DESIGN ROBUSTNESS OF SUBMARINE NETWORKS USING OPTICAL ADD AND DROP MULTIPLEXING

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Abstract: Optical Add and Drop multiplexing (OADM) offers increased connectivity, optimized bandwidth allocation and cost-effective system design. In submarine systems, the OADM function can be inserted either in a terminal station between two segments or within a submerged Branching Unit (BU). The insertion of such a function makes the design of the systems more complex, mainly because failures may lead to changes in the channel loading of the system, which could create undesired traffic disturbances in other parts of the system. The design of the system must therefore be managed, so as not to be detrimental to the traffic availability across the network.

1 OADM IN SUBMARINE NETWORKS

Insertion of an OADM in Submarine Line Terminal Equipment (SLTE) maintains through-connectivity while reducing the need for regeneration in intermediate stations (Figure 1 top) for the through-traffic. In addition, an OADM SLTE enables flexible bandwidth allocation throughout system life. Thanks to recent improvements in SLTE performance, such as FEC improvements and new modulation formats, this OADM solution can also be used for concatenation of already installed systems.

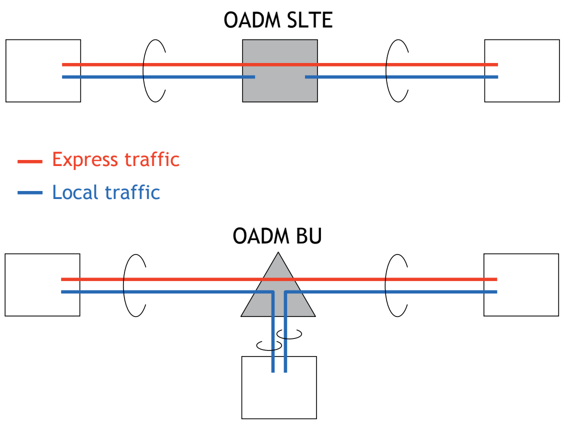

Figure 1 : OADM in Submarine Systems

Insertion of an OADM BU in the main trunk of submarine networks allows branch stations along the trunk cable route to be connected without increasing the number of fibre pairs on the trunk cable (Figure 1 bottom). Integrating an OADM function in branching units increases the robustness of the system against cable cuts in the shore-end sections of intermediate stations as the express traffic is routed directly by the offshore branching unit. In some systems, robustness can be further improved by installing the OADM BU in deeper waters beyond the continental shelf.

2 OADM SLTE

In current submarine systems using Dense Wavelength Division Multiplexing (D-WDM) with more than one hundred channels, the OADM can be performed at band level (Figure 2) rather than at channel level. Each band of wavelengths added/dropped at intermediate stations provides access to a defined number of channels for local traffic.

Figure 2 : Example of Band Multiplexing in Intermediate SLTE Station

This bandwidth allocation provides the required add and drop granularity, but it is important to preserve the capability to implement future upgrades at higher bit rates without disturbing existing traffic channels, and for the system to be robust against different failure scenarios (i.e. cable cuts) which can occur during the system life.

3 SYSTEM DESIGN WITH OADM SLTE

Systems integrating such an OADM function must be designed taking into account the longest transmission path of the express traffic but also taking into account the fact that a cable cut in one sub-segment may lead to changes in the channel loading of the other parts of the system, thereby disturbing the transmission performance of the remaining channels.

To illustrate this, Figure 3 (top) shows the received spectrum after 5800 km of a partially loaded system. The optical gain of the system is clearly distorted in these conditions, but can be reshaped by lighting up loading channels to replace the missing express wavelengths (Figure 3 bottom).

In case of a cable cut in the first sub-segment, the loading channels can be automatically activated in the intermediate station to compensate for the loss of the express wavelengths.

