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# Large capacity optical networks applying multi-stage hetero-granular optical path routing

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ABSTRACT

We propose a novel scalable large-scale OXC architecture with a two-stage hetero-granular optical path switching mechanism based on a combination of different granular optical selective switches and an appropriate network design algorithm that can make the best use of the proposed OXC architecture for building cost-effective large capacity optical networks. Simulation results verify that our proposed solution can offer a significant overall network cost reduction. The cost efficiency of networks based on the architecture is also investigated in relation to switching component cost and different network parameters.



## 1. Introduction

Recent advances in WDM techniques and related optical node technologies have significantly enhanced the capacity of backbone and metro networks [1,2]. Optical wavelength routing networks employing reconfigurable optical add/drop multiplexers (ROADMs or OXCs) have been deployed worldwide to meet the current rapid traffic expansion spurred by the penetration of broadband access including ADSL and FTTH [3]. In the near future, further Internet traffic growth is expected due to the introduction of new wavelength services [4–7] and video-centric services including ultra-high definition TV (up to 60–72 Gbps/ch) and 3D-TV [8]. The need for cost-effective and low power consumption bandwidth-abundant networks that can support the ever-increasing traffic is becoming more and more critical [3,9]. Next generation ROADMs/OXCs are required to be able to support the substantially increased number of fibers on each link connecting adjacent nodes [10]. The development of large scale ROADMs/OXCs, therefore, will be critical [11,12]. Most existing ROADMs/OXCs are developed on wavelength selective switches (WSSs) [13–15] and to create a larger scale ROADM/OXC, higher port count WSSs are necessary. The highest WSS port count commercially available at present is 20+ and it seems unlikely that the port count can be substantially increased cost-effectively. The straightforward way to enlarge the port count is to cascade WSSs. This, however, requires a considerable number of WSSs per input fiber and the loss is also increased. For example, if we use $1\times9$ WSSs (the most commonly utilized size at present), the two stage architecture yields $1\times81$ WSS, however, it requires ten $1\times9$ WSSs per incoming fiber. Hence to develop an $81\times81$ OXC with $1\times9$ ($1\times20$) WSSs, the total required number of WSSs becomes 1620 (972), since the broadcast-and-select architecture can no longer be applied; instead, the route-and-select architecture needs to be utilized. New approaches that enable cost-effective and scalable large-scale OXCs are thus indispensable.

It has been found that ensuring perfect routing capabilities in the targeted large-scale OXCs that support an increased number of fibers between adjacent nodes is not always necessary [11]. For example, wavelength paths in an input fiber that need to be delivered to one of the adjacent nodes, do not always need to be distributed to all the parallel output fibers on the link to the node. It is

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expected that wisely setting an intra-node wavelength routing limitation, i.e. a restriction on output fiber selection of each link for incoming wavelength path groups (wavebands) in which a group of wavelength paths, a waveband, cannot be routed separately to more than one selectable output fiber on each link, can reduce the necessary hardware scale. This approach will be effective if the increase in the number of necessary fibers on the link is kept to a small number. Such a routing scheme can be realized cost-effectively thanks to the recent development of waveband selective switches (WBSSs), an extension of WSSs, which can handle optical paths at the waveband granularity level. Advances in WSS and WBSS systems have been recently presented [13–17] and the world's first $1\times5$ and $1\times10$ WBSS prototypes, monolithically fabricated on a PLC chip, have been successfully developed [16,17]. The developed $1\times10$ WBSS [17], which is composed of ten $1\times16$ optical switches and eleven $1\times10$ cyclic AWGs, is integrated on a $82\times52$ mm$^2$ PLC chip. It is expected in the future that the simple and compact implementation of the WBSS devices will realize further integration; for example, using silicone photonics technologies to integrate multiple devices on a chip will yield higher cost effectiveness than WSSs. The WSS or WBSS-based architectures offer the considerable advantage of modular growth capability; expanding the node scale requires only the addition of necessary WSSs or WBSSs and hence, incremental cost-effective expansion is possible.

