Subcarrier Restoration for Survivable Multi-Flow Transponders in Elastic Optical Networks

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***Abstract*—We discuss survivability considerations for multi-carrier-based elastic optical networks, focusing on the multi-carrier transponder (MCT). We explain the necessity of subcarrier restoration that can recover multi-carrier connections using backup sub-channels. An initial evaluation shows our restoration scheme improves transponder reliability.**

Keywords—elastic optical network; restoration; multiflow optical transponder; multi-carrier

I. INTRODUCTION

Significant research efforts have been done toward Elastic Optical Networks (EONs), which will maximize spectral efficiency by way of the evolution of flexible optical/electrical devices and the flexible grid which was standardized in ITU-T. The spectral efficiency of EON has been verified. One of the key technologies of EON is the bandwidth variable transponder (BVT); it alters the number of subcarrier modules and modulation formats to realize the flexibility in bandwidth and spectrum to meet the changing optical path demands. This concept is expected to bridge the gap between large capacity, beyond-100G era, multi-carrier transmission, and the wide variety of optical path demands. The novel concept of the multi-flow transponder (MFT) [1], or sliceable bandwidth variable transponder [2], has been gathering attention. By assigning subcarrier modules as needed to satisfy optical path demands, each of which have different destination and bitrate, it can generate optical channels flexibly such as a large-capacity optical channel by bundling subcarrier modules and multiple optical channels by unbundling them. In this paper both BVT and MFT are categorized as the multi-carrier transponder (MCT) in that they have multiple subcarrier modules. Their building blocks are briefly summarized in Fig. 1. For MCTs to offer sufficient flexibility, the number and capacity of the subcarrier modules must be sufficient. However, increasing the number of subcarrier modules heightens the risk of transponder failure.

This paper discusses issues of MCT reliability from the viewpoint of optical networking. In addition, we explain the subcarrier restoration scheme and evaluate its impact on the transponder reliability. Section II overviews the different kinds of transponder architectures and describes the necessity of improving reliability, especially that of MFT. Section III addresses subcarrier restoration and evaluates its effectiveness.

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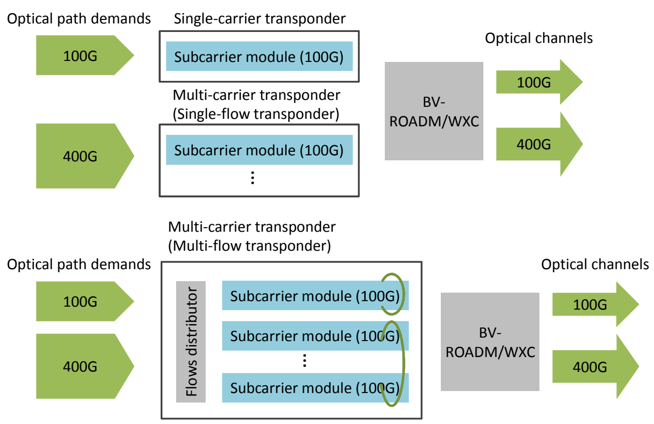

Fig. 1. Transponder types and their simplified building blocks.

Section IV concludes the paper.

II. TRANSPONDER RELIABILITY CONSIDERATIONS

This section elucidates MCT reliability by comparing different transponder architectures. First, the impact of the difference between single-carrier and multi-carrier characteristics on transponder reliability is discussed. Second, we discuss how the MCT's ability to generate multiple optical channels impacts transponder reliability.

A. Necessity of improving MCT Reliability

As mentioned before, BVT enhances spectra utilization efficiency by selecting the necessary numbers of subcarriers. Thanks to BVT, appropriate spectra are tailored to various optical path demands, each of which has a different bitrate from a single type of transponder. MFT is an evolution of BVT, and can assign residual subcarrier resources to other optical paths. This subsection we compare these MCTs and the single-carrier-transponder (SCT) in terms of transponder reliability.

