TRANS-OCEANIC OADM NETWORKS: FAULTS AND RECOVERY

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Abstract: Classical undersea networks are based on simple trunk and branch topologies. Recently there is a renewed interest in deploying Optical Add/Drop Multiplexing (OADM) undersea networks to increase the traffic distribution flexibility and reduce the cost of bandwidth delivery. We study the performance impact of cable faults in regional undersea OADM networks. A terminal-based recovery procedure enabled by a fault resilient network design can significantly improve the performance on surviving segments.

INTRODUCTION

Historically, long-haul undersea trunk-and-branch networks have provided point to point connectivity through the routing of dedicated fiber pairs. Optical Add/Drop Multiplexing (OADM) network architectures enable a more flexible distribution of transmission connectivity over a traditional fiber pair infrastructure while reducing the cost of bandwidth delivery. Sharing the capacity of dedicated fiber pairs among multiple branches is an attractive network solution especially in networks including landings with mixed amounts of capacity requirements. However, it comes with new challenges in network design and management. Due to their sheer length long-haul undersea networks are prone to be affected by nonlinear impairments[1]. Power management in OADM DWDM environments remains a major challenge. Traffic interrupting faults such as cable cuts can cause the loss of channels propagating on the undersea line leading to severe optical power changes for the remaining channels. In OADM networks single cable cuts can simultaneously impact multiple digital line segments (DLS) sharing the same fiber pair. It is of great importance to understand and identify the vulnerabilities of the network to possible locations of cable cuts. To maintain traffic on the surviving channels sophisticated recovery procedures are required. The recovery routines have to rely on a fault resilient transmission design and specialized power management procedures at the terminal stations.

Tyco Electronics Subsea Communications LLC ("TE SubCom" formerly known as Tyco Telecommunications (US) Inc.), has a solid record of contracted OADM network solutions based on its robust, expandable OADM technology platform that allows flexible bandwidth delivery to multiple landing points. Many issues related to specifics of undersea systems including handling of power distribution, nonlinear effects, fault analysis at both initial and full loading are being carefully treated using proprietary state-of-the-art modeling tools and laboratory test beds.

In this paper we have examined a typical scenario for a regional undersea network where the express path carried the bulk of the traffic and the add/drop traffic represented only a small portion of the overall capacity. We have shown that express traffic can be maintained in the presence of a cut in the add/drop path. More significantly we show that the add/drop traffic through the surviving optical paths can be recovered and maintained in the face of a cut in the express path.

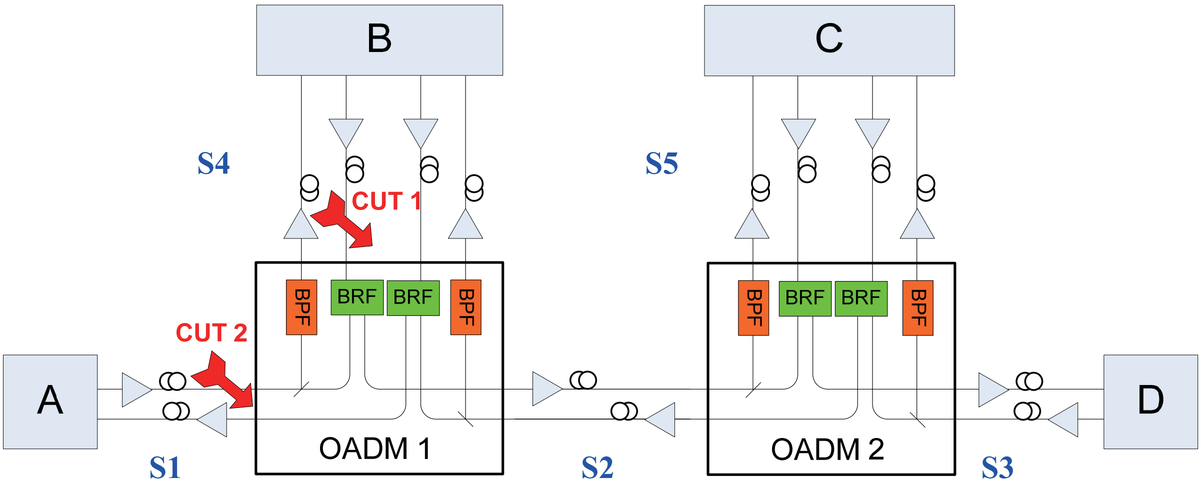

Figure 1: Network layout.