Based on these observations, we propose a novel large-scale OXC architecture that utilizes a two-stage multi-granular optical path routing mechanism made possible by the combination of optical selective switches (i.e. WSSs/WBSSs) for creating cost-effective large capacity optical networks. The proposed OXC architecture has two variants. We first evaluate the required hardware scale of the proposed OXC architectures and clarify the effective cost bound of WBSSs in a comparison with conventional WSS-based OXCs. We then develop an appropriate network design algorithm that considers the intra-node routing restrictions to make the best use of the proposed OXC architectures. Simulations prove that a significant total network cost reduction can be obtained by applying our proposed network design algorithm together with the developed OXC architectures. Implementing the developed OXC architectures can effectively reduce the node scale (i.e. numbers of WSSs, the key factor that determines the complexity, reliability and cost of the node system). Finally, the impact of important network parameters including waveband capacity and network size on the achieved network cost is also investigated. The related investigations of this work, a node scale estimation given the assumption of 3D MEMS-based WSSs/WBSSs [18] and a preliminary network design proposal for the first variant of the proposed architecture [19], have been presented at international conferences.

## 2. Large-capacity optical cross-connects utilizing 2-stage multi-granular optical path switching

### 2.1. Proposed large-scale OXC architecture

We propose a large-scale OXC architecture that employs a 2-stage multi-granular optical path switching mechanism that can be implemented by combining WSSs and WBSSs. The proposed architecture utilizes wavelength level switching (1st-stage) and wavelength path group switching (2nd-stage). In the first switching stage, optical paths are selected and switched at the wavelength level by WSSs, and then in the second stage, they are routed in waveband paths, groups of wavelengths, to the appropriate output fibers on an output link connected to one of the adjacent nodes by using WBSSs. Each input fiber has its own 2-stage switching module; a WSS at the first stage and several WBSSs in the second one for output fiber connection. Based on the output arrangement on WBSSs, there are two variants of the proposed node architecture, which are shown in Fig. 1. The first variant is the node-first (denoted as NF) architecture; it dedicates each WBSS to one adjacent node. The other is the fiber-first (called FF) architecture; it utilizes each WBSS for only one fiber index of all links to adjacent nodes. Hereafter, we investigate and clarify the efficiency of both variants in a comparison with conventional WSS-based OXCs.

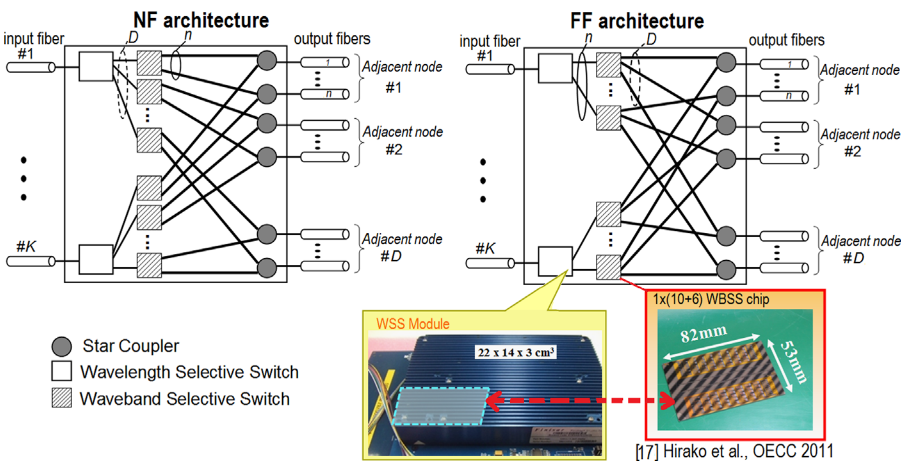


**Fig. 1.** Proposed OXC architectures with 2-stage routing mechanism.