# Agile Subsea Networks

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**Abstract:** Approaches to configurable optical routing including fiber switching and WSS spectrum routing have become ubiquitous in undersea transmission systems. These agile architectures must be reconsidered as the fiber pair count, fiber technology and branching node complexity of those systems continues to grow. 

## 1. Introduction to the Evolution of Agile Capacity Routing in Undersea Systems

In this paper, the history, the present status and the future evolution of agile capacity routing in fiberoptic undersea transmission systems will be discussed. This paper reflects the author experience in this area [1,2] and is clearly declared not to be a full academic review. The extensive work of colleagues in submarine technology evolution in the areas of increased fiber pair and cable capacity, decreased system cost and cost-per-bit, and increased fiber pair and spectrum routing agility is gratefully acknowledged [3].

As recently as 2017, placing active reconfigurable optical elements such as optical switches in undersea equipment, and controlling that equipment from shore, was novel for the subsea industry. The term "undersea ROADM" (Reconfigurable Optical Add Drop Modem) applied to products with multiple OADM optical filter options, with optical switches to select between those filters. However, in practical usage, it was difficult to negotiate even a single bandwidth allocation agreement for a trunk fiber pair between multiple branch site owners. For this "switched ROADM", the resulting need to define multiple OADM band allocation options made the use case limited, and not appropriate for the complex branching architectures of modern networks (Figure 1).

The concept of moving from OADM filters to wavelength selective switch (WSS) technology for submarine equipment to gain true flexible-grid ROADM functionality was being carefully discussed in 2017 [1], due to the high reliability requirements inherent to undersea equipment. But customer desire to finalize capacity routing closer to the system activation date, and to support more branch stations on the same trunk fiber pair, led to the acceptance of undersea WSS ROADMs soon afterwards [4,5,6]. The "Open Cable" design approach [6,7] had also been introduced to undersea systems, bringing freedom to select submarine line termination equipment (SLTE) including coherent modems closer to the activation date. In general, the customer goal has been maximum freedom in undersea capacity usage, independent from the lengthy process of building the undersea hardware.

As of 2021, WSS-based WSS ROADMs have become ubiquitous, providing flexible-grid add and drop functionality that can be reconfigured from shore. The units often contain optical amplification to compensate for the WSS losses, and optical switches to implement WSS redundancy for enhanced reliability, and for WSS bypass for support of loss-of-power situations. The units may also provide loss of power detection on the trunk and branch inputs, so that automatic reconfiguration can be provided to maintain trunk loading when cable damage occurs. The WSS ROADMs may provide separate branch fiber pairs from a branch station with access to both directions of one trunk FP, or may have more specialized configurations to reduce branch FP counts.

Optical fiber switch routing is also common in undersea branching units [8], allowing a trunk fiber pair to either access branch fiber pairs, or to bypass the branch entirely. More complex switching functions are available, for example to select between two trunk fiber pairs for access to the branch, or a more generalized 2FP function to make connections between two fiber pairs in each of the three cables connecting to the branching unit. These designs allow the user to bypass damaged branch cables, or to actively choose the network connectivity based for example on evolving system capacity needs, landing permit issues or political situations.

## 2. Impact of Changing Subsea Technology on the Implementation of Subsea Capacity Routing Agility

There are unique design aspects for undersea fiberoptic cable systems in areas such as equipment mechanical density and strength, ship handling, high voltage powering, and long-term reliability so that new product developments are the result of wide-ranging expertise in many areas in addition to optical transmission technology specialists.

### *2.1. Impact of Cable Capacity on Subsea Agility*

The total capacity of undersea cables has been steadily growing. The capacity of individual C-band fiber pairs (FPs) has however stabilized due to multiple factors, including the high spectral efficiency of modern coherent modems and the high optical pump power efficiency of the Space Division Multiplexing (SDM) approach to transmission path design in undersea systems [9]. As a result of these technology updates, the increase in capacity is being implemented primarily with increasing fiber pair (FP) counts, with 24FP trunk cables along the Trans-Atlantic route, and (12-16FP) trunk cables along longer routes. The fiber pair counts on branch cables that interconnect to both directions of trunk traffic are sometimes even higher than on the trunk, exceeding 24FPs.

