Spectrum- and Energy-Efficient Multicasting over Multicast-Incapable EONs with Member-Only Flexible Relay

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Abstract: We propose to enable multicast in elastic optical networks that only have multicast-incapable nodes by using member-only flexible relay. Compared with the traditional overlay multicast, the proposed scheme can be spectrum- and energy-efficient.

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1. Introduction

Recent research has demonstrated the use of the optical orthogonal frequency-division multiplexing (O-OFDM) technology to build elastic optical networks (EONs) [1]. Compared with the fixed-grid wavelength-division multiplexing (WDM) networks, the EONs based on O-OFDM have finer switching granularity and higher bandwidth efficiency. It is known that multicast is widely used in today's Internet to enable applications such as teleconference, IP television, and etc. Moreover, there recently has been a growing demand to support the e-Science applications that can transfer Petabyte-scale data to several geographically dispersed users [2]. To this end, researchers have studied the multicast schemes in WDM networks intensively [2–4]. Since EONs attain more flexible bandwidth management in the optical layer, they could support multicast more efficiently, however the multicast schemes in EONs are still under-explored.

Wang *et al.* studied multicast in EONs whose nodes are all multicast-capable (MC) [5]. Nevertheless, since the MC nodes usually have complicated structures and are expensive due to the additional light-splitters [3], it is neither necessary nor realistic to have practical EONs built with them when multicast traffic cannot dominate the network capacity. Previously, people relied on the overlay multicast scheme in optical networks that were built with multicast-incapable (MI) nodes [2]. In this paper, we propose a novel scheme that allows the EONs built with MI nodes to carry multicast requests efficiently. By leveraging the member-only flexible relay, the proposed scheme requires the same amount of transponders as in the traditional overlay multicast, and can achieve effective savings on spectrum-utilization and energy-consumption.

2. Multicasting over EONs with MI Nodes

We model the physical EON topology as a directed graph, $G(V,E)$, where V and E are the sets of MI nodes and fiber links, respectively. A multicast request can be represented with a triple $R_m(s,D,B)$, where $s \in V$ is the source node, $D \in V \setminus \{s\}$ is the set of destinations, and B is the bandwidth requirement in Gb/s. We use notation $M = \{s,D\}$ to denote all member nodes in R_m. In order to serve a multicast request R_m, we need to construct a light-tree from the source node s to all destinations in D. Since all of the nodes in V are MI, we cannot split the lightpath in the optical layer at any of them. In this work, we study two multicast schemes to construct the light-tree, which are the overlay multicast (OL-Multicast) and the multicast with member-only flexible relay (MOFR-Multicast).

For OL-Multicast, we decompose the multicast request $R_m(s,D,B)$ into multiple unicast request $\{R_u(s,d,B), d \in D\}$, and construct $|D|$ unicast lightpaths with the shortest-path routing to carry the multicast session. $|D|$ O-OFDM transponders are needed to serve the request. For MOFR-Multicast, we construct a light-tree from s to D, which is composed of several segmented lightpaths under the restriction that each lightpath can only start and end at the members of the multicast session, i.e., $M = \{s,D\}$. A member node is referred as a "relay-node" if one or more lightpaths start from it. According to this definition, s is also a relay-node. The relay-nodes equip transponders to perform flexible relay with necessary optical-to-electrical-to-optical (O/E/O) conversions. Since the relay-nodes can only be selected from $M = \{s,D\}$, we still only need $|D|$ transponders in the EON. While some of the transponders are pushed close to the destinations, the spectrum and energy resources can be saved effectively.

When the light-tree is finalized, both schemes allocate necessary frequency slots (FS') on it to deliver bandwidth B from s to D. In this work, we assume that there is no O/E/O conversion within a lightpath, and hence the spectrum continuity and spectrum non-overlapping constraints should be applied to each lighpath. We incorporate the distance-adaptive modulation assignment [7] to further explore the benefit of the proposed member-only flexible relay. An O-OFDM transponder can select its modulation-level from *BPSK*, *QPSK*, *8QAM*, and *16QAM*, whose transmission reaches are assumed to be 5,000 km, 2,500 km, 1,250 km, and 625 km, respectively. When the transmission distance of a lightpath permits, the transponder selects the highest modulation-level and perform FS assignment with the first-fit

