THE CASE FOR OADM UNDERSEA BRANCHING UNITS WITH BANDWIDTH RE-USE

Daniel Welt (TATA Communications)
Email: daniel.welt@tatacommunications.com

TATA Communications
1441 Carrie-Derick, Montréal (Québec), Canada H3C 4S9

Abstract[1]**:** Undersea transmission networks are often built by consortium, or groups of "Partners" that combine their resources. Given the cost dimension, and the limit on the number of fibre pairs in undersea systems, they often face the challenge to establish a fair and efficient way to share the finite capacity among themselves and between many sites. "Wet OADM" with bandwidth re-use, supported by branching units with OADM functionality, is an efficient way to address such challenge. By allowing full mesh connectivity between sites without any transit through intermediate landing stations, OADM Branching units with bandwidth re-use are the best tools to maximize the availability and capacity of the undersea networks. This paper illustrates the OADM BU advantages from the Purchaser/User point of view and suggests methods to facilitate its implementation.

[1] Note: the views expressed in this paper only reflect the views of the author and not necessarily the views of TATA Communications.

1. INTRODUCTION

The purpose of this paper is to promote the case for a “true” OADM application in undersea systems where availability is maximized, active branching units minimize the impact of cable cuts and optical bandwidth is re-used to truly maximize the system capacity.

Basic OADM Principle

OADM, or “Optical Add Drop Multiplexing” is a conventional method to combine DWDM channels on a single optical fibre. It is widely used in terrestrial networks.
One implementation method is to use optical sub-bands. The basic building block is illustrated in Figure 1: On the drop side, a wide band optical splitter sends a copy of the trunk signal to a branch. An optical filter (optional) blocks all but the channels which destination is the drop site. On the add side, new channels in the same optical sub-band are injected in the trunk. In the trunk an optical filter blocks the dropped channels, allowing re-use of the optical spectrum.

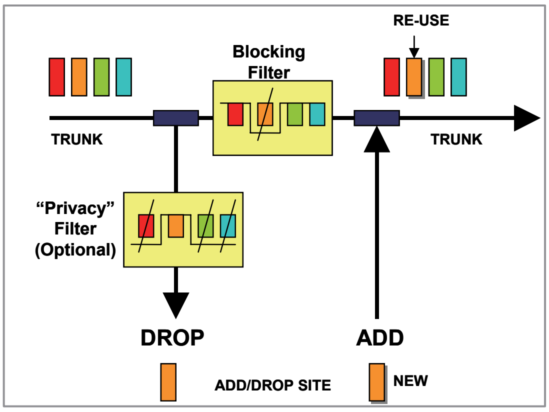

Figure 1: Add/Drop with Bandwidth Re-use

2. A LITTLE BIT OF HISTORY

The idea to route traffic at undersea nodes using Add/Drop multiplexing is not a new one. It was first implemented in TAT-9, a now retired transatlantic regenerated PDH-based 591.2Mbps system that was put in service in 1991. The driver was to satisfy the “customer-states” requirements of USA, Canada, France, UK and Spain to share what was at that time a very limited resource in an optimum way. It was not strictly speaking “OADM” because the add/drop functionality was done in the electrical domain, but the “eADM” functionality enabled for the first time to route capacity smaller than the full fibre capacity to an end point, via an undersea device. It was possible to add/drop individual 140Mbps streams or individual DS3s to a branch.

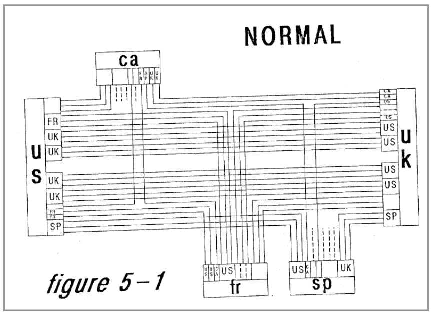

Figure 2: TAT-9 “eADM” traffic flow

However, considered by some expensive, complicated and unreliable, the TAT-9 experiment was unique and no other system was ever built the same way, paving the way for the “ADM-less” era that prevails until today.

