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A routing and wavelength assignment scheme considering full optical carrier replication in multi-carrier-distributed optical mesh networks with wavelength reuse

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ABSTRACT

This paper proposes a routing and wavelength assignment (RWA) scheme that considers full optical carrier replication to minimize the number of required wavelengths for wavelength-reusable multi-carrier-distributed (WRMD) mesh networks. Unlike the conventional wavelength division multiplexing networks where each node contains multiple laser diodes, the WRMD networks use a light source, called the multi-carrier light source, to ease the difficulty of controlling many light source devices. The optical carrier replication at any node of optical carrier or any end node of lightpath, called full optical carrier replication, improves the performance of the conventional schemes, which do not consider full optical carrier replication. This paper first formulates the RWA problem considering full optical carrier replication as an integer linear programming problem that minimizes the number of required wavelengths to satisfy the given lightpath setup requests. A heuristic RWA scheme is then proposed to solve the RWA problem in practical times. Simulation results show that our proposed heuristic RWA scheme for the WRMD network achieves a near-optimum number of wavelengths. In addition, it is able to reduce the number of required wavelengths for lightpath establishment, compared to the conventional scheme.

1. Introduction

With the rapid growth of both the Internet and available bandwidth, wavelength division multiplexing (WDM) technology has been as a promising candidate for the next generation network (NGN). WDM technology has the potential to meet rising demands for high bandwidth and low latency communication [1]. Conventional WDM networks attempt to meet the explosive demand for network bandwidth by using more laser diodes (LDs) to provide sufficient wavelengths. This will increase network energy consumption and implementation cost. Moreover, the complexity of optical carrier management increases with the number of wavelengths [2]. In other words, it will be difficult to adequately control the wavelengths of huge numbers of LDs, since each wavelength of each LD has to be adjusted individually to satisfy the extremely narrow channel spacings demanded.

A multi-carrier-distributed optical network with wavelength reuse capability [3,4] was introduced as a solution. This network is called the wavelength-reusable multi-carrier-distributed (WRMD) network. As shown in Fig. 1, the WRMD network places a multi-carrier light source (MCLS) in an MCLS node, as the communication light source device. A number of MCLSs are reported [5,6], and high-capacity, 2000 km long-distance WDM transmission experiments using MCLS are demonstrated [7].

In general, the MCLS node consists of an MCLS, wavelength selective switch (WSS), and multiple wavelength converters (WCs) to avoid wavelength collisions in the network. The MCLS is able to generate stable and multiple optical carriers at the same time over long periods [5–9]. The generated multiple optical carriers are utilized not only as distributed carriers of the network, but also continuous-wave (CW) probes of the WCs. The individual wavelengths are used as optical carriers. The MCLS generates the optical carriers and passes them to all requesting source nodes for lightpath establishment. By replacing many widely dispersed LDs with the single MCLS, the difficulties posed by monitoring and controlling a large number of LDs are greatly simplified.

Each node in the WRMD network, which is called a regeneration point [3], consists of an optical add-drop multiplexer (OADM), an

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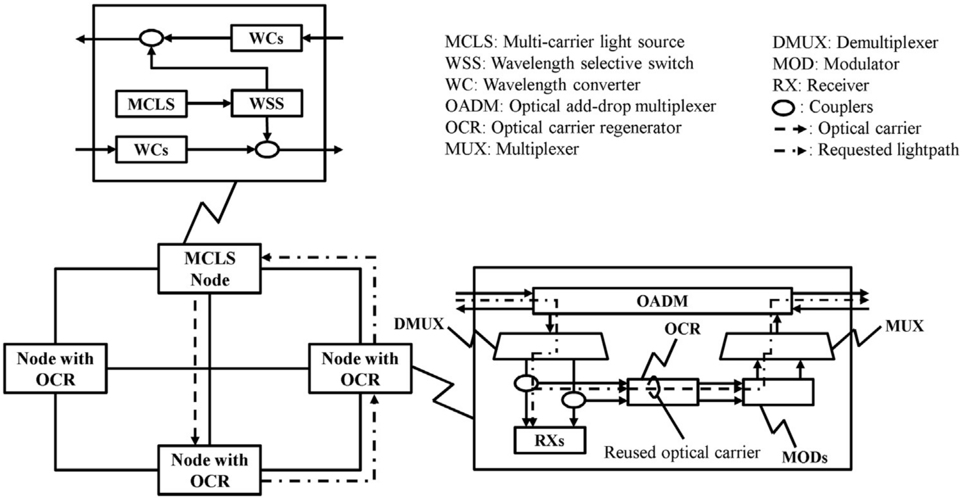

Fig. 1. WRMD network architecture.

optical carrier regenerator (OCR), multiplexers (MUXs)/demultiplexers (DMUXs), external modulators (MODs), and receivers (RXs). The OCR allows the nodes to reuse a wavelength to satisfy multiple disjoint lightpath requests. However, the number of transmission spans and the transmission length limit the available number of OCR nodes [7]. The scalability of the WRMD ring network is experimentally investigated in [7], while the WRMD mesh network is assessed from a transmission point of view in [10].

