenated cyclic AWGs to realize the WB MUX/DEMUX (see Fig. 3). The key to the WB MUX/DEMUX is that it retains multi/demultiplexing granularity at the individual wavelength channel level while outputting WBs at different ports. This means that conventional individual wavelength channel AWGs can be utilized. The salient feature of the WB MUX/DEMUX is that it can accommodate multiple input fibers simultaneously and demultiplex each band to different output ports, which makes it very effective in reducing the cost and size of WBXC (see Fig. 4). In [14], possible arrangements of two-AWG concatenation were elucidated. Connection patterns that eliminate all waveguide crossing, which suits monolithic realization, were demonstrated, and those that maximize MUX/DEMUX port utilization efficiency were also provided. The device was suucssfully fabricated using silica PLC (Planar Lightwave Circuit) technology on a chip; chip size was 3 x 7 cm as shown in Fig. 4. The device was designed to accommodate forty 100-GHz spaced channels on an ITU-T grid (8 channels x 5 wavebands) per fiber and six input fibers [15]. The measured average fiber-to-fiber insertion loss was 3.08 dB. The average coherent crosstalk was less than -39.5 dB when six input fibers were connected simultaneously.

3. Conclusion

The introduction of wavebands was shown to reduce optical switch size at cross-connects. Network design complexity was shown to be effectively resolved by a newly developed hierarchical optical path network design method. A new waveband MUX/DEMUX was also demonstrated. It is shown that the hierarchical path arrangement is an efficient and effective means to create large-throughput networks.

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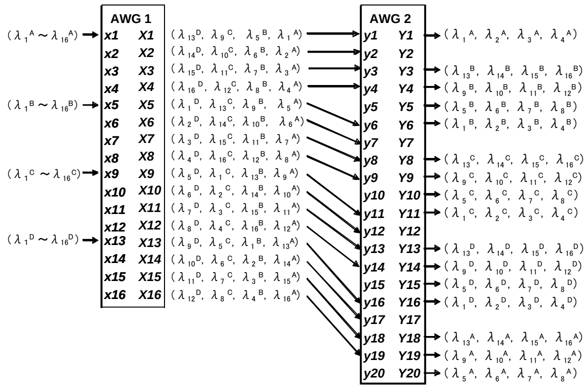
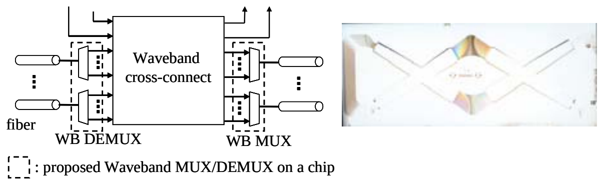


Figure 3 An example of WB MUX/DEMUX with continuous waveband arrangement



(a) (b)

Figure 4 (a) Structure of an all-optical packet router, and (b) fabricated WB MUX/DEMUX chip using PLC technology

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