With the development of all optical amplification (EDFA) and WDM/DWDM technologies, the building blocks to enable more refined and more efficient networking applications via OADM technology appeared to be in place. The enormously limiting factors of “eADM” technology such as power-hungry ASICs and large footprint impossible to scale up were replaced by very small components requiring no power at all. OADM was the perfect technology for undersea networking. However, procuring an OADM solution from any of the current suppliers remains very challenging.

3. THE CASE FOR OADM

The case for OADM in undersea systems is a very simple one. There are 3 drivers:

1) Efficient and fault-tolerant use of capacity: The density of the optical mesh increases and more and more “smaller” countries/cities connect to the global optical network. At the same time, the design capacity per optical fibre increases, growing from values lower the 1 Tbps to multiple Tbps in the near future with the development of bandwidth-efficient solutions such as 40Gbps on 50GHz optical grid. From an economic point of view it becomes necessary to share the capacity of a single optical fibre between multiple landings. At the same time it does not make sense to expose to fibre cuts the entire capacity of each optical fibre. For each pair of A-Z nodes, only A-Z traffic should go to shore and the rest should stay in the relatively safe deep-sea portion. A simple case study in section 4 illustrates that point (see Figures 4 and 5).

2) Minimize Round Trip Delay: Traffic transiting via multiple landings naturally has an increased

round trip delay that is penalizing for the now dominant IP traffic.

3) Simplifies administration: Traffic transiting through intermediate sites where it does not need to drop necessitates transiting and OA&M arrangements that complicate the contracts, reduce overall availability and generate costs that would otherwise not be necessary.

4. THE OADM AVAILABILITY ADVANTAGE

CASE STUDY

In order to illustrate the fundamental reason in favour of the use of OADM in undersea systems, a case study is presented. The system is a trunk and branch network with 7 landings (2 end nodes and 5 branch nodes) and 2 fibre pairs, 1 local and 1 express. Transmission paths, or DLSs, are created between each pair of the 7 nodes (T1 to T7). Simple availability calculations easily show the availability advantage of skipping branches where traffic does not need to go. To illustrate the case in more graphic terms a simulator is run to illustrate the life of the system in terms of down time, comparing an OADM solution versus a non-OADM solution.

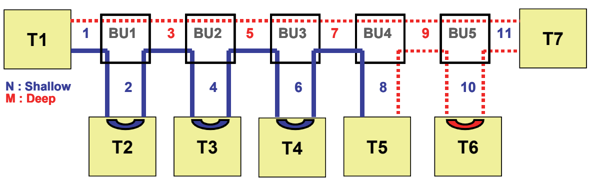

Figure 4: DLS T1-T5 path without OADM (Short route in blue, long route in red)

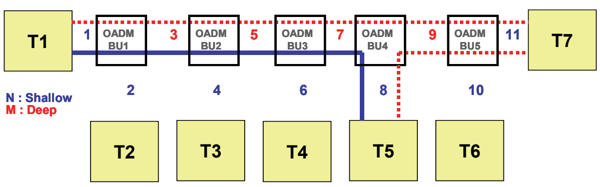

Figure 5: DLS T1-T5 path with OADM (Short route in blue, long route in red)

The following parameters are used:

- Length of deep water sections (sections 3, 5, 7 and 9): 1,000 km each
- Length of branch sections (sections 1, 2, 4, 6, 8, 10 and 11): 200 km (in shallow water)
- Probability of fibre cut in deep water: 0.025 per 100 km per year
- Probability of fibre cut in shallow water: 0.25 per 100 km per year
- Repair time: 10 days

The simulator is run for 1000 system lives and statistics are presented that provide among other parameters:

- The unavailability time in days per DLS for 10 years. The case presented in this paper is for the DLS going from node T1 to node T5

- The maximum number of simultaneous faults in that DLS (which would translate in a maximum number of ships required simultaneously at a given time during the 10 years observation period)

Unavailability Results:

Figure 6 illustrates the simulator output and the distribution of the results. As expected, the OADM DLS between T1 and T5 that goes through only 2 branches (versus 5 branches for a DLS going to every landing) has its unavailability reduced by about 55%, which is close to the 60% that would be obtained if the contribution of the trunk was zero.