For the case of interest we have focused on the strategies to restore add/drop traffic when the express path is affected by a cut as this represents the more severe case where most of the optical power on the trunk is redistributed to the surviving add/drop channels.

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 27.2 nm 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. 3-port Band Reject Filters (BRF) were included in the OADM nodes to allow the reuse of the add/drop wavelength band. The Band Pass Filter (BPF) was used to emulate network management related features not discussed here.

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-optic modulators (AOM) allowed us to introduce the BPF (Path 2) or BRF (Path 3) into the transmission path as needed to capture the transmission and filtering effects

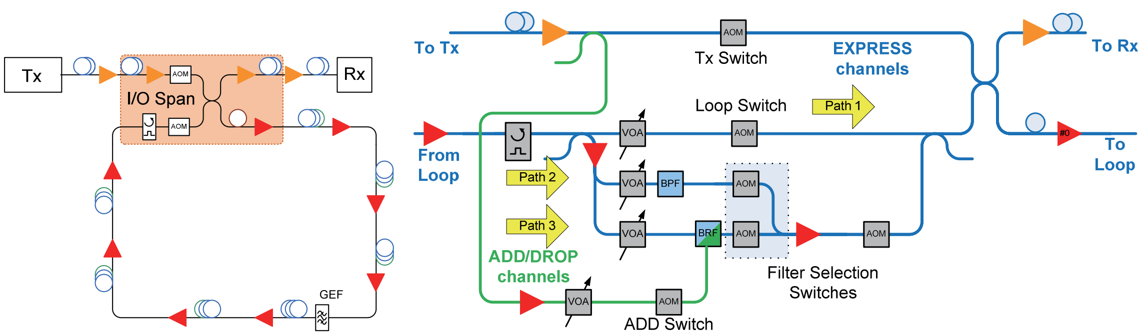

Figure 2: A configuration of re-circulating loop with I/O span contained in shaded box is shown on left; detailed configuration of I/O span is shown on right.

of the emulated 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 BRF. The details of this experimental setup were reviewed in ref. [3] and [4].

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 or the express path at OADM node 1 (labeled "Cut 1" and "Cut 2" in Figure 1).

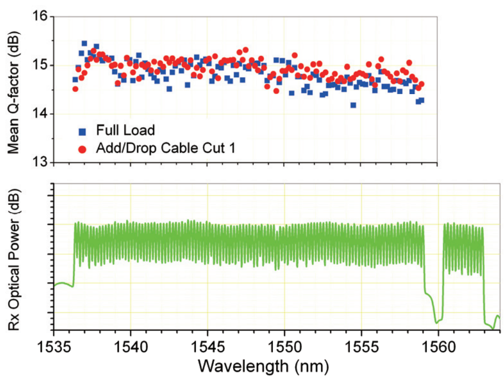

Figure 3: Express path performance data and spectrum at normal operation as detected at Station D.

EXPERIMENTAL RESULTS

Figure 3 shows the WDM spectrum detected at Station D for normal operation, 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 due to the fault were within the measurement accuracy. No recovery procedure is required for this fault scenario. This is an expected result due to the relatively small number of add/drop channels.

