THE NEXT GENERATION OF RECONFIGURABLE UNDERSEA NETWORKS

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Abstract: There is an industry trend in undersea cable systems towards single-owner or few-owner systems, allowing the cable capacity and connectivity to be optimized at a higher level than the individual fiber pair. This change in ownership model provides opportunities for more complex network architectures to support increased overall network resiliency, beyond the current "Trunk and Branch" configurations. These network architectures will benefit from enhanced reconfigurable capacity routing options, including hybrid combinations of Wavelength Selective Switch ROADMs and whole fiber-pair switching. New approaches are needed to provide the shore-based electrical power throughout these higher complexity undersea cable networks. The addition of API-based management of all reconfigurable undersea elements will support customized network control functionality.

1. INTRODUCTION

There is an industry trend in undersea cable systems towards single-owner or few-owner systems where cable capacity and connectivity are better optimized at the total cable level rather than the fiber pair level [1]. Together with high year-over-year capacity growth rates, the number of fiber pairs in each undersea cable has therefore been steadily increasing [2].

The use of wet-plant reconfigurability in undersea systems has also grown [3,4,5]. This trend began with electrical power routing and has since expanded into the optical domain [6].

High-reliability optical switches inside Branching Units (BUs) enable entire fiber pairs to be switched between trunk and branch paths, whether to reroute the entire fiber pair capacity, to protect against branch cable faults, or to route fiber pairs to branch-based Optical Add Drop Multiplexing (OADM) devices.

The utilization of reconfigurable optical add drop multiplexing (ROADM) at the fiber pair level has also increased, evolving rapidly from fixed filter switching (switched ROADMs) to undersea-qualified wavelength selective switch filtering (WSS ROADMs). This move towards reconfigurable filtering in undersea systems has greatly improved the ability to redistribute system capacity after a system is deployed.

This paper discusses technologies available for increased network reconfigurability and introduces new higher complexity network architectures that can now be supported.

2. WSS ROADMs

The most recent reconfigurable optical component to be introduced to undersea system design is the Wavelength Selective Switch (WSS) [7]. The WSS filter provides in-service reconfigurable optical filtering and frequency-dependent attenuation control. User-defined spectrum bands can be re-routed between terminal sites, with only the re-assigned spectrum being directly impacted by the reconfiguration process. The WSS attenuation control can be used to re-adjust wet plant spectrum shape or to compensate for differential losses between the trunk and add paths.

The basic WSS functionality provides reconfigurable spectrum allotment between trunk and associated branch fiber pairs. As shown in both ROADM configurations of Figure 1, the Trunk/Add WSS selects between inbound optical spectra on the Trunk IN and Branch IN fibers to generate the outbound Trunk OUT spectrum.

The optional Drop/Loading WSS in the left-hand ROADM of Figure 1(a) includes drop-path filtering. This configuration can generate a fully-loaded Branch OUT spectrum by combining the filtered drop spectrum from the Trunk-IN port with recycled loading from the Branch-IN port. This configuration enforces Drop-Security requirements by restricting the drop-path spectrum to just that portion assigned to the branch station. In Figure 1(b), alternatively, the entire Trunk-IN spectrum is passed through to the Branch-OUT port and can then be further filtered in the branch station.

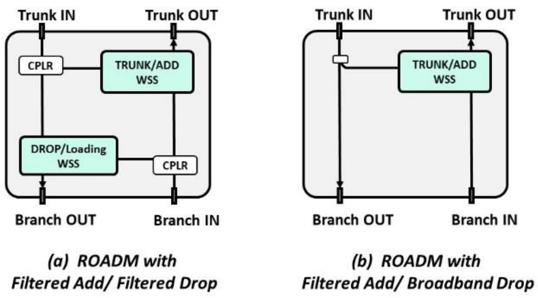

Figure 1: High-level ROADM Filter Diagram

In selecting ROADM technology for undersea use, many design considerations must be addressed. Components are deployed in pressurized undersea units of limited size, with limited available of DC power, and must have the capability to survive the harsh ship-based deployment stresses. Often WSS redundancy is included in the design to provide in-place sparing within the undersea ROADM unit. To demonstrate reliability and design-life objectives, an extensive component qualification process is followed. For these reasons, the device technology and architectures for undersea systems tend to be different than for terrestrial applications.