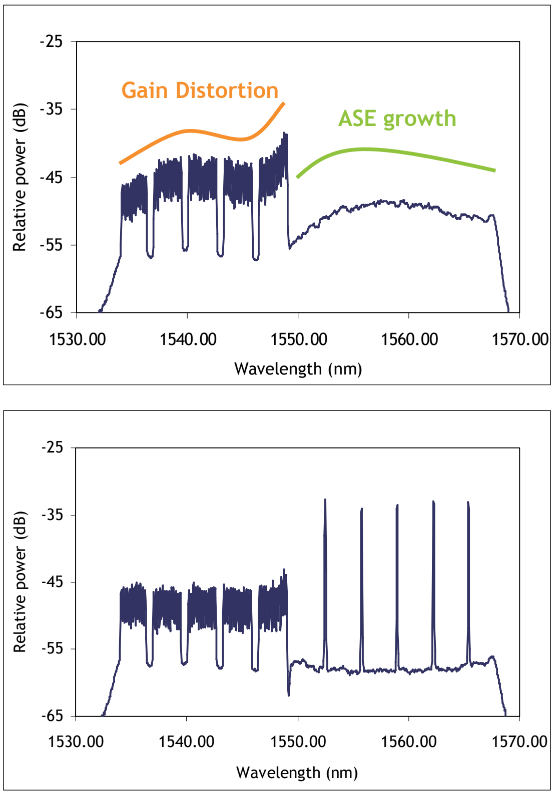

Figure 3 : Received Spectrum after 5800 km with Partial Loading (top) and with Loading Channels Lit Up (bottom)

The effectiveness of loading channels to maintain the traffic availability and performance is demonstrated by experimental results using 136 channels modulated at 10 Gbit/s with RZ-DPSK format shown in Figure 4. The Q factors of 136 channels and of 64 channels with loading channels were measured as being almost equal.

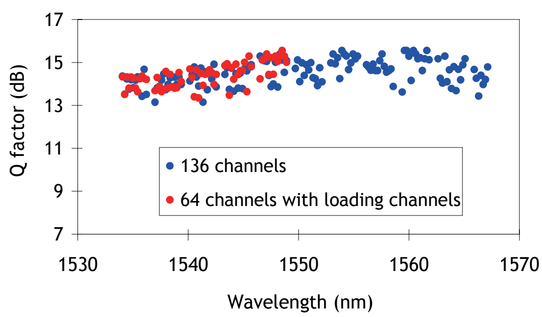

Figure 4 : 5800 km Transmission Performance - Q Factor of 136 Channels in Blue – Q Factor of 64 Channels with Loading Channels in Red

Loading channels, activated in case of cable cut, make the system self-healing allowing to offer robust system design with OADM SLTE in intermediate station.

4 OADM BU

Two major types of OADM BU can be considered to design a WDM system, usually called “no wavelength re-use BU” and “wavelength re-use BU”.

The no wavelength re-use BU is designed based on simple optical coupler without any filtering function within the BU. This simple optical architecture allows flexible bandwidth allocation while limiting the express capacity as the ‘drop’ channel bandwidth is not re-used to insert the ‘add’ channels as shown in Figure 5.

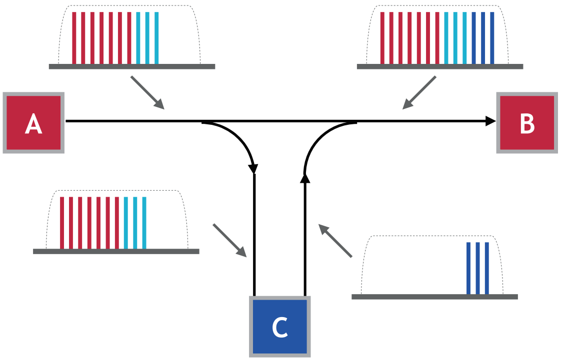

Figure 5 : No Wavelength Re-use BU Scheme (Express Channels in Red, Drop Channels in Light Blue, Add Channels in Dark Blue)

The wavelength re-use BU includes optical filtering functions on the trunk and the branch as shown on Figure 6. The trunk optical filter removes the ‘drop’ channels and creates room for insertion of the ‘add’ channels permitting wavelength re-use [1]. However, the use of filters leads to a guard band of a few hundreds of GHz due to the shape of the edges of the optical filters. Despite the necessity of guard bands in the case of large add and drop capacity, the wavelength re-use BU offers higher express capacity than the no wavelength re-use BU.

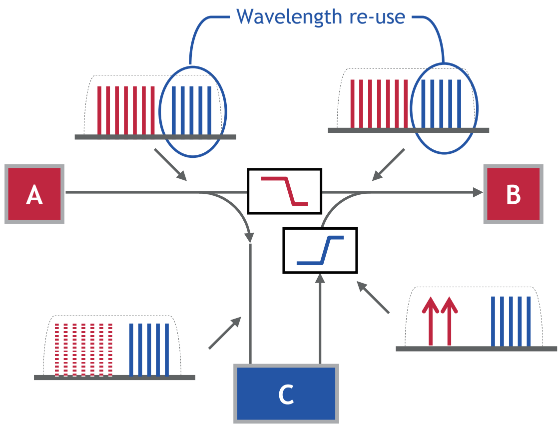

Figure 6 : Wavelength Re-use BU Scheme (Express Channels in Red, Drop Channels in Blue, Add Channels in Blue, Red Arrows Represent Loading Channels)

The ‘add’ filter removes the loading channels which are used to pre-emphasize the ‘add’ channels compared to the express channels, optimizing the overall channel transmission performance. The ‘add’ filter can also allow removal of the noise generated by the repeaters of the branch in case of cable cut.