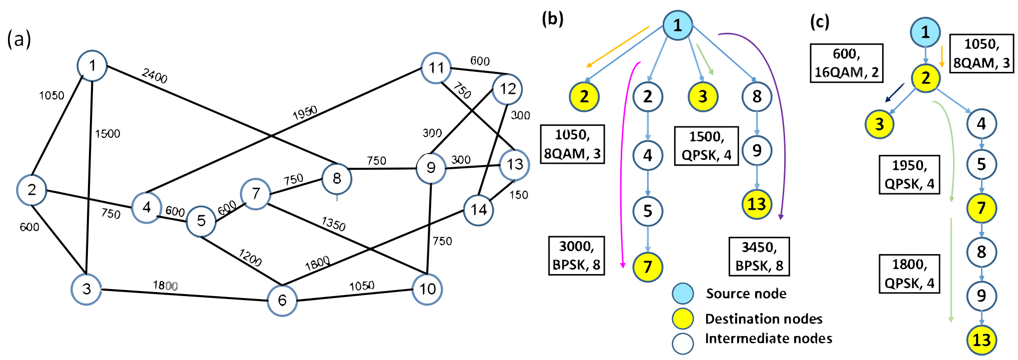

Fig. 1. (a) NSFNET topology (fiber lengths in kilometers). (b) An example of OL-Multicast. (c) An example of MOFR-Multicast.

scheme. We define the capacity of an FS as C_{FS}, and assume that C_{FS} is 12.5 Gb/s, 25 Gb/s, 37.5 Gb/s, or 50 Gb/s, for the modulation levels above. Therefore, we need to allocate $\lceil \frac{B}{C_{FS}} \rceil$ contiguous FS' on each lightpath in the light-tree.

Fig. 1 illustrates the examples of OL-Multicast and MOFR-Multicast. With the NSFNET topology in Fig. 1(a), we have a multicast request $R_m(1,\{2,3,7,13\},100)$ to serve. As shown in Fig.1(b), OL-Multicast decomposes R_m into four unicast lightpaths and calculate the shortest path for each of them. For instance, the shortest path for 1 to 7 is 1→2→4→5→7, which has a transmission distance of 3,000 km. We determine the modulation-level of this lightpath as *BPSK* and need to allocate 8 contiguous FS' to deliver 100 Gb/s capacity. Similarly, we mark the triple of {path length, modulation-level, number of FS'} on each lightpath. OL-Multicast needs 23 FS' to serve the request. Apparently, and four transponders are needed. In Fig. 1(c), MOFR-Multicast constructs a light-tree for $R_m(1,\{2,3,7,13\},100)$ and segments it into four lightpaths. Here, we have *Nodes* 1, 2 and 7 as relay-nodes. For this scheme, we need 4 transponders and only 13 FS' to serve the request.

3. Algorithm to Find Light-trees for MOFR-Multicast

For each multicast request $R_m(s,D,B)$, the task of calculating the light-tree for MOFR-Multicast is equivalent to solving the constrained multicast routing problem [4] for a network where only the member nodes in $M = \{s,D\}$ are multicast-capable (MC). Specifically, we adopt the following procedures to calculate the light-tree for $R_m(s,D,B)$,

Step 1: Construct two node sets V_{in} and V_{out} to store the member nodes that are currently in the light-tree or not, respectively, and initialize $V_{in} = s$ and $V_{out} = D$.

Step 2: For all node pairs $v_{in} - v_{out}$, where $v_{in} \in V_{in}$ and $v_{out} \in V_{out}$, find the shortest paths from v_{in} to v_{out}.

Step 3: For all the paths, insert the shortest one into the light-tree and move the corresponding v_{out} from V_{out} to V_{in}.

Step 4: If $V_{out} = \emptyset$ stop the procedures, otherwise go back to **Step 2**.

The above procedures are similar to those of the member-only multicast routing algorithm [4], and hence we can construct a near-optimal light-tree, in which the flexible relay only happens at the member nodes.

