On Adaptive Traffic Restoration in P2MP-TRX-based WSONs

Yuxiao Zhang[1], Meihan Wu[1], Ruoxing Li[1], Qian Lv[1], Zuqing Zhu[1]

1. University of Science and Technology of China, Hefei, Anhui 230027, China, Email: zqzhu@ieee.org

Abstract: To deal with the service recovery after a single-link failure in point-to-multipoint transceiver (P2MP-TRX) based wavelength-switched optical networks (WSONs), we propose two restoration strategies and design an algorithm to optimize the restoration cost based on them.

OCIS codes: (060.1155) All-optical networks; (060.4251) Networks, assignment and routing algorithms.

1. Introduction

Nowadays, emerging network services are transforming the traffic pattern in metro/aggregation networks from point-to-point (P2P) to hub-and-spoke (H&S). This accelerates the development of coherent point-to-multipoint transceivers (P2MP-TRXs) that can better adapt to the traffic imbalance between hub-leaf pairs [1]. Meanwhile, it is known that the combination of P2MP-TRXs and wavelength-switched optical networks (WSONs) leads to better spectrum efficiency and cost-effectiveness [2,3]. Survivability is always an important issue for metro/aggregation networks. Although how to plan survivable P2MP-TRXs-based WSONs with shared-path protection has been studied in our previous work [3], the restoration scheme that can be dynamically applied in response to single-link failures in a P2MP-TRXs-based WSON without protection has not been explored. This work tackles the problem and proposes an adaptive algorithm.

2. Problem Description

We model the topology of a WSON a graph $G(V,E)$, where V and E are the sets of nodes and fiber links, respectively. Each node $v \in V$ contains an optical switch for frequency slot (FS)-level sub-wavelength switching, and hub and leaf P2MP-TRXs [1] can be placed in the node to be connected with the optical switch. When a single-link failure happens, we need to apply a restoration scheme that can effectively recover the affected flows based on the *status quo* in the WSON. We define a set $\mathbf{R}$ to include all the affected flows, each of which is modeled as $r_i = (s_i, d_i, x_i)$, where i is its index, s_i and d_i are its source and destination, and x_i denotes its throughput in terms of required subcarriers (SCs) on a P2MP-TRX. Here, we assume that each SC occupies 4 GHz and provides a capacity of 12.5 and 25 Gbps with the modulation formats of DP-QPSK and DP-16QAM, respectively [1]. Note that, the modulate format of the SCs on a P2MP-TRX depends on the quality-of-transmission (QoT) of the P2MP-TRX, *i.e.*, if the length of its lightpath is within 500 km, DP-16QAM is used, and DP-QPSK, otherwise [3]. The restoration of flows in $\mathbf{R}$ leverages the spare resources in the WSON, and we propose two restoration strategies as shown in Fig. 1.

Fig. 1(a) briefly explains the restoration in a P2MP-TRX-based WSON. We place two hub P2MP-TRXs on *Node* 2, where the first hub is at 100 Gbps and has leaf P2MP-TRXs on *Nodes* 3 and 5, respectively, and the second hub is at 400 Gbps and has leaf P2MP-TRXs on *Nodes* 1 and 4, respectively. The solid lines in the figure indicate working paths, and Fig. 1(b) shows the spectrum usages on links before the link failure. After *Link* 2-3 is cut, flows $r_2(2,4,2\text{ SCs})$ and $r_3(2,3,1\text{ SC})$ are interrupted and thus need to be restored. The first strategy expands the FS usage of in-service P2MP-TRXs to activate unused FS', which can be used to recover r_2 with the restoration path marked with the purple dashed line in Fig. 1(a). Hence, the cost of this strategy is the cost of newly-activated FS'. The second strategy needs

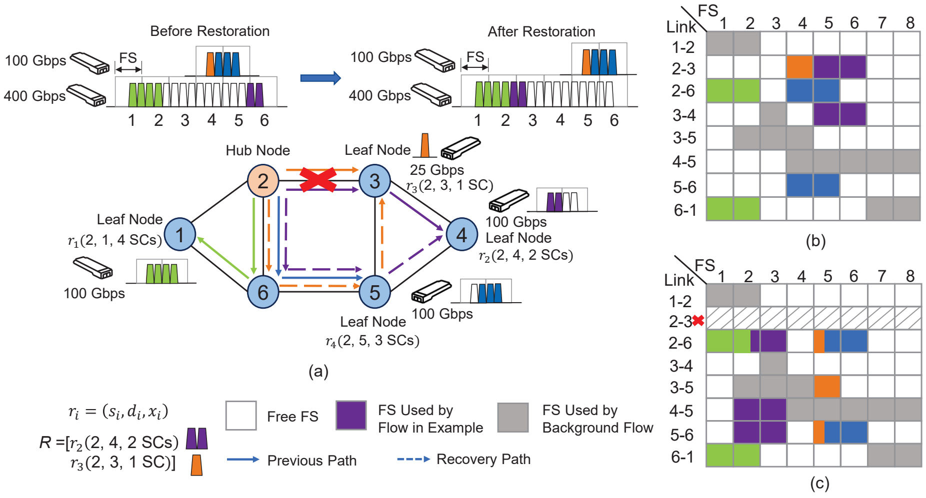
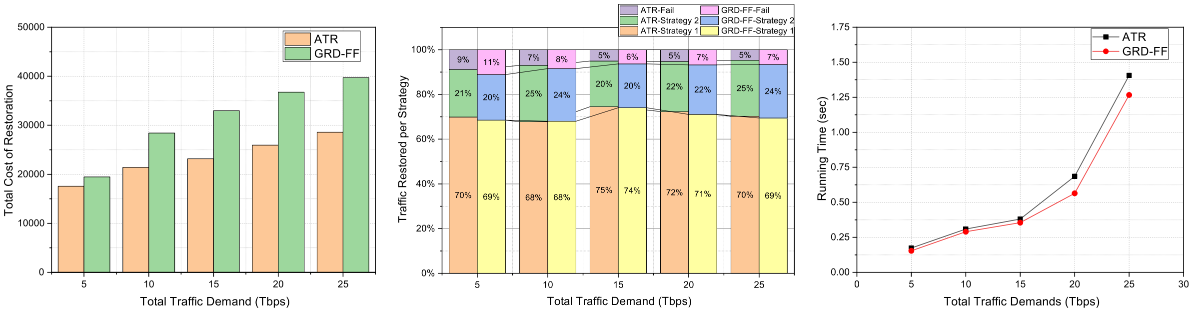