Depending on the required network topology and capacity, the system will be designed using one of the two BU types.

The no wavelength re-use BU is preferred in case of systems requiring low add and drop capacity and non-repeatered branches such as scientific networks [2].

The wavelength re-use BU is typically selected for systems with large add and drop capacity and with repeatered branches.

5 SYSTEM DESIGN WITH OADM BU

At first sight, routing the wavelengths in a submerged BU protects the express traffic from cable cuts in the shore-end sections of the intermediate branch stations. However in such a case of cable cut (Figure 7), the express traffic may be impacted as the loading of the system is affected by the loss of the ‘add’ channels from the branch. In this case, the system loading cannot be corrected by lighting up loading channels because of the filter inserted on the trunk path of the OADM BU.

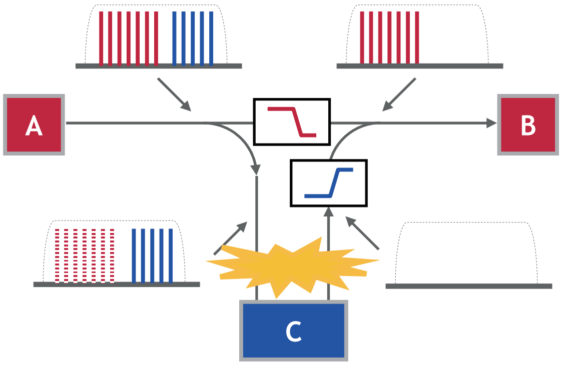

Figure 7 : System Loading in Case of Cable Cut in Shore-end Section of Intermediate Station

Such failure scenarios must be taken into account when designing the system so that this change in channel loading induced, in this example, by the loss of the 'add' channels does not lead to the loss of the express traffic. This can be done, for example, by allocating margins in the design or by using available design margins.

6 EXAMPLE OF ROBUSTNESS BY DESIGN

Let's consider the example of a 6150 km long network depicted in Figure 8, with an express fibre pair and two 3075 km long omnibus fibre pairs, one containing an OADM BU to connect the C station with 50% add and drop capacity.

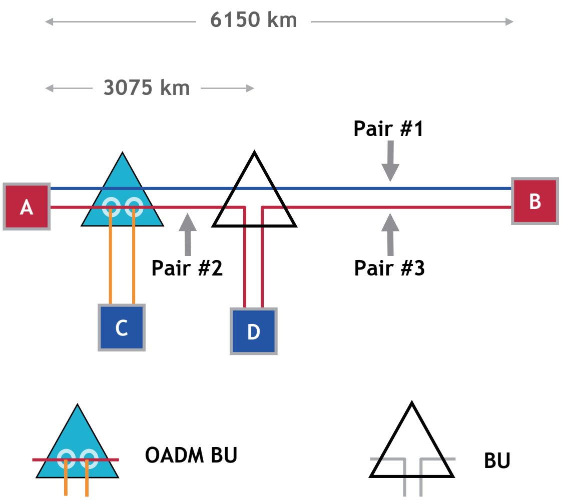

Figure 8 : Express Fibre Pair: Pair #1 – Omnibus Fibre Pair (with OADM BU): Pair #2 – Omnibus Fibre Pair (No OADM BU): Pair #3.

The design of repeatered systems results in a constant repeater span length across any given system. This repeater span length is defined by the design of the express fibre pair which is the most critical in terms of performance. It follows that the omnibus fibres have about 3 dB transmission performance margins if their length is half of the express fibre length.

Transmission tests simulating failure scenarios on this example network were carried out to evaluate the transmission performance of the channels under a cable cut scenario.

Figure 9 shows the received optical spectrum of the 6150 km express fibre pair. Figure 10 shows the distorted received spectrums with 50% channel loading that could result from a cable cut in the BU section in first omnibus considering a worst case 3075 km transmission length.