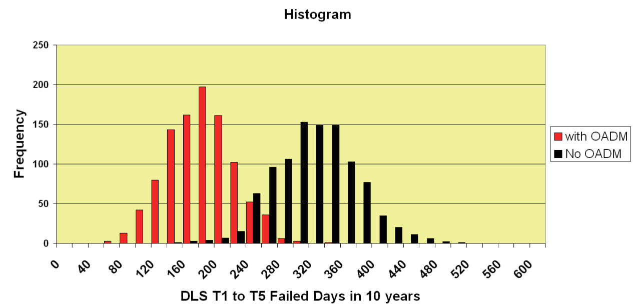

Figure 6: Probability distribution of the number of unavailable days for DLS T1 to T5 in 10 years, with OADM (red) and without OADM (black), simulated

Similar calculations and simulations can be run for all DLSs. The process is straightforward and naturally demonstrates what common sense dictates, that is the very significant availability gain of the OADM solution versus a non-OADM solution.

Number of simultaneous faults

Using the same principles, one can also investigate the probability of having simultaneous faults, which in turn require more than 1 repair ship in order to protect a given DLS.
The next Figure shows the simulated distribution of the number of simultaneous failure for DLS T1 to T5, with and without OADM. With OADM, the probability that no multiple failures will occur is

53% and the probability that 2 simultaneous failures will occur is 45%.
But with the same network and same probability of cut, the same DLS running on a non-OADM network (Figure 4) has a probability of 80% to suffer 2 simultaneous failures that in turn require access to 2 repair ships in the region.

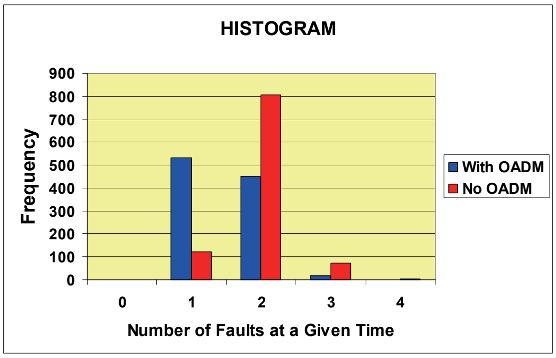

Figure 7: Probability distribution for the occurrence of simultaneous failures in 10 years for DLS T1 to T5, with and without OADM, simulated

Using Internal restoration to mitigate against branch failures

In a trunk and branch system, it is possible to mitigate against branch failures to a degree by establishing system-internal restoration using an express fibre pair (1+1 internal restoration). In such scenario (shown in red in figures 4 and 5), the DLS has 2 copies: one on a short route and one on a long route. Its availability becomes dominated by the trunk availability, and therefore becomes comparable to the OADM availability scenario. However, this reduces the available bandwidth by 50%. In other word, in order to keep the same availability as an OADM DLS, 50% of the bandwidth must be wasted. This is illustrated by the figure below that compares the unavailability numbers for the OADM case versus the non-OADM 1+1 case: both plots are similar.

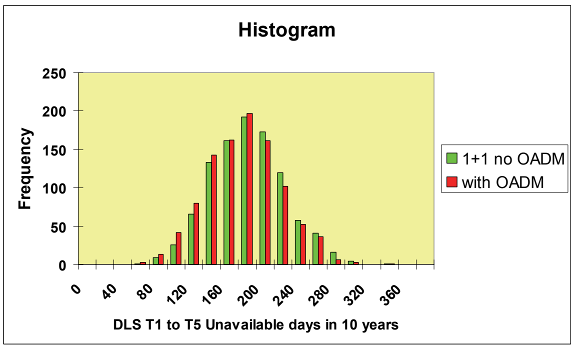

Figure 8: OADM versus non-OADM 1+1 internal restoration, simulated (with express fibre pair)

5. THE CASE FOR OADM WITH BANDWIDTH RE-USE

The case for OADM being made on the basis of improved availability and reduced latency, it is important to address the second point that is the need for bandwidth re-use.