4. Simulations for Performance Evaluation

We evaluate the performance of OL-Multicast and MOFR-Multicast with the NSFNET topology shown in Fig. 1(a). We study the scenario that there are multiple multicast requests to be set up in the EON, and compare the spectrum-utilizations and energy-consumptions from the two multicast schemes. The average number of destinations (i.e., $|D|$) in the multicast requests is 3, and the member nodes of each request is randomly selected. The bandwidth requirement B is uniformly distributed within [12.5, 125] Gb/s. We calculate the power consumption of O-OFDM transponders with the energy model formulated in [6]. For fair comparisons, the request sets are the same for the two multicast schemes, and for each set, both schemes serve the requests with the same order.

In the simulations, we serve different sets of multicast requests and consider the maximum index of used FS' on all links, the total used FS' in the network, and the total power consumption of all transponders. After serving all pending multicast requests, we scan the last used FS' on all links, find the one whose index is the maximum, and obtain the maximum index of used FS' on all links. We calculate an occupied FS on a link as one used FS and perform the summation over all links to get the total used FS' in the network.

Fig. 2 and 3 show the simulation results on the maximum index of used FS' on all links and the total used FS' in

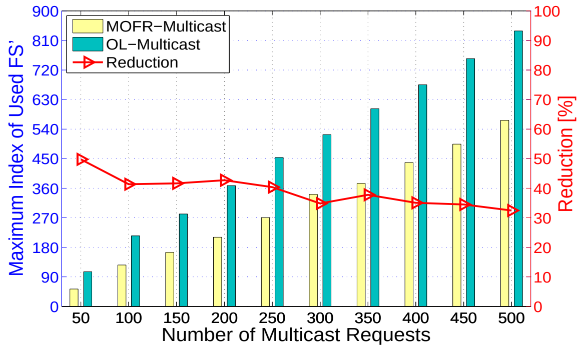

Fig. 2. Results on maximum index of used FS'.

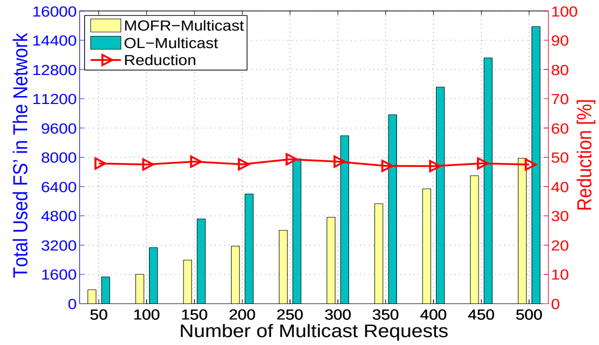

Fig. 3. Results on total number of used FS'.

Table 1. Results on total energy consumption of transponders.

# of requests		50	100	150	200	250	300	350	400	450	500
Power comsumption (KW)	MOFR	58.8	125.3	178.8	241.9	297.8	363.0	420.2	488.2	539.9	605.8
	OL	70.9	151.6	214.4	291.3	359.2	437.4	508.0	590.6	647.0	730.9
	Reduction(%)	17.1	17.4	16.6	17.0	17.1	17.0	17.3	17.3	16.6	17.1

the network. It can be seen that compared with OL-Multicast, MOFR-Multicast can achieve 48% and 47% reductions on the maximum index of used FS' and the total used FS' in the network, respectively. We also observe that when the number of requests increases, the reduction on the maximum index of used FS' decreases slightly. We believe that this observation can be explained as follows. Compared with them in OL-Multicast, the lightpaths in MOFR-Multicast require less FS' on average due to the higher modulation-levels permitted by the shorter transmission distances. When the EON becomes crowded with more multicast requests, this phenomenon can induce spectrum fragmentation, which compensates certain reduction on the maximum index of used FS' on all links. From Table. 1, we can see that the transponders in MOFR-Multicast consume 17% less power than those in OL-Multicast. The benefit of this lower power consumption results from the higher modulation-level permitted by the shorter transmission distance in average.

5. Conclusion

We proposed a novel scheme that allows the EONs built with multicast-incapable nodes to carry multicast requests efficiently. By leveraging the member-only flexible relay, the proposed scheme required the same amount of transponders as in the traditional OL-Multicast, and could achieve effective savings on spectrum-utilization and energy-consumption. The simulation results showed that compared with OL-Multicast, the proposed MOFR-Multicast achieved 47% and 17% savings on the spectrum-utilization and energy-consumption, respectively.

6. Acknowledgments

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