3. UNDERSEA NETWORKS

A typical “Trunk and Branch” undersea system architecture for one fiber pair is shown in Figure 2. Each connecting line represents a bidirectional fiber pair, and the arrows indicate the directions of outbound branch connectivity at each node.

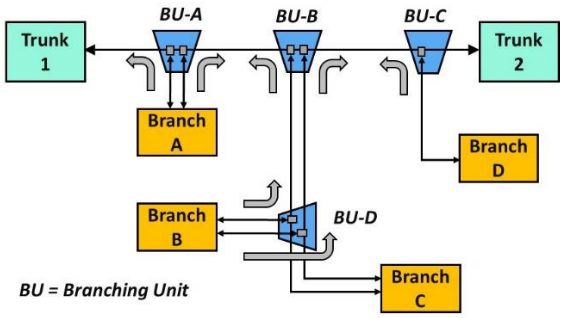

Figure 2: Example of undersea network branch connectivity

The BU nodes connect branch sites to the trunk fiber pair, as for Branch A, or with “branches -on- branches” as for Branches B and C. There are also applications for “outbound-only” nodes as for Branch D, where undersea connectivity is not required between two sites. This configuration is typically used at the system edges for network redundancy in the case of cable damage near the Trunk 2 landing site.

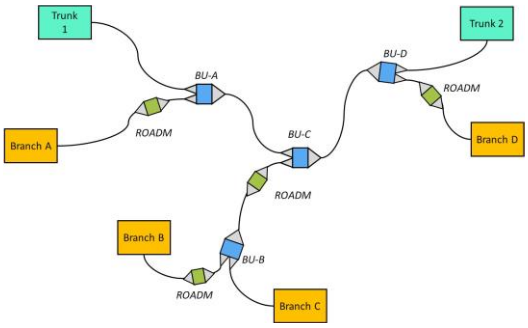

Figure 3: Physical network routing between Branching Units

Figure 3 illustrates the use of three-port BUs to implement the architecture of Figure 2 above. The BUs provide both optical and electrical power routing between the trunk and branch paths. ROADM units are also shown on each branch path, although those units are only required for fiber pair spectrum sharing between sites, not for full-fiber routing.

Figure 4 shows a multi-fiber-pair implementation of BU-A in Figure 1, with separate ROADMs connecting branch fiber pairs to each trunk fiber pair. This configuration is our comparison point for considering other architectures.

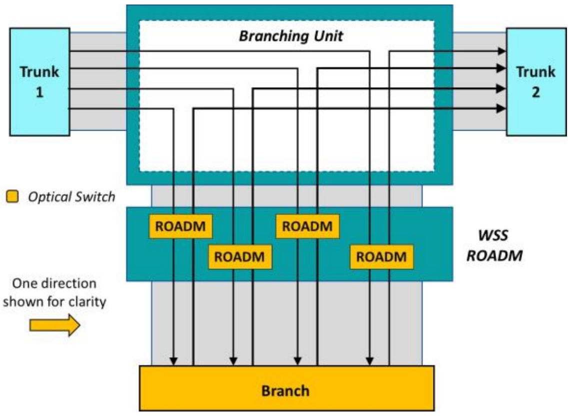

Figure 4: BU/ROADM architecture with ROADM on every trunk fiber pair

The inclusion of optical switches in undersea networks provides a significant increase in routing flexibility at branching nodes, while improving overall system reliability. Figure 5 shows the utility of optical switches to enable bypass of a damaged ROADM or branch cable. In this application, the trunk traffic remains on the trunk cable during the branch or ROADM repair process.

As previously mentioned, the shift in cable ownership from "many owners per fiber pair" to "many fiber pairs per owner" has caused a shift in submarine architectures. Now the entire fiber pair is an important unit of spectrum allotment, and there is a consequential impact on the usage of switched branching units, and on the ratio of trunk fiber pairs to ROADMs.

When a customer owns multiple fiber pairs, there is a reduced requirement to divide the spectrum of individual fiber pairs. In this situation, the fiber switched BU can be used without the expense of a corresponding ROADM, so that the entire trunk fiber pair spectrum is either routed to the branch cable or remains on the trunk cable.