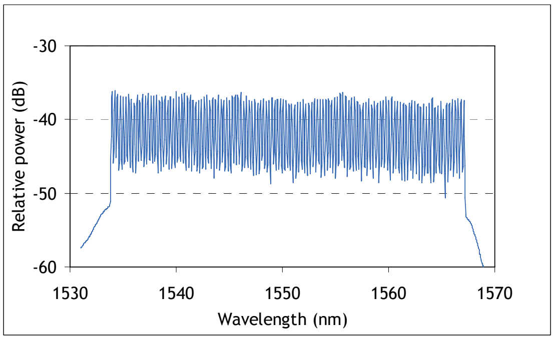

Figure 9 : Pair #1 Received 132-channel Spectrum in Blue

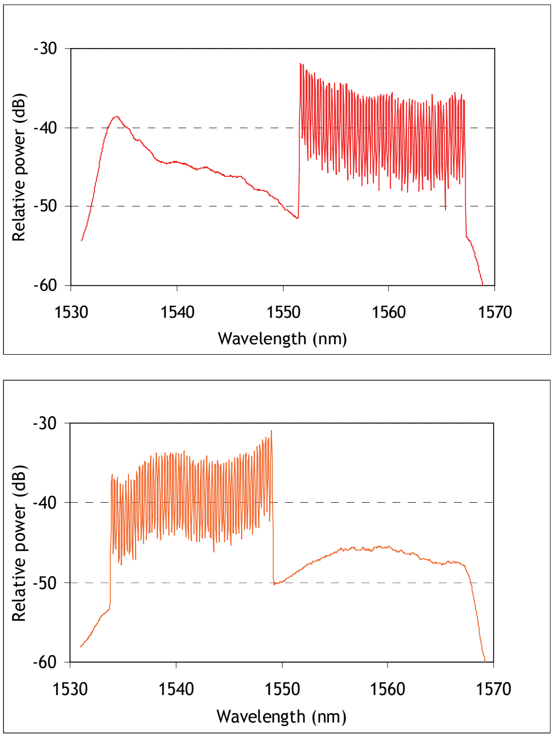

Figure 10 : Pair #2 Received 58-channel Spectrum with Cable Cut in the OADM BU Section on the Branch (Top) – Pair #2 Received 58-channel Spectrum with Cable Cut in the OADM BU Section on the Trunk (Bottom)

The transmission performance of the received channels modulated at 10 Gb/s with RZ-OOK format corresponding to the three presented spectral curves is shown in Figure 11. The measured Q factors after 3075 km transmission indicate that part of the available margins coming from the reduced transmission length have been consumed. However the Q factor results recorded after 3075 km transmission and corresponding to the case of a cable cut in the branch remains higher than the performance results recorded after 6150 km transmission without any pre-emphasis adjustment.

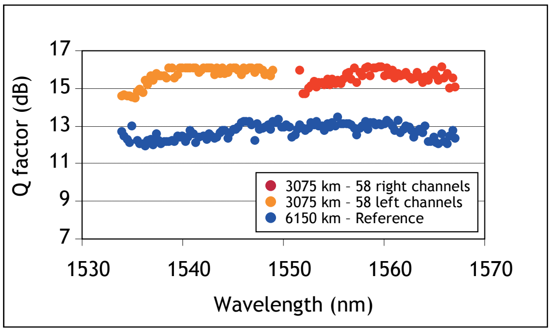

Figure 11 : Pair #1 Q Factor for Full Multiplex in Blue - Pair #2 Q Factor in Red (58 Channels at Longest Wavelengths) - Pair #2 Q Factor in Orange (58 Channels at Shortest Wavelengths)

These experimental results demonstrate the possibility to offer robust systems with high capacity OADM BU by managing available margins.

7 CONCLUSION

The design of WDM systems including OADM SLTE and OADM BU can be managed without questioning the renowned system robustness of submarine systems by considering failure scenarios in the design phase. Together with the flexibility offered by OADM solutions, it is also possible to offer self-healing capabilities with OADM SLTEs and systems which are robust by design with high capacity OADM BUs.

8 REFERENCES

[1] Olivier Gautheron, Gerard Bassier, Vincent Letellier, Georges Grandpierre, Patrick Bollaert, "8 x 2.5 Gbit/s WDM transmission over 6000 km with wavelength add/drop multiplexing", Electronics Letter, 1996 vol32 issue 11.

[2] Antoine Lecroart, Nazeeh Shaheen Peter Shawyer, "Cabled Science Observatories Solutions: Bringing Power and Broadband Communication to the Ocean Depths", Suboptic 2007, Baltimore USA, TuA2.4.

