# AGILE UNDERSEA NETWORKS BASED UPON ADVANCED OADM TECHNOLOGY

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**Abstract:** The ability to share bandwidth on an undersea fibre using OADM technology has rapidly become a standard offering in Undersea Networks, with a dramatic increase in deployment occurring during the last decade. However, as traffic demands change and requirements on network resiliency become greater, the limitations of static OADM topologies become apparent. Significant progress had been made in component technology to allow for sub-band and wavelength level routing in the undersea network. This capability, combined with next generation transponders capable of compensating for trans-oceanic levels of accumulated dispersion represent the dawn of a new era of highly adaptable undersea networks.

## 1. OADM UNDERSEA NETWORKS-HISTORY

During the last decade we have witnessed an increase in the demand and implementation of Optical Add Drop Multiplexing (OADM) technologies in undersea fibre-optic Telecommunications Networks. In an OADM network, the same fibre pair is shared for connectivity among multiple stations by sharing the optical bandwidth over different digital line sections (DLSs). The OADM technologies in undersea networks consisted originally of either fixed filters networks or broadband couplers/splitters located at each OADM node. Figure 1 shows a typical OADM configuration using a static 're-use band' OADM design approach. In the typical $\pi$-network topology of Figure 1, a portion of the band of one fibre pair is assigned to express traffic between the stations A and D, and the remainder of the usable band on the same fibre pair, minus guard-bands, is assigned to local add-drop traffic to and from stations B and C. Note that in the example of Fig. 1 the same optical sub-band is shared for traffic between stations A and B , between stations B and C and between stations C and D: this is the concept of the re-use band OADM design. Prior to the re-use band design, other and less efficient add-drop design approaches were introduced: the broadband OADM design approach, which has no filters in the OADM nodes and where the wavelength management is carried out entirely at the stations; the broadcast-collect design approach which utilizes fixed sub-band or channel assignments but is used for traffic connectivity exclusively to/from East or to/from West.

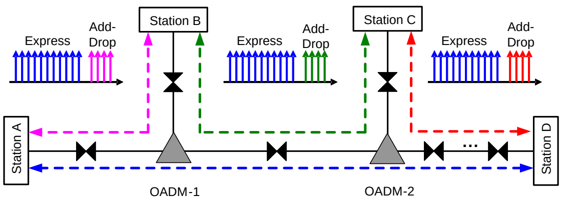


**Fig. 1 – Typical $\pi$-network topology with two OADM nodes.**

As a reference, numerous undersea OADM nodes based on fixed filter design have been deployed in different regions of the world, and more will be deployed in the near future.
As illustrated in Fig. 1, fixed band OADM technologies have thus greatly increased the flexibility for traffic management as they allow for allotment of the overall

optical band to separate sub-bands which are assigned to different add/drop and express locations, thus providing a higher traffic throughput per fibre pair, reducing the cost of bandwidth delivery, and improving latency as some wavelengths travel through the shortest fibre path. There are however a few limitations for the fixed band design approach: guard bands at the boundaries between sub-bands are always required; in the event of a cable fault on a segment, traffic recovery may be limited, as it may not be possible in some cases to recover the traffic transiting through some of the surviving segments. In addition, the allotment between the express sub-band and the local add-drop sub-bands is just based on the initial traffic demands. However as traffic demands change over time, it is a significant operator's benefit to make the network more and more agile, such that new traffic configurations can be accommodated upon demand via remote commands..

## 2. RECONFIGURABLE R-OADM UNDERSEA NETWORKS – PRESENT AND OUTLOOK

More advanced technologies that allow deployment of undersea Networks using reconfigurable OADM (ROADM) nodes are being introduced. Some technologies that allow flexible and dynamic reconfiguration of traffic, and that have been embraced by the broader optical communications market, have been presented in the literature [1, 2].

In ROADMs, TE SubCom technologies enable to switch any input wavelength to any of its output ports with as needed power level adjustment via controllable optical attenuation, thus eliminating most restrictions of a static band approach. The quality and reliability of the SubCom technologies have also matured to a point that ROADMs are now being introduced commercially in the undersea market: the reliability aspects of ROADM technologies have been under study for quite some time. With the introduction of SubCom technologies in ROADMs, the undersea networks are provided with the flexibility of grid-less, fully reconfigurable and remotely controllable nodes, thus allowing individual wavelengths to be assigned remotely as either express traffic or add-drop traffic. This introduces a great deal of flexibility in the network: it is typical for example that the express band is allotted a significant portion of the overall optical fibre band at initial deployment, but as the traffic demand in the branch stations grows over time, the portion of the band allotted to the express traffic could be later reduced to allow increase of traffic capacity in the local add-drop sub-bands. Fig. 2 illustrates a possible scenario of band allocation at initial deployment versus a future traffic configuration enabled by remotely reconfiguring the ROADM nodes over time.