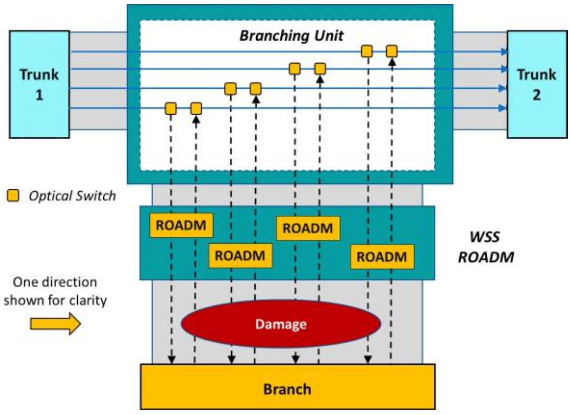

Figure 5. BU/ROADM architecture with bypass switching for branch fault protection

Figure 6 shows an even more cost-efficient node solution compared to Figure 5 that includes full-BU fiber switching on all fiber pairs, but ROADM functionality on only one fiber pair. The ROADM provides "partial fiber pair" spectrum allotment to the branch station.

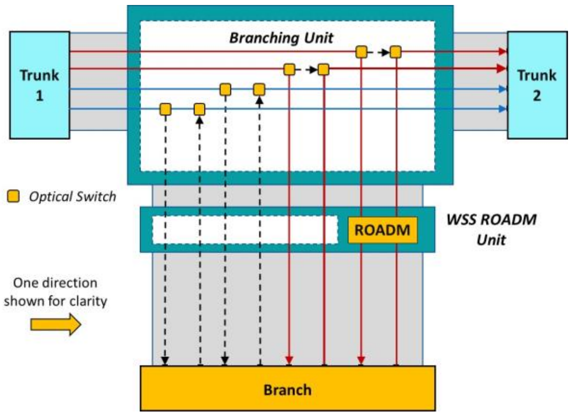

Figure 6. BU/ROADM architecture with bypass switching on all fiber pairs, but ROADM on only one fiber pair

Once the branch site traffic through the ROADM increases beyond the capacity of one full fiber pair, another trunk fiber pair can be diverted from the trunk and connected to the branch. In this configuration, the one ROADM fiber pair continues to provide incremental increases in spectrum requirements to the branch site.

Another increase in BU flexibility comes from optical cross-connect switching in the assignment of trunk fiber pairs to branch fiber pairs. In the generic example of Figure 7, two of the four trunk fiber pairs can be selectively routed onto the two available branch fiber pairs, with the other two trunk fiber pairs bypassing the branch site.

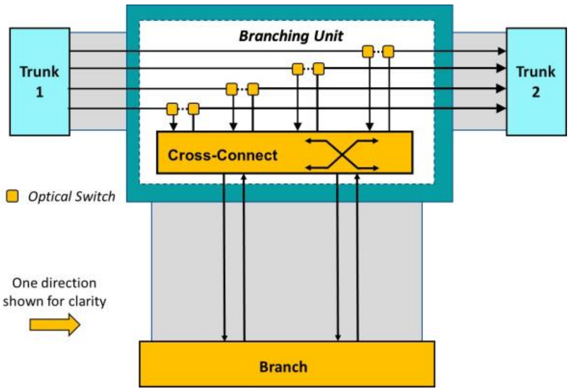

Figure 7. BU architecture with flexible full fiber pair routing between trunk and branch

A likely application of this cross connect capability is to allow system owners to select among a larger number of trunk fiber pairs for connection to a more limited number of branch fiber pairs. This flexibility allows the branch station connectivity to be maintained when the currently assigned trunk fiber pair is damaged or is required for additional capacity to a different site. Another benefit of the optical cross connect is to allow decisions on trunk fiber pair assignments among branch locations to be deferred until later in the overall system design process.

There may be a very different approach to future capacity allocation on systems with traditional multi-owner consortium fiber pairs. For example, the ROADM architecture may support higher port count architectures to allow multiple trunk fiber pairs to share the limited resources of a limited number of branch fiber pairs.

Branch A from Figure 1 is illustrated with this configuration in Figure 8. The branching unit may or may not include trunk bypass fiber switching, although it is recommended for protection of trunk traffic against branch cable damage.

