Faults and Recovery Methods in Regional Undersea OADM Networks

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Abstract *An experimental study of faults in an important class of undersea OADM networks demonstrates that channel performance through surviving segments can be recovered by the terminal-based procedures enabled by a fault resilient network design.*

Introduction

Most undersea networks are based on trunk-only or trunk and branch topologies in which the capacity of a fiber pair supports connections between only two stations. Optical Add/Drop Multiplexing (OADM) in undersea networks allows more connections and greater flexibility in capacity allocation with little increase in system cost. However, sharing the capacity of a single fiber pair among multiple landing creates new challenges in network design and management. This is especially true in long-haul undersea networks, which are likely to be affected by nonlinear impairments[1] that complicate the channel power management in OADM DWDM systems. System faults such as a cable cut cause power redistribution among channels in surviving paths calling for sophisticated recovery procedures. For most undersea systems, rerouting traffic is expensive, if possible. Therefore, channel availability relies on the fault resilient transmission designs and the specialized power management procedures of the OADM system. Here we have examined the performance of an important class of regional undersea OADM networks in which the express path carries the bulk of traffic and the add/drop traffic represents a small portion of the overall capacity. We have shown that express traffic can be maintained in the face of a cut in the add/drop path, and, more significantly, the add/drop traffic through the surviving optical paths can be maintained in the face of a cut in the express path.

Experimental Setup

We studied a typical π-network configuration as shown in Figure 1. The express path from Station A to Station D was 5000 km long. Two OADM nodes were located at 1300 km and 4000 km from Station A. The add/drop path from Station B to Station C was 3800 km long. We assumed a conventional undersea system design that was based on single stage amplifiers and dispersion managed fiber spans. Amplifier spacing across the network was about 80 km. The amplifier bandwidth supports 136x10 Gb/s channels spaced at 25 GHz. The express path from A to D carried the bulk of the traffic (114 channels) and the OADM connectivity between A to B, B to C, and C to D was 13 channels. There were 9 unused channel slots around the add/drop channels as guard band. A set of Band Pass Filters (BPF) was included in the OADM nodes to provide the add/drop capabilities and to emulate network management related features not discussed here.

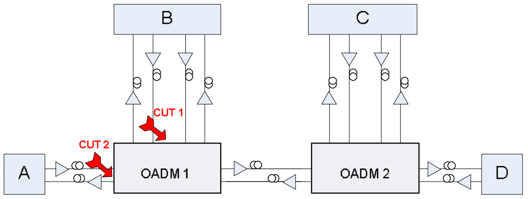

Fig. 1: Network topology.

Figure 2 shows the experimental setup based on a single re-circulating loop[2,3]. The loop included 7 spans of Dispersion Flattened Fiber and one gain equalization filter (GEF). The I/O Span of the loop was modified to accommodate the OADM nodes. Specially designed timing circuitry for the acousto-optical modulators (AOM) allowed us to introduce the appropriate filter BPF 1 (Path 2) or BPF 2 (Path 3) into the transmission path as needed to capture the transmission and filtering effects of the emulated

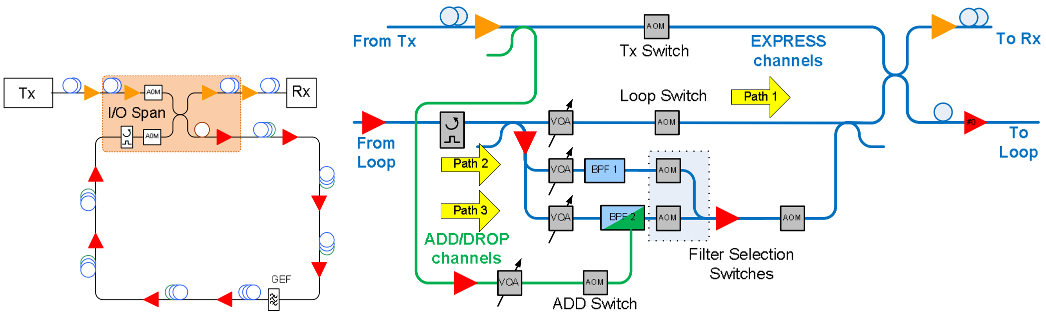

Fig. 2: Re-circulating loop detailed configuration of I/O span for experimental setup.