Cable Cut 2 in the express path had a strong impact on the performance of the remaining add/drop channels. The significant number of lost express channels, caused a dramatic power increase in the add/drop channels leading to severe non-linear impairments and traffic disruption. WDM spectra before and after the cut as received in station C are shown in Figure 4. The increased power per channel in the add/drop band is clearly visible resulting in significant performance degradation as shown in the top part of Figure 4. The Q factor of several channels dropped below typical FEC threshold values making a recovery procedure essential. The recovery was implemented by adjusting channel launch power levels and adding idler tones at the transmitter in station B. The performance of the successfully recovered add/drop channels is also shown in Figure 4.

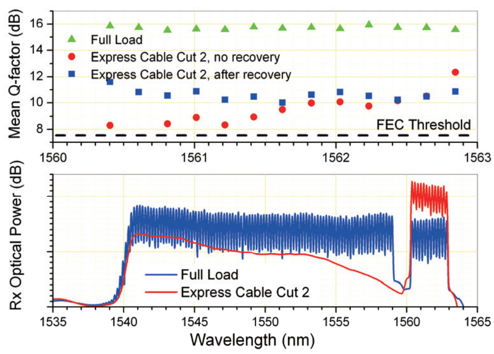

Figure 4: Add/drop path performance data and spectra as detected at Station C.

FAULT RECOVERY STRATEGIES

As it was shown the fault impact and recovery are very dependent on specific system design. The margin on channels on the surviving portion of the system can be impacted either positively or negatively by the loss of the channels from the failed sections. For the case we have discussed in this paper one can construct a cable cut fault impact matrix for the various cut locations and the DLSs. An example of such a matrix constructed for the system studied above is given in Table 1. Based on results of such analysis, network operators can develop their expectations on network performance implications during a fault occurrence and identify the most affected network segments that will require recovery procedures. Table 1 shows that two of the surviving network segments will require recovery procedures under the fault conditions. The goal of a recovery procedure is to restore an affected channel performance to the level sufficient to provide error free performance at the client interface while awaiting the network repair and subsequent restoration to pre-fault level of performance. To ensure that such restoration is possible, the needs of the fault recovery mechanisms should be included in the base network design. The fault recovery itself can then be implemented through pre-defined algorithms and look-up tables.

CONCLUSIONS

Network faults and their impact on performance of surviving segments have been studied experimentally for a typical regional OADM undersea network. We demonstrated that a fault resilient network design and proper terminal-based recovery procedures can rebalance the power distribution in the WDM bandwidth and restore the performance of the surviving traffic to a level that can ensure service availability over the time period needed for a network repair.

DLS	Cut Location	Impact on Service
A to D	S1	Same as non-OADM: service lost till repair
D to A	S1	Same as non-OADM: service lost till repair
A to B	S1	Same as non-OADM: service lost till repair
B to A	S1	Same as non-OADM: service lost till repair
B to C	S1 - Adjacent to OADM 1	Service interuption possible till recovery process complete
	S1 - with 1 or more reptrs between Cut and OADM 1	No service interuption
C to B	S1	No service interuption
C to D	S1	No service interuption
D to C	S1	No service interuption
A to D	S2	Same as non-OADM: service lost till repair
D to A	S2	Same as non-OADM: service lost till repair
A to B	S2	No service interuption
B to A	S2	No service interuption
B to C	S2	Same as non-OADM: service lost till repair
C to B	S2	Same as non-OADM: service lost till repair
C to D	S2	No service interuption
D to C	S2	No service interuption
A to D	S3	Same as non-OADM: service lost till repair
D to A	S3	Same as non-OADM: service lost till repair
A to B	S3	No service interuption
B to A	S3	No service interuption
B to C	S3	No service interuption
C to B	S3 - Adjacent to OADM 2	Service interuption possible till recovery process complete
	S3 - with 1 or more reptrs between Cut and OADM 2	No service interuption
C to D	S3	Same as non-OADM: service lost till repair
D to C	S3	Same as non-OADM: service lost till repair

Table 1: Example Cable Cut Fault Impact Matrix for the express path cuts.

REFERENCES

[1]. P. Bayvel in Optical Fiber Communications, IVB, 2002.
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