Network Performance Simulation of Novel Joint Multicasting Capable Optical Cross-Connect Based on Space- and Frequency-Splitters

SUMMARY The network performance of a single joint multicasting capable optical cross-connect (jMC-OXC) integrating both space- and frequency-splitters is simulated. The results show that the jMC-OXC architecture with limited frequency-splitters can obtain a close performance to that with full frequency splitters. The improvement offered by jMC-OXCs on the performance of multicasting routing is also discussed.

key words: multicasting, multicasting capable optical cross-connect (MC-OXC), space splitter, frequency splitter

1. Introduction

As high-bandwidth real-time streams applications such as HDTV gain popularity, there rises a demand to implement multicasting (one source to multiple destinations) at optical layer. The concept of light tree proposed in [1] is a point to multipoint optical channel supporting multicasting at optical layer.

To realize light tree, an optical cross-connect (OXC) called multicasting capable OXC (MC-OXC) is required. A splitter and delivery (SaD) switch, main part of a strictly non-blocking MC-OXC, is proposed in [2] and the improved one called multicast-only SaD (MOSaD) is proposed in [3] to save cost. In both SaD and MO SaD, space splitter is used, which can duplicate one input optical signal into multiple outputs (fanout) on the same frequency (wavelength). Another kind of wavelength convertible optical splitter called multi-wavelength converter (we call it frequency splitter) is recently demonstrated in [4]. The wavelength convertibility is an important feature to improve the network performance.

Space splitter is wavelength inconvertible, while the frequency splitter has limited fanout, decreased optical signal-to-noise-ratio (OSNR) [4] and is also expensive. We thus propose an MC-OXC architecture called joint multicasting capable optical cross-connect (jMC-OXC) consisting of both space splitters and frequency splitters. We also design three schemes to analysis network performance of a single jMC-OXC using dynamic simulation. The simulation shows that jMC-OXC with limited frequency splitters can obtain close performance to that with full frequency splitters. We also demonstrate that the frequency (wavelength) convertible jMC-OXCs can be used to improve the performance of multicasting routing at optical layer.

2. General Architecture of jMC-OXC

The architecture of jMC-OXC is illustrated in Fig. 1(a), where space and frequency splitters are integrated as a joint multicasting capable element (jMC-E). A jMC-E consists of one to 2 space splitters, one 1 to S1 space splitter, and one 1 to S2 frequency splitters, as shown in Fig. 1(b). The total fanout of a jMC-E is S (S = S1 + S2). Up to S1 fanout with wavelength continuance are produced by the space splitter, and up to S2 fanout with wavelength convertibility are produced by the frequency splitter.

3. Performance of a Single jMC-OXC

Our simulation is confined in a single jMC-OXC architecture to provide more detailed inspection.

Suppose a jMC-OXC has F input/output fiber links, W wavelengths in each fiber link, and totally W optical space switches (OSW) with dimension of F×F [2]. Suppose the fanout (S) of a jMC-E is the minimum of W and F. We con-
sider three schemes: 1) only space splitters are used; 2) only frequency splitters are used; and 3) both space splitters and frequency splitters are used. The simulation parameters are listed in Table 1. The fanout (S) remains the same for all three schemes to ensure that their performance can be fairly compared.

Both uni- and multi-casting requests are considered. Suppose 100α% (0 < α < 1) requests are multicasting requests and all requests arrive at the jMC-OXC in a Poisson process with rate λ. The holding time of each request is exponentially distributed with a mean µ. So the load measured in Erlangs is λµ. For any switching request, R different output fibres (called multicasting/unicasting members in this letter) are randomly selected according to the uniform distribution. R changes from 2 to 3 among all multicast requests and is 1 constantly for the unicasting case. The proposed wavelength assignment and performance evaluation algorithm is described as follows.

Input: A multicasting request \( R_e(I_{ij}, \{M_{pq}\}) \), where

\( I_{ij} \) is the input signal arriving at the jth wavelength of the ith input fibre (1 ≤ i ≤ F, 1 ≤ j ≤ W);

\( \{M_{pq}\} \) denotes the member (destination) set, and the element \( M_{pq} \) denotes the pth member on the qth output fibre (1 ≤ p ≤ R, 1 ≤ q ≤ F, \(|{M_{pq}}| = R\)).

Output: Member set \( |{M_{pq,v}}| \) and K (the number of blocked members), where

\( M_{pq,v} \) denotes that the member \( M_{pq} \) is assigned with the vth wavelength (1 ≤ v ≤ W).