Fig. 1. Restoration in P2MP-TRX-based WSON, (a) network operation, (b) and (c) FS usages before and after fiber cut.

to reconfigure a hub P2MP-TRX to change its central frequency, when the first strategy is unavailable. For example, r_3 used the 4-th FS before the fiber cut, but there is no feasible path between *Nodes* 2 and 3 using the 4-th FS after the cut. Therefore, as shown in Fig. 1(c), r_3 can be successfully recovered when its hub P2MP-TRX is reconfigured to use the 5-th and 6-th FS'. We use c_f to denote the cost of activating a new FS, and define the cost of a P2MP-TRX reconfiguration as c_r, where we have $c_r \gg c_f$. Meanwhile, we hope to point out that deploying new P2MP-TRX(s) is not allowed in the restoration, and thus certain flows might not be able to restored due to insufficient resources. We define the penalty of failing to recover a flow as c_l. Finally, the total cost of restoring the flows in $\mathbf{R}$ can be obtained as $c_f \cdot n_f + c_r \cdot n_r + c_l \cdot n_l$, where n_f, n_r and n_l are the corresponding numbers of FS', P2MP-TRX reconfigurations and flows, respectively. Note that, a flow can be recovered by leveraging multiple lightpaths, *i.e.*, it is allowed to experience optical-electrical-optical (O/E/O) conversion(s) on intermediate node(s) before reaching its destination.

3. Algorithm Design

Intuitively, the restoration can be achieved with a greedy approach that handles the affected flows in $\mathbf{R}$ sequentially. Specifically, for each $r_i = (s_i, d_i, x_i)$ in $\mathbf{R}$, we traverse the idle SCs of all the hub P2MP-TRXs on s_i, then adopt the first-fit scheme to find an available restoration strategy for it. We refer to this greedy algorithm as GRD-FF. However, GRD-FF does not fully explore the benefits of the two proposed strategies to make the restoration more resource-efficient and cost-effective. Therefore, we design another algorithm, namely, adaptive traffic restoration (ATR) as follows. First, we sort the flows in $\mathbf{R}$ in descending order of their throughput. Then, for each flow $r_i = (s_i, d_i, x_i) \in \mathbf{R}$ in the sorted order, we check the hub and leaf P2MP-TRXs on s_i and d_i, respectively, and record the available FS' between each hub-leaf pair in a set $\mathbf{T}$. Then, if r_i can be recovered with any FS block(s) in $\mathbf{T}$, we just select the one with the lowest cost. Otherwise, we calculate K shortest paths between s_i and d_i, and try to use them to recover r_i even though multiple lightpaths (multiple hub-leaf pairs) might be used. If r_i still cannot be recovered, it is unrecoverable.



(a) Total restoration cost

(b) Distribution of restoration strategies

(c) Running time

Fig. 2. Simulation results with NSFNET topology.

4. Simulation Results

Our simulations use the 14-node NSFNET topology [4]. Each FS occupies 12.5 GHz, and each fiber link can accommodate 358 FS'. A hub P2MP-TRX operates at 100 or 400 Gbps, while the capacity of a leaf P2MP-TRX is 25 or 100 Gbps. For a P2MP-TRX at $\{25, 100, 400\}$ Gbps, its maximum spectrum usage is $\{1, 2, 6\}$ FS', respectively, corresponding to $\{1, 4, 16\}$ SCs. Each simulation first randomly generates H&S traffic with a total volume of $[5, 25]$ Tbps, and then randomly selects a link to fail to get the affected flows in $\mathbf{R}$. To ensure statistical accuracy, we obtain each data point by averaging the results from 10 independent runs. Fig. 2(a) compares the performance of ATR and GRD-FF in terms of total restoration cost, which shows that ATR always achieves flow recovery more cost-efficiently than GRD-FF, reducing the total cost by 24.3% on average. Fig. 2(b) analyzes the distributions of the restoration strategies used by the two algorithms, showing that ATR always recovers more flows than GRD-FF by utilizing the idle resources in the WOSN more intelligently. The results on running time in Fig. 2(c) (*i.e.*, the total running time to restore all the affected flows) suggest that the running time of ATR is similar as that of GRD-FF, just slightly longer.

5. Summary

We proposed two restoration strategies for P2MP-TRX-based WSONs to address single-link failures and designed a resource-efficient algorithm based on them. Simulation results confirmed the performance of our proposal.

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