Considering the WRMD network architecture, the latency of the packet sent by the regeneration point is neither different from that of the conventional WDM nor reconfigurable optical add/drop multiplexer (ROADM) node. The analysis of cost and power consumption was presented in [2]. It observes that the WRMD network has lower cost and power consumption than the conventional WDM network when the number of wavelengths becomes large. For large-scale networks, which must support an increasing number of lightpaths, there may be a need to have more than one MCLS node to use wavelength resources efficiently.

Wavelength management in the WRMD network is more complex than that in the conventional WDM network, since the routing and wavelength assignment (RWA) schemes in the WRMD network must take into account both optical carrier connections and requested lightpaths while maximizing the reuse of the optical carrier connections. An optical carrier connection connects the MCLS node and a requested lightpath, or between two requested lightpaths. For this reason, an RWA scheme satisfying these constraints is needed for the WRMD network. This paper assumes that lightpath setup requests are statically given in advance, and focuses on RWA schemes under the static scenario. The RWA problems in the WRMD network are often decoupled into two separate subproblems in order to make the solution more tractable. The first subproblem is routing, which can be classified into fixed routing and alternate routing. The second subproblem is wavelength assignment, which obeys the following three rules:

- Each requested lightpath uses only one wavelength, as shown in Fig. 2(a),
- Each requested lightpath uses an optical carrier generated by an MCLS node or a reused optical carrier from another established lightpath, as shown in Fig. 2(b),
- To avoid wavelength collision, optical carriers and requested lightpaths on the same fiber link must be assigned different wavelengths, as shown in Fig. 2(c).

To support the network scalability, the RWA scheme for the WRMD network needs to use of the available resources efficiently, e.g., optical

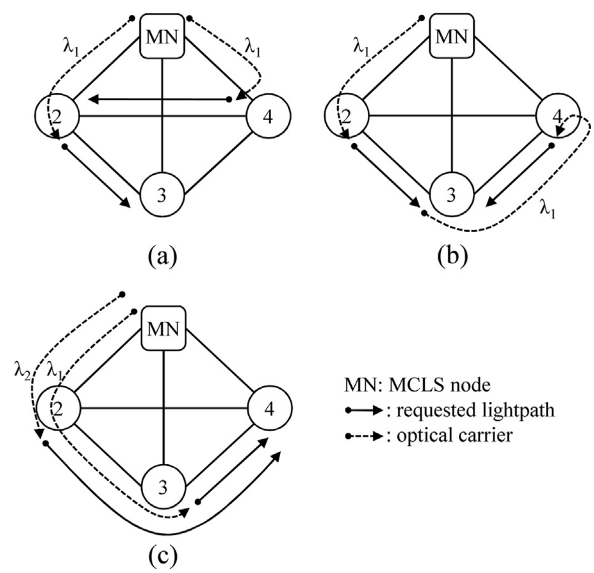

Fig. 2. WRMD mesh network rules and conditions.

carrier replication for lightpath establishment. There are two works considering the optical carrier replication [10,11]. Both works take into account the optical carrier replication only at any MCLS node or any regeneration point. In other words, the optical carrier can be split into several other optical carriers at any MCLS node or any regeneration point, and each optical carrier is used to establish another requested lightpath. Since each node in the WRMD network is equipped with the OCR, it is possible to replicate optical carriers at any node of optical carrier or any regeneration point, which is called full optical carrier replication, to reduce the number of required wavelengths. Note that there is no additional hardware cost on full optical carrier replication. The optical power of the carrier needs to be considered for full optical carrier replication. As each node includes both pre- and post-amplifiers, the optical power loss of the split carrier signal can be compensated at each node. An optical amplifier in the WRMD network is able to control its amplifier gain. However, no study has addressed the use of full optical carrier replication in the WRMD mesh networks.

This paper proposes an RWA scheme that considers full optical carrier replication for WRMD mesh networks to minimize the number of required wavelengths for lightpath establishment. A heuristic RWA scheme is introduced to solve the RWA problem in this paper. This scheme consists of a routing algorithm and a wavelength assignment algorithm, which are run separately. We introduce lightpath selection