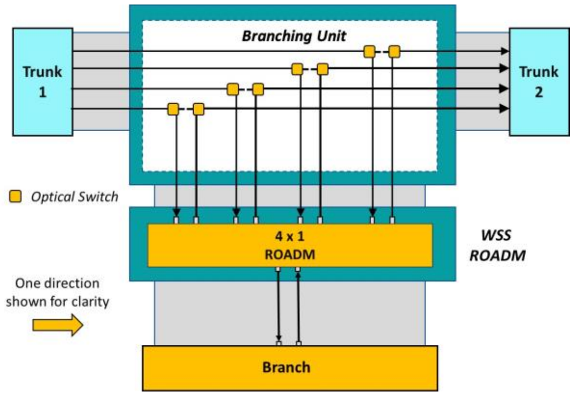

Figure 8. BU/ROADM architecture with four trunk fiber pairs sharing ROADM spectrum access to one branch fiber pair

This architecture introduces significant cross-fiber pair routing complexity to fully load the branch fiber pair spectrum. In addition to assigning trunk spectrum to different branch sites on one fiber pair, the spectrum assignments of all four fiber pairs must be co-managed. In practice, it may be more effective to manage the routing of traffic onto specific trunk fiber pairs using terminal equipment rather than with complex spectrum routing in the wet plant.

4. ADVANCED ARCHITECTURES

The increased network flexibility introduced by optical switching and WSS filtering can be used to implement more complex architectures beyond the tree-and-branch discussed so far.

Most cable damage occurs near shore, largely due to anchors. An example network to maintain overall connectivity between terrestrial locations during repair activities is shown in Figure 9, with interconnect cables between trunk cables, with both interconnect ends terminating on BUs.

There are issues to consider for this type of configuration. The "recovery" configuration will be longer, so that either higher performance must be engineered into the system, or the fiber pair capacity must be reduced for the longer path.

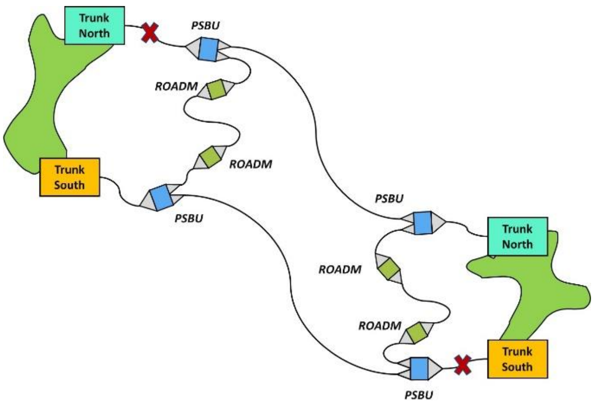

Figure 9: Network with Cross-Cable interconnects

The adjustable data rates of modern coherent modems can support operation at lower OSNR values when recovery routes are active, so that overall capacity is reduced but remains in-service. If cables are at full capacity prior to the cable fault, then prioritization will be required to define which in-service traffic on the recovery path is displaced by recovery traffic.

5. POWERING FLEXIBILITY

The issues related to powering a new and interesting network configuration can be as challenging as the optical routing issues, since electrical power is provided to undersea systems through conductors in the cable.

Power Switched versions of Branching Units (PSBU) were the first level of configuration flexibility added to submarine systems [6]. Current versions can support both the electrical power switching and the optical switching described above. Figure 10a shows a typical system powering configuration for Figure 1, with trunk-to-trunk and branch-to-BU powering. Power feed equipment is located at each cable station. A sea ground is provided at the BU for the branch cables.

Figure 10b shows how the powering configuration can be changed to keep the surviving network in-service in the case of cable damage near Trunk 1 and Branch C. Here, the PSBU is reconfigured to connect the trunk and branch electrical paths.