There is currently open discussion in the industry on what the next new technology should be for additional capacity [10]. As those technologies introduce more transmission paths, whether that be extra single mode fibers [11], or extra cores in Multiple Core Fiber (MCF) [12-15], or extra bands in C+L transmission [16,17], it is advantageous for equipment cost and complexity to shift the capacity routing level of aggregation towards per-fiber or per-core, with reduced levels of "optical spectrum routing".

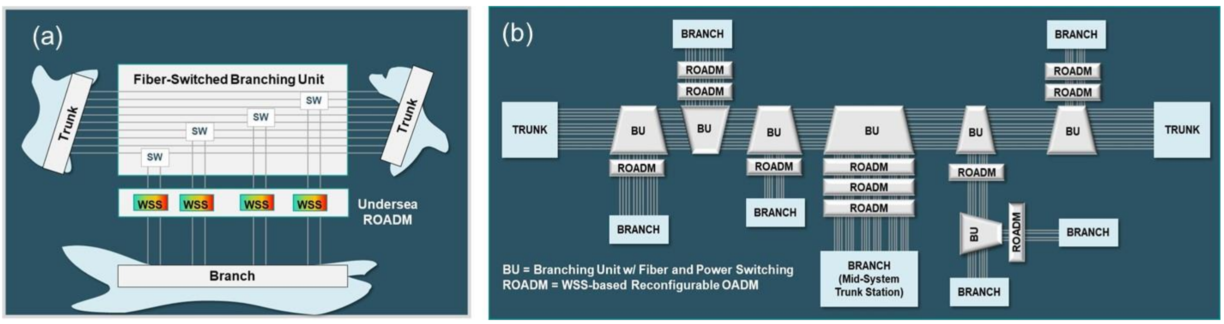


Figure 1: a) Node with fiber switching and WSS ROADM; b) example of complex multi-node submarine network.

Fiber with reduced coating thickness [18], for example 200um reduced from the typical 250um, will allow the cable fiber packing density to be increased without otherwise modifying the cable inner tube dimensions. This near-term improvement could, for example, allow higher FP count cables such as (26 – 32FP) to be provided for branch cables that connect to 24FP trunk cables.

Multiple Core Fiber (MCF) has also been proposed for use in undersea systems with initial consideration for uncoupled-core 2-core or 4-core fiber [12-15]. As with all new technology, the consideration of MCF for undersea applications must be analyzed in terms of cost-per-bit system pricing, electrical power efficiency, reliability, ability to meet system gain shape targets. In terms of agile networking, there could be a notable advantage in reduced cost and complexity if entire MCF fibers can be routed through optical switching, without breaking out the individual cores for per-core switching or per-core WSS ROADMs.

The addition of an "L-band" of traffic to the existing C-band has been used in a few undersea systems in approximately 2018 [16,17], and more recently been used in terrestrial systems to put more capacity on existing FPs. This "C+L" approach may be used once again in undersea systems at the point where other approaches to adding "more fibers" or "more cores" are not available. From an agile networks point of view, separate C-band and L-band ROADM structures are required, so the physical space and component counts in undersea housing for DWDM routing of optical spectrum are not reduced relative to two C-band fiber pairs. There is however an advantage in reduced fiber pair and housing penetration count. There are also architecture options where for example only one of the two bands has access to a branch station, reducing the required undersea equipment, but the existing C+L system provides full branch access to both the C-band and L-band

### *2.2. Impact of Electrical Powering on Subsea Agility*

Undersea systems are powered from shore, through conductors in the cable, so power connectivity architectures and power dissipation are key design parameters [3]. On longer routes in the range of $\geq$ 10,000km, the system capacity tends to be limited by available electrical power, not by the number of fiber pairs that can be supported by the cable and repeaters as on shorter systems. In undersea systems, the cost of a system is strongly dependent on the OSNR requirements, and therefore to the fiber characteristics, span lengths, and repeater counts. It is important that any new equipment added for fiber or spectrum routing flexibility should not result in OSNR impairments that will require shorter amplifier spans and more repeaters.

The Power Feed Equipment (PFEs) used to power systems from shore are increasing in maximum voltage level, currently supporting up to ±18kV [19,20]. Any new agile routing equipment, as well as the cable and repeaters, must be able to support operation at these higher voltage levels and the corresponding "surge current" levels that may occur when a cable is damaged. Agile equipment must also be power efficient, to minimize impact on cable fiber pair count and total capacity from having multiple branching nodes along the trunk powering path. Power in undersea cables translates directly to capacity and/or length and must be very carefully preserved and allocated.