There are OADM solutions proposed by some Suppliers where no filtering is done, as shown in Figure 9.

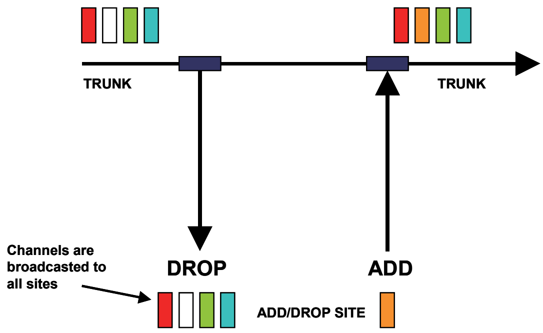

Figure 9: Add/Drop without Bandwidth Re-use

These solutions are sometimes referred to as "wideband OADM". Although such design approach is simple and allows the flexibility to allocate traffic without constraints, the major drawbacks are:

1) The optical spectrum cannot be re-used and there is a loss of capacity even when accounting for the optical guard bands (when the number of nodes is small enough).
2) Channels are broadcasted everywhere, unless optical filters are added.
3) When there is a cable cut, the wide band noise of optical amplifiers is not filtered and therefore, failure on one leg can affect transmission on other legs, violating the principle of independence of the transmission paths and reducing overall system availability.

How to By-pass Guard Band limitations

In "wideband OADM" with no filtering, the total bandwidth available ("BW") is shared among all the DLSs. In a system with N nodes, there are N*(N-1)/2 DLSs and therefore, assuming that each DLS is allocated equal bandwidth, each DLS has a bandwidth of 2*BW/N*(N-1).

In an OADM with bandwidth re-use guard bands are needed to protect against channel interference due to filter imperfection. The spectrum is sliced and the maximum number of slices is defined by the traffic in the part of the system carrying the maximum number of DLSs, which is the middle of the system. For example, for a system with 4 nodes (3 segments), the maximum number of spectrum slices is needed in segment 2 between node 2 and node 3.

One can show that the number of spectrum slices depends on N being odd or even. The next table shows the number of spectrum slices needed in a trunk and branch system with N nodes.

No. of nodes	2	3	4	5	6	7	8
No. of DLSs	1	3	6	10	15	21	28
Spectrum slices	1	2	4	6	9	12	16

Table 1: Number of spectrum slices required in a 1-Fibre-Pair trunk-and-branch OADM system with N nodes when all DLSs are allocated the same capacity

If we define the bandwidth re-use gain as the total usable bandwidth when bandwidth is re-used, versus the wideband OADM case (where bandwidth is not re-use), and we plot such gain versus the number of nodes, and we take into consideration the guard band, Figure 10 can be plotted.

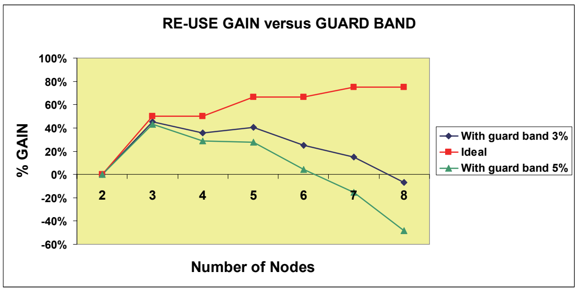

Figure 10: Bandwidth gain of "OADM with bandwidth re-use" versus "wideband OADM", versus number of nodes and guard band size, for equally distributed DLS capacity

Although it is true that the OADM with bandwidth re-use advantage reduces with the number of nodes, and especially if the guard band is large (e.g. 5%), the work around is to use 2 fibre pairs where each fibre pair can be setup to support only a fraction of the DLSs.