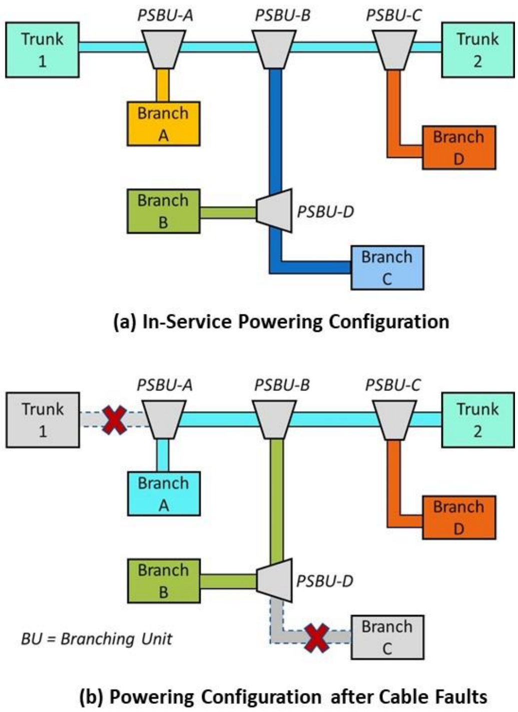

Figure 10: In-service and fault-condition powering configurations

There are unique powering design issues related to the network configuration of Figure 9. There are no “branch stations” on either end of the intra-trunk cables.

An example powering configuration for Figure 9 is shown in Figure 11, with each network segment powered between one station and one PSBU. The PSBUs can be reconfigured during trunk shunt fault events.

6. NETWORK CONTROL

The inclusion of ROADMs and optical spectral monitoring in the undersea plant for network routing flexibility requires higher-level application tools to allow system administrators to take full advantage of the provided network flexibility.

The concept of a high-level orchestrator enabling network administrators to combine terrestrial and undersea equipment domains into a seamless management control system has long been discussed as illustrated in

Figure 12 [8] and has recently become generally available.

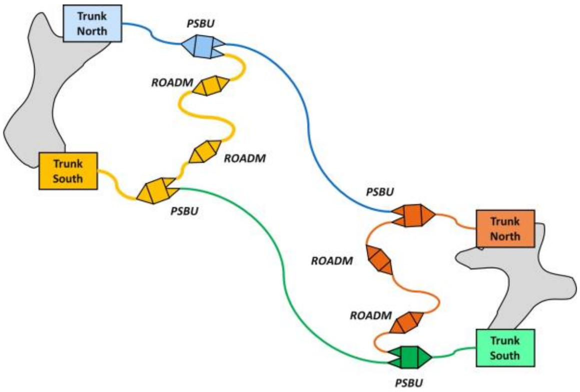

Figure 11: Powering example for interconnected cables

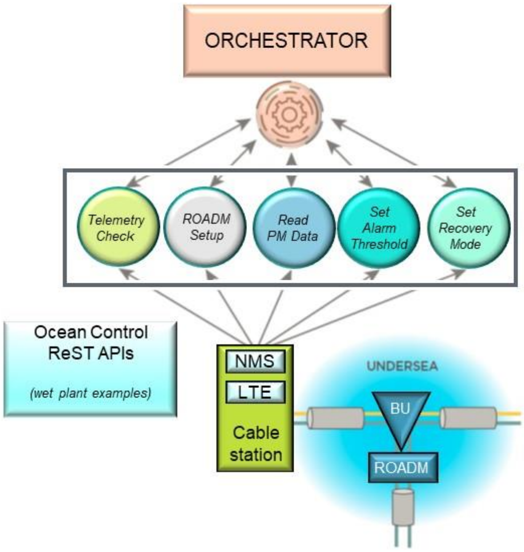

Figure 12. Ocean Control Diagram

The SubCom NMS-based "Ocean Control" ReST API interface provides access control for the reconfigurable BU types as described in this paper. With this feature, for example, optical spectrum within one fiber pair or full fiber pair route assignments can be changed by an orchestrator that has visibility into the entire customer network. Alarm information and Line Monitoring System information [9] can be programmatically retrieved and used in customer-developed applications. The system owner has much greater independence to customize network control and monitoring approach.

7. CONCLUSION

There have recently been two areas of significant change in submarine systems. The number of fiber pairs in individual network segments has begun to increase, leading to an increase in the requested flexibility in fiber pair and spectrum routing. There have also been requests for increased complexity in overall network architectures, expanding beyond trunk-and-branch towards branch-off-branch trees and more mesh-like networks. These changes represent a significant opportunity for larger penetration of flexibly reconfigurable branching node architecture and technologies in the submarine market.

8. REFERENCES

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