### *2.3. Other Impacts on Subsea Agility*

The contracts for undersea systems specify a system life of at least 25 years. This requirement impacts the initial system design in terms of allowing for end-of-life system OSNR, including performance margins to support an agreed upon number and types of undersea repairs. The undersea repair process requires the addition of cable length to the system for each repair, so that the ship can bring both cable ends to the surface for the repair activities. The amount of additional cable added to the system then depends on the water depth at the repair location. The reliability of agile optical routing equipment also impacts the number of required repairs, and associated design margins, and impacts the expected out-of-service times while repairs are made.

Several design steps are taken to minimize the impact of agile optical routing equipment reliability on system performance. All optical components are put through a rigorous "undersea qualification" process, that may result in a difference in what technologies are preferred for undersea versus terrestrial use. The electronic and optical designs include component and configuration redundancy, to minimize fault impact from single failures. Architectures are designed to "fail" to an acceptable configuration when electrical powering is lost, to minimize the impact on the overall system. For example, with optical switches to bypass elements such as WSS filters and optical amplifiers when impending loss of power is detected, so that loss of power to a reconfigurable add drop multiplexer (ROADM) that is powered from a branch station does not result in loss of trunk traffic through the unit.

## 3. Conclusion

The design process for undersea systems is complex, with design interaction between many factors including system and fiber pair capacity, transmission technology, branching node architecture, electrical powering, and degree of agile fiber pair and optical spectrum routing. The continuing network capacity and complexity growth will bring corresponding evolution in network agility technology and architectures.

## 3. References

[1] L.D. Garrett, "*Design of Global Submarine Networks*," JOCN, vol. 10, no. 2, pp. A185-A195, 2018.
[2] L.D. Garrett, "*Multinational Submarine Networks*," OFC 2017.
[3] *Undersea Fiber Communications Systems,* 2nd ed., J. Chesnoy, Academic Press, 2016.
[4] Press Release: "*Jupiter 400-Gbps ROADM Submarine Network to Connect Japan, U.S., Philippines*," 2017.
[5] Press Release: "*TE SubCom Chosen to Extend MainOne Cable System to Francophone Region*," 2018.
[6] Press Release: "*Southern Cross and Alcatel Submarine Networks Sign NEXT Supply Contract, Signaling Start of Manuf. Phase*," 2019.
[7] P. Pecci et al., "*Design of Submarine Open Cables*," OFC 2018, M1D.4.
[8] Press Release: *"Announcing the Grace Hopper Subsea Cable, Linking the U.S., U.K. And Spain,"* 2020.
[9] Bolshtyansky et al., *"Single-Mode fiber SDM Submarine Systems,"* JLT 2019.
[10] J.D. Downie, "Maximum Submarine Cable Capacity Analysis with C-band, C+L band, and Multicore Fiber C-band," OFC 2018.
[11] Press Release: "*HMN Tech Launches 32FP Petabit-Level Repeater Prototype*," 2021.
[12] Y. Tamura et al., *"Low-Loss Uncoupled Two-Core Fiber for Power Efficient Practical Submarine Transmission,"* OFC 2019, M1.E5.
[13] T. Hayashi et al., *"Low-loss multi-core fibers for submarine transmission,"* SubOptic 2019, OP10-3.
[14] J. D. Downie et al., "*Techno-Economic Analysis of Multicore Fibers in Submarine Systems*," OFC 2021, Th4C.4.
[15] Press Release: "*NEC, Sumitomo trial uncoupled multi-core submarine fiber*," 2021.
[16] Press Release: "*TE SubCom Sets Record for Transmission Capacity Using C&L Technology*," 2017.
[17] Press Release: "*NEC first to achieve 50Tb submarine cable over 10,000km by using C+L EDFA*," 2017.
[18] W. Niu et al., "*Thin-Coated Fibers for High-Density Optical Interconnects*," OFC 2021, M3C2.
[19] Press Release: *"SubCom to build Google's Firmina Cable,"* 2021.
[20] Press Release: *"HMN Tech Launches 18kV Power Feeding Solution,"* 2021.