As an example DLSs for systems with 6 and 7 nodes using 5% guard band are spread on 2 OADM fibre pairs with bandwidth re-use. There are many ways to do so. If we divide the spectrum slices equally between the 2 fibre pairs (+/- 1), Table 2 below indicates that the net gain of doing this, versus having 2 wide-band OADM fibre pairs, is very significant.

Total Link Bandwidth (per FP)	1280		Gbps
Number of nodes	6	7	
Number of DLSs	15	21	
Total Usabe Bandwidth (NO RE-USE)	1280	1280	Gbps
Bandwidth per DLS (NO RE-USE)	85	61	Gbps
Guard Band (5%)	60		Gbps
Spectrum slices on 1 FP	9	12	
Bandwidth per DLS (1 FP with guard band)	89	52	Gbps
Total Usable Bandwidth 1FP (with re-use)	1333	1085	Gbps
RE-USE GAIN 1FP	4.17%	-15.23%	
ADD 1 FP			
Total Usabe Bandwidth (NO RE-USE)	2560	2560	Gbps
Bandwidth per DLS (NO RE-USE)	171	122	Gbps
FP1 spectrum slices	4	6	
FP1 DLSs	8	11	
FP2 spectrum slices	5	6	
FP2 DLSs	7	10	
FP1 bandwidth per DLS with guard bands	275	163	Gbps
FP2 bandwidth per DLS with guard bands	208	163	Gbps
FP1 Total Usable Bandwidth (with re-use)	2200	1797	Gbps
FP2 Total Usable Bandwidth (with re-use)	1456	1633	Gbps
TOTAL Bandwidth (re-use)	3656	3430	Gbps
RE-USE GAIN 2FP	**43%**	**34%**	

Table 2: OADM Re-use gain with 2FP

In this example, splitting the DLSs on 2 fibre pairs enables optimum spectrum re-use and provides a capacity gain above 30%.

6. ENABLING TECHNOLOGIES

Having established the clear advantages of OADM with bandwidth re-use, the problem remains to obtain from the Suppliers the tool kits to do so.

Although it would be the burden of Suppliers and not a direct scope of this paper to address this issue, the following observations can be made:

Optical Spectrum Constraints

Because of the extreme lengths, undersea systems are implemented with a fixed optical loading/spectrum approach.

The capabilities to implement very complex optical layers, as sometimes promoted by some Suppliers of terrestrial optical networks, cannot be implemented.

The undersea repeaters have insufficient capabilities to adapt to changes of the input spectrum as generated by faults in OADM systems. For example, the figure below illustrates what happens in a wideband OADM system when the trunk is cut.

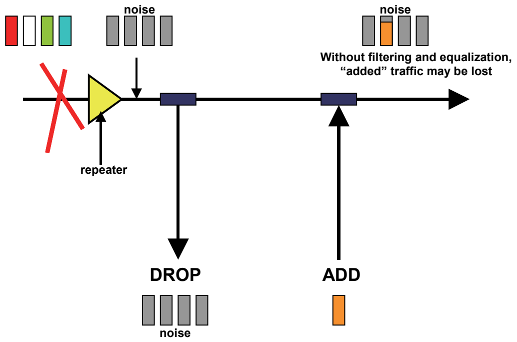

Figure 11: impact of a trunk fault on added traffic

The upstream repeaters may generate so much noise that all traffic downstream is degraded or lost. Problems like this are addressed in terrestrial systems by having EDFAs with complex functions such as automatic shutdown, transient suppression etc. that do not exist in undersea repeaters.

There are certainly several ways to address that issue and Suppliers may propose. However, it is the opinion of the author that, if minimum effort is required, and repeater design does not change, the best enabling technology is an active branching unit capable to mitigate the effect of OADM on the transmission spectrum.

7. THE CASE FOR AN ACTIVE AND UNIVERSAL OADM BRANCHING UNIT

It may have been the headaches related to TAT-9 "eADM" branching units, the 5-year development period, relatively high cost and relatively complicated integration, or perhaps not, but the fact remains that branching units architectures went back to basic after that era, preventing the establishment of optimized undersea nodes. However, the fact is that there is no fundamental reason against active branching units with an optical core enabling proper OADM functionality. The issue of branching unit reliability, or lack of, usually relates to the high voltage power switching function that is a completely separate issue all together.

