Innovative Submarine Transmission Systems using Full-tunable ROADM Branching Units

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