1. IF \( \exists \) the jth wavelength available for signal \( I_{ij} \), go to 2;
ELSE, K:=R and Stop.

2. Case (scheme 1): \( \forall M_{pq} \in \{M_{pq}\} \), IF the jth wavelength is available for member \( M_{pq} \), member \( M_{pq} \) is satisfied then \( M_{pq} \) is confirmed; ELSE, member \( M_{pq} \) is rejected and K:=K+1.

Case (scheme 2): \( \forall M_{pq} \in \{M_{pq}\} \), IF a wavelength, e.g., the vth wavelength is available for both member \( M_{pq} \) and jMC-E, member \( M_{pq} \) is satisfied then \( M_{pq} \) is confirmed; ELSE, \( M_{pq} \) is rejected and K:=K+1.

Case (scheme 3): \( \forall M_{pq} \in \{M_{pq}\} \), IF both member

\[ M_{pq} \text{ and } \text{jMC-E are available on the } j \text{th wavelength, } M_{pq,i} \text{ is confirmed; } \text{ELSEIF the } j \text{th wavelength is unavailable but a converted one, e.g., the } v \text{th wavelength is available, } M_{pq,v} \text{ is confirmed; } \text{ELSE, } M_{pq} \text{ is rejected and } K:=K+1. \]

The First-Fit wavelength assignment strategy is used in step 2 for scheme 2 and 3. A metric called Average Member Blocking Probability (AMBP) is defined to evaluate the network performance, which is the ratio of the number of total rejected members to all requested members. Totally 5 × 10⁶ multicasting requests are considered at each load. Figure 2 shows the simulation results of AMBP. It is clear that the AMBP is lowest in the scheme 2 and highest in scheme 1. The reason is that using frequency splitters can set up extra connections that are not achievable by space splitter due to the wavelength contentions. The network performance is obviously improved by replacing some space splitters’ fanout with frequency splitters’ fanout. The scheme 3 is a tradeoff between the limited fanout of frequency splitters and the improved network performance. Figure 2 also shows the AMBPs at α of 0.65 are higher than those at α of 0.40 due to the severer unavailability of free jMC-Es at larger α.

A detailed inspection on the ratio of multicasting switching requests being wholly offered (i.e., all R (R ≥ 2) members are satisfied as a whole) to all requested is illustrated in Fig. 3, which shows more multicasting requests are wholly offered in scheme 2 than those in scheme 1.

### Table 1 Simulation parameters for three schemes.

<table>
<thead>
<tr>
<th>Schemes</th>
<th>F</th>
<th>W</th>
<th>S</th>
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<th>S2</th>
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Fig. 2 Average member blocking probability (AMBP) vs. load in Erlangs for three schemes.

Fig. 3 Ratio of wholly offered multicasting to all requested vs. size of multicasting members (at 36 Erlangs load, α=0.5).
and scheme 3. It also shows a close performance between scheme 3 and scheme 2.

4. Potential Multicast Routing Performance of jMC-OXCs

Since jMC-OXC is inherently capable of all-optical wavelength conversion, it is expected to improve multicast routing performance of optical networks.

In a *sparse light splitting network* where only a limited number of MC-OXCs are employed, a light tree may not be sufficient for satisfying all destinations. Such an example is illustrated in Fig. 4(a) where multicast streams will be delivered from node 0 to node 2, 5, 6 and 7 via light tree on wavelength $w_1$. Unfortunately, node 5 will not be reached since node 6 is multicast incapable. The solutions called *light forest* [5] and *overlapped tree* [6] have been proposed recently. A source-based light forest consists of multiple light trees originating from the same source. In an overlapped tree, more than one branches can share the same topology edge. Illustrative source-based light forest and overlapped tree are shown in Fig. 4(b) and Fig. 4(c) respectively. In Fig. 4(b), another light tree operating on wavelength $w_2$ is constructed from node 0 to node 5 via node 1, 3 and 6, while in Fig. 4(c), an overlapped branch (also on $w_1$) is found from node 4 to node 5 via node 3 and node 6, where edge 3-6 is shared by two branches. If no additional common wavelength exists along 0-1-3-6-5 or no extra common $w_1$ exists along 4-3-6-5, source based light forest or overlapped tree will be invalidated. However, if jMC-OXC nodes are used, node 5 may still be reached if any common wavelength exists along 0-1-3-6-5 or 4-3-6-5 since jMC-OXC is wavelength convertible, as shown in Fig. 4(d). Therefore, jMC-OXC can increase the probability of successfully constructing a light tree or a light forest.

5. Conclusions

The novel jMC-OXC is a tradeoff architecture considering network performance and device availability or capital investment. It also can improve the performance of multicast routing due to its wavelength convertibility.

References