The main issue with MCT is that increasing the number of subcarrier modules also increases the risk of transponder failure. This is mainly due to two factors. The first is that a subcarrier module failure is regarded as failure of the whole transponder. In the current discussion of beyond-100G OTN standardization in ITU-T, in which multicarrier transmission is expected to be a necessary feature, actions after subcarrier module failure are not determined. The second factor is that we

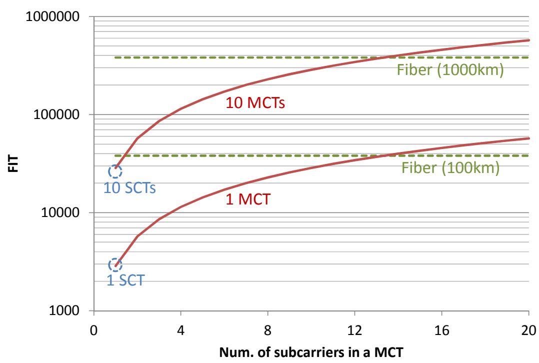

Fig. 2. FIT rates of subcarrier transponders, multicarrier transponders, and fibers.

cannot replace parts at the subcarrier module level. As an MCT consists of multiple subcarrier modules, we need to replace the whole transponder if even just one subcarrier module fails. This issue is especially critical for MFTs, because replacing a transponder disconnects multiple optical channels.

A subcarrier module has almost the same building blocks as the traditional SCT [2], so we can consider an MCT as an aggregation of SCTs in terms of failure probability. Failure probability of SCT may be not so serious compared to other components such as fiber, so client-side protection [3] was sufficient for supporting both transponder and fiber failure. However, the failure probability of MCT increases in proportion to the number of subcarrier modules. Figure 2 shows the failure in time (FIT) as a function of the number of subcarriers in an MCT. We assume mean-time between failures (MTBF) of 1km fiber as 2.63E06 hours, and that of SCT is assumed to be 3.5E05 hours [4]. FIT rate is calculated by 10E09/MTBF. FIT rate of MCT is that of SCT multiplied by the number of subcarrier modules; we assume that the subcarrier module failures are statistically independent and any part of subcarrier module failure result in the whole transponder failure. Figure 2 indicates that the FIT rate of MCT drastically increases as the number of subcarriers increases. Even 10 SCTs are more reliable than 100km fiber, but 10 MCTs may be more fragile than 1000km fiber. Thus, transponder failure is not negligible compared to fiber, especially MCT failure, so we need to take measures to increase MCT reliability.

B. Reliability Consideration of MCT

This subsection discusses two considerations about MCT reliability: how to lengthen transponder failure period and issues about transponder failure recovery.

One of the most effective approaches for lengthening transponder failure period is to ensure that subcarrier module failure does not trigger transponder failure. A straightforward approach is to equip the MCT with backup subcarrier modules. If a module fails, its traffic is switched to the backup module at both ends of the transponders. We call it subcarrier restoration. It is similar to 1:N link protection. This approach complicates transponder structure, but can increase transponder reliability. The importance of backup modules is also explained in [5]. We note that switchover is conducted after detecting module failure, so we need to take other approaches to avoid temporary disruption.

A similar approach is proposed in [6]; it employs erasure coding techniques for recovering subcarrier modules instead of switching. At the transmitter side erasure-coded data is generated and transmitted through the backup subcarrier module, and if any subcarrier module is down, failed data is recovered by decoding erasure-coded data at the backup subcarrier module. This approach requires the additional function of erasure coding at the transmitter and decoding at the receiver, but temporary disruption does not occur.

Determining actions after transponder failure is also an important issue. Table I summarizes the available actions that correspond to failure type, failure recognition type, and transponder type. There are three situations for failure restoration: subcarrier-level restoration against subcarrier module failure, transponder-level restoration against transponder failure, and transponder-level restoration against subcarrier module failure. The traditional approach of protecting single-carrier transponder failure is simple: switching to the secondary transponder on transponder failure. This approach is also applicable to fiber cuts. There are, however, several options for determining MCT recovery. Subcarrier restoration can improve transponder reliability, but once the transponder does not work, we need to switch the traffic to backup channels to replace the transponder. We can see that determining the action after transponder failure is as important as subcarrier restoration.

Figures 3 and 4 compare the unavailability of SCT and MCT without protection and with client-side protection, respectively. "Availability" means the rate of time over which client traffic frames are successfully transported. This evaluation assumes no fiber cuts and considers only subcarrier module failure. From the subcarrier module count aspect, four sets of SCTs are equivalent to an MCT with four subcarrier modules. We can see that unprotected SCT and MCT have the same availability, but when we employ protection, MCT has lower availability than SCT. In Fig. 3 any a subcarrier module failure leads to client traffic disruption in both SCT and MCT. On the other hand, in Fig. 4, a subcarrier module failure does not cause disruption in either type of transponder but MCT has a higher probability of disruption at the next failure than SCT.