Therefore, the proposal in support of the notion of an optimized undersea node is the following:

1) The undersea telecommunications community should put aside traditional Supplier differences and define an optical architecture for a universal OADM undersea network. To do so, a universal sub-band architecture should be defined and agreed in order for all future systems to be able to support optimized OADM traffic if so chose the Customers.

2) A universal optical block should be defined to support an active OADM branching unit that would be capable to maintain constant optical loading in case of cable cut and alteration of the DWDM stream, by using EDFAs internally capable to (a) adjust optical levels and (b) become optical noise sources.

AN OPTICAL BLOCK PROPOSAL

If the principle of a fixed optical spectrum must remain, the active OADM branching unit should be able to compensate for spectrum variations. In order to do so, the following block schematic is proposed for discussion.

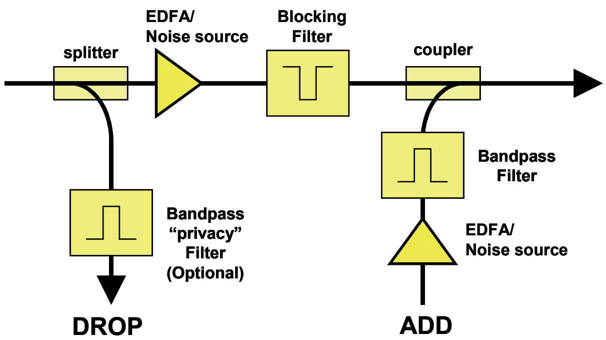

Figure 12: Active OADM Branching Unit Optical Block Proposal

The basic concept is that the optical spectrum from node "n" is shaped for node "n+1" using EDFAs, also used as noise sources, and traditional filters. By doing this, and as shown in the next 2 figures, both cases of trunk failure and branch failure are managed. The EDFAs adjust the spectrum slices or add noise in such a way the impact downstream is minimized.

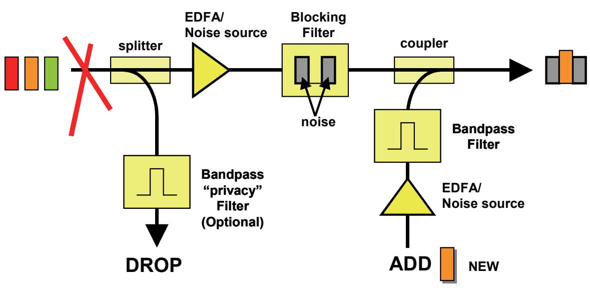

Figure 13: Effect of Trunk Failure on Active OADM BU

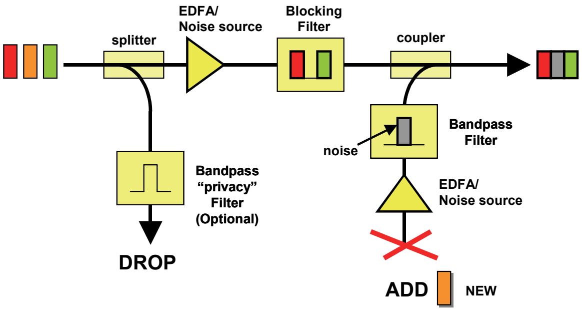

Figure 14: Effect of Branch Failure on Active OADM BU

8. CONCLUSION

This paper has illustrated the simple concepts that support the architecture of undersea systems that make use of the OADM technology with bandwidth re-use. The net gain in availability and capacity should justify the modest developments required to establish an industry standard branching unit supporting these capabilities. The objective is to propose a simple way forward to advance undersea system networking beyond the fixed point-to-point links and establish some guidelines to enable all users to maximize availability and bandwidth, minimize round trip delays and offer to all Customers the best services.

END OF DOCUMENT