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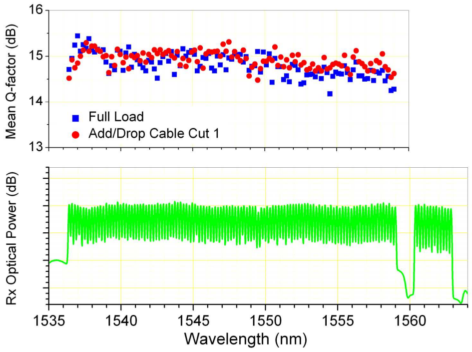

Fig. 3: Express path performance data and spectrum at normal operation as detected at Station D.

system with high fidelity. Cable cuts in the add/drop path have been emulated by shutting off the ADD AOM switch shown in Figure 2, while cable cuts in the express path were emulated by disconnecting the jumper between the variable optical attenuator (VOA) and the BPF 2.

Fault Scenarios

Several cable cut scenarios and their impact on remaining channels of the network were investigated. After a cable cut all channels from the affected path are lost and the output power of the undersea amplifiers is redistributed to the remaining channels. This leads to a significant power increase of the remaining channels with possible consequences for performance. A cable cut in the immediate vicinity of an OADM node has the largest impact on the remaining channels. We focused our investigation on the effects of a cable cut in the add/drop path (Cut 1) or the express path (Cut 2) at OADM node 1.

Experimental results

The average express path performance doesn't significantly change with a cut in the add/drop path. Therefore, no recovery procedure is required in that fault scenario. This is an expected result due to relatively small number of add/drop channels. Figure 3 shows WDM spectrum of fully loaded system detected at Station D, which includes both the express band (originating at Station A) and the add/drop band (originating at Station C). Performance of the 114 express channels before and after the cut is also shown. Performance changes caused by the cut are within the measurement accuracy. It should be noted that while the channels corresponding to the add/drop band between Stations B and C are absent; the same band is later filled with channels from Station C to D. This part of the spectrum can be seen at the longer wavelength edge of the band in Figure 3.

Cable Cut 2 in the express path has a strong impact on performance of the add/drop channels. Losing the express channels causes a dramatic increase in the power per channel of the add/drop channels. This can lead to severe non-linear impairments and traffic disruption. Comparison between WDM spectra before and after Cut 2, as seen in station C, is shown in Figure 4. The increase in add/drop band channel power is clearly visible. Both spectra also show effects of BPF filtering at short wavelength edge of the band. The performances of the add/drop channels are shown in the top plot of Figure 4. It is apparent that the power increase drives them into a nonlinear regime, causing significant performance degradation. Q factor of several channels dropped below typical FEC threshold values making a recovery procedure desirable. The recovery was implemented by adjusting channels and adding idler tones at the transmitter in station B. Performance of the recovered channels as shown in Figure 4 by squares is significantly below the nominal operation before the cut (triangles), but it is sufficient to maintain error-free traffic on the client side while system is being repaired and original level of performance is restored.

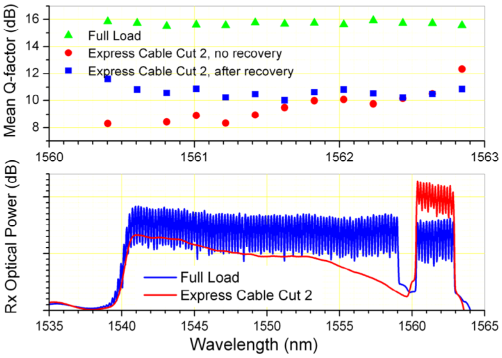

Fig. 4: Add/drop path performance data and spectra as detected at Station C.

Conclusions

Network faults and their impact on performance of surviving segments have been studied experimentally for a system topology representing an important class of regional OADM undersea networks. We demonstrated that the network can be designed to allow recovery of all channels in surviving optical paths following a cable cut. The recovery is enabled by a combination of filtering and terminal-based recovery procedures to rebalance the power distribution in the WDM bandwidth. The result is channel performance (Q margin) at an acceptable level to ensure service availability over the time period needed for network repair.

References

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