C. Reliability Consideration of MFT

The main advantage of MFT is that it can accommodate multiple client traffic streams, each of which has a different destination as the distribution function is delegated from client layer to server layer. This aggregation can simplify interconnections between router line cards and transponders [1, 7]. On the other hand, this aggregation also has the risk of multiple client traffic disruptions with only a single transponder failure. Therefore, transponder reliability is especially important for MFT.

However, subcarrier restoration is not always applicable to MFT. The basic concept of subcarrier restoration is to re-assign disrupted bandwidth resources (e.g. time slot) to the remaining subcarriers (Fig. 5). If sufficient available resources exist in the residual subcarriers, multicarrier channels can be restored

TABLE I. AVAILABLE ACTIONS FOR FAILURE TYPE, FAILURE RECOGNITION TYPE, AND TRANSPONDER TYPE

	Failure type	Subcarrier module failure		Transponder failure
	Failure recognition type	Subcarrier module failure	Transponder failure	
Transponder type	Single carrier transponder	(None)	(None)	Client-side protection or restoration
	Multi-carrier transponder	Subcarrier restoration	Client-side protection or restoration	Client-side protection or restoration

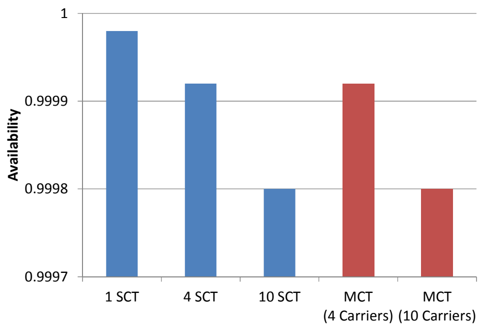

Fig. 3. Availability comparison of SCTs and MCTs without protection.

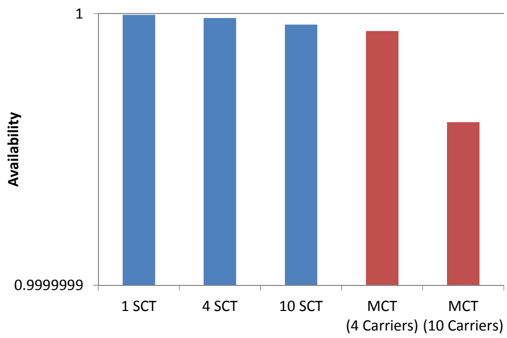

Fig. 4. Availability comparison of SCTs and MCTs with client-side protection.

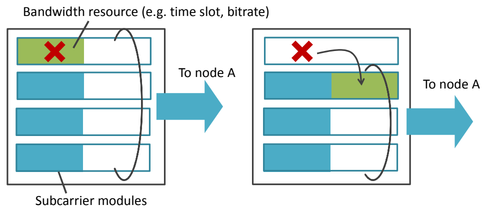

Fig. 5. Subcarrier module restoration for MCT

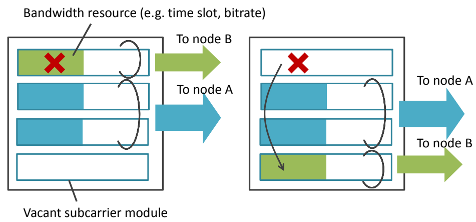

Fig. 6. Subcarrier module restoration for MFT

immediately. This re-assignment function may be realized by technologies such as the next-generation OTN framer. On the other hand, if the destination of failed subcarrier modules and that of the residual subcarrier modules are different, the traffic carried by the failed subcarrier modules cannot be restored.

III. MULTICARRIER RESTORATION SCHEME FOR MFT

In the light of the above, we can see problems with MFT restoration. Our solution, a simple subcarrier restoration scheme, improves transponder reliability. The key to this scheme is the provision and reallocation of backup subcarrier modules. This means that MFT should have at least one sharable subcarrier module to which no client traffic is assigned (Fig. 6). This vacant module represents an additional cost, but it can backup optical channels in any direction. For example, if a transponder has 10 subcarrier modules, 6 of which are used, the remaining 4 modules can backup the 6 working modules regardless of channel direction. This functionality can be realized effectively if the flow distributor utilizes the concept of software defined networks (SDN).