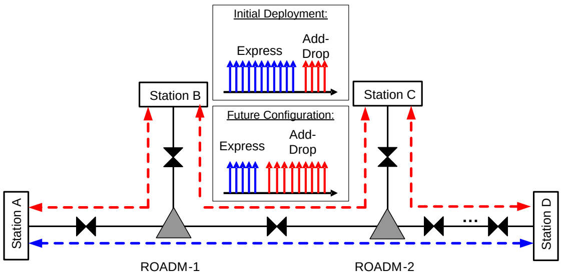


**Fig. 2 –Agile π-network topology with two ROADM nodes. The ROADM nodes can be flexibly and remotely reconfigured based on traffic demand to accommodate increasing add/drop band to express band ratio, or to re-route individual wavelengths.**

As traffic gets re-routed via a ROADM to a new path using wavelength-specific switching commands, some channels will travel along a new and much different path distance and will experience a new fibre chromatic dispersion map. With the well established direct detection transmission technologies, this change would translate into optical adjustments needed in the terminals, sometimes severe or even service affecting. However the recent deployment of coherent technologies at both 40Gbit/s and 100Gbit/s has completely overcome this issue, as digital signal processing (DSP) of coherent technologies provides for flexible and adjustable level of chromatic dispersion compensation in the electrical domain, and over a very wide range that will cover all possible distances in the undersea network. As a reference point, a typical transpacific distance, on a wet plant optimized for coherent transmission is well within the reach of DSP compensation capabilities in coherent transceivers. This is a fundamental technology leap that coherent technologies have brought to optical networks, in comparison with the former direct detection technologies. In addition coherent technologies have been extensively demonstrated via experiments over ultra long-haul distances up to transpacific range [3, 4], reaching spectral efficiencies as high as 400% at 100Gbit/s, corresponding to sub-Nyquist channel spacing.

Another important design advantage of ROADM based networks is the possibility to concatenate multiple nodes without any significant impairment to the channel performance. First the evolution of the OADM technology has brought to a significant reduction of the width of guard-bands, as compared to the fixed band designs: in ROADMs, in the case of the larger channel spacings there are no channels lost to guard-bands at the boundaries between express and add/drop sub-bands, while only very few channels may be lost at the tighter channel spacings used at 100Gbit/s transmission. Also due to spectral narrowing effects, the fixed filter designs would typically impose an upper limitation on the maximum number of nodes that can be concatenated on the same fibre, with a typical of only a few concatenated nodes when using the fixed filter band technology. On the other hand, improvements in specifications of ROADM modules, which could achieve broad flat passbands, have enabled transmission through extensive ROADM networks which can therefore concatenate a larger number of OADM nodes if needed.

ROADM-based nodes also provide great resiliency in the network to withstand fault events, for example cable cuts caused by external events. Several fault scenarios and their impacts to the network had been experimentally investigated and reported [5, 6], however ROADMs provide greater flexibility as they can reconfigure the network to fill in with channels (or equivalent power) all the sub-bands where channels are lost after cable cuts. For example, when a cable cut occurs in a branch cable, the associated ROADM node can be re-configured so that the entire optical band of the fibre is transmitted through the trunk as express traffic, and this temporary configuration would continue for as long as the branch segment is inoperable and cannot support transmission. The above fault scenario is depicted in Fig. 3.

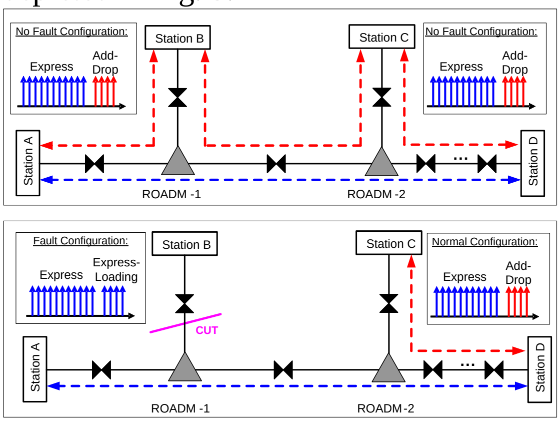


**Figure 3. ROADM reconfiguration for node 1 in the event of a cable cut in the B branch: wavelengths previously routed through the B-branch are re-assigned to the trunk as express traffic. Top picture shows the normal (i.e. no fault) configuration, bottom picture shows the configuration in the event of a cable fault in segment B. Further, Station A can supply the express-loading as indicated in the box 'Fault Configuration'.**

ROADM nodes provide great flexibility also at the time of initial installation: if a branch segment is not installed initially, a ROADM unit is not required initially, and the entire optical band of a fibre pair can be dedicated to express traffic; at the time a branch segment is installed the associated ROADM node would be installed as well and configured to allow traffic to and from the newly built branch station. This is a significant advantage of ROADM based designs, as operators do not have to worry about having stranded band at initial deployment, which on the other hand they had to consider in the fixed filter OADM designs.

Similar technologies as used in ROADMS can be greatly beneficial also in the land terminals: Loading units in the land terminals using SubCom technologies can provide the flexibility of either loading the partially unused regions of the optical band at initial deployment, or of helping to recover the network after a fault. In fact a loading unit in a terminal could be designed to fill in with dummy channels those parts of the optical band where channel power is lost due to a sudden event such as a cable or fibre break in a part of the network. In addition a loading unit in a land terminal could be designed to render upgrades or fault recovery in a ROADM network seamless. The outlook in particular is that fault recovery could be developed and implemented independently of specific line terminating equipment used and of specific supplier constraints and equipment.

## CONCLUSION

The most advanced ROADM technology that is being introduced in the undersea market has been discussed. This new SubCom technology allows for great flexibility in the design of fully reconfigurable OADM networks. ROADM based nodes provide for the needed flexibility to support wavelength level routing, wavelength reuse, remote configuration, dynamic channel equalization, no pre-planning of traffic demand, flexible addition of branches and fault recovery. The advantages of SubCom technologies used in the terminals as well as coherent technologies used in the context of undersea ROADM based networks have also been highlighted and discussed.

## 3. REFERENCES

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