We verified the advantage of the proposed scheme in terms of reliability of optical path demands. The evaluation was conducted under point-to-point connection and 400 and 100 Gb/s optical path demands were assigned until total bitrate reached 10 Tb/s. We assumed the rate for each demand to be 400 Gb/s : 100 Gb/s = 1: 4. We compared the four transponder architectures listed below:

a) Mixed-line-rate which uses 400 and 100 Gb/s fixed-rate transponders.

b) MFT (1 Tb/s) without subcarrier restoration, i.e. subcarrier module failure is taken as transponder failure.

c) MFT (1 Tb/s) with subcarrier restoration and without backup modules. Subcarrier restoration is available if there is at least one unused subcarrier module.

d) MFT (1 Tb/s) with subcarrier restoration and backup modules (proposed architecture). At least one subcarrier module is secured.

We assume that all transponders consist of multiple 100 Gb/s subcarrier modules. For example, the 400 Gb/s fixed-rate transponder has four 100 Gb/s subcarrier modules, and a 1 Tb/s MFT has 10 subcarrier modules. All subcarrier modules have

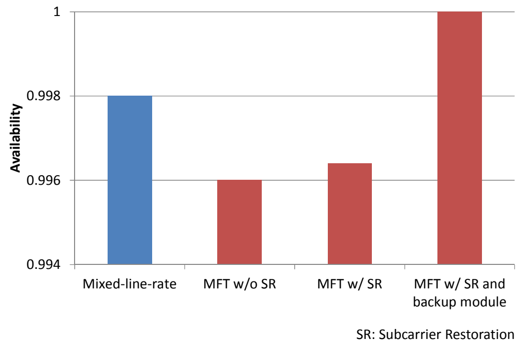

Fig. 7. Availability of transponders without protection.

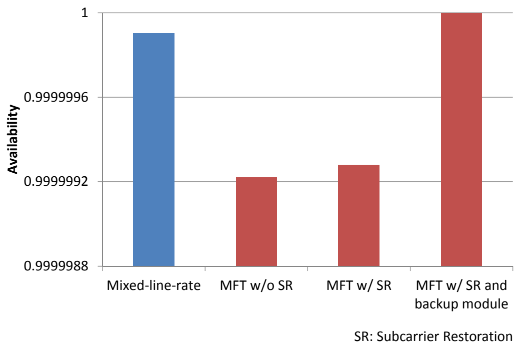

Fig. 8. Availability of transponders with client-side protection.

availability of 0.9999. The evaluation considers only subcarrier module failure, so other failure types such as fiber cut are not considered.

Fig. 7 compares the availability of the four transponder architectures without protection. If subcarrier-level restoration and backup modules are unavailable, MFT has lower availability than mixed-line-rate architecture; however, the proposed architecture has much higher availability than the other architectures at almost 1. Fig. 8 also shows the same result as Fig. 7. We can see that subcarrier restoration and the usage of backup subcarrier modules is necessary if the same or better availability of the traditional transponder architecture is required. The impact of occupying backup modules on the number of transponders is shown in Fig. 9. This figure compares mixed-line-rate, MFT without backup modules, and MFT with backup modules, and each of them does not include protection. We can see that MFT saves large number of

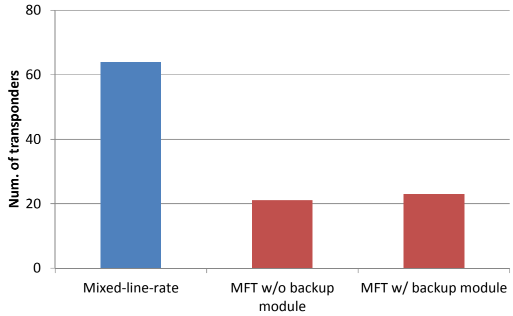

Fig. 9. Number of transponders.

transponders (about 67%), and that the increase of MFT caused by setting backup modules (about 8.7%) is not as big as the introduction of MFT.

IV. Conclusions

This paper discussed the necessity of improving MFT reliability as MFT failure probability increases with subcarrier counts and direction. We proposed a subcarrier restoration scheme which includes subcarrier re-allocation and the setting of backup subcarrier modules. An initial evaluation showed that the proposed scheme dramatically increases MFT reliability with small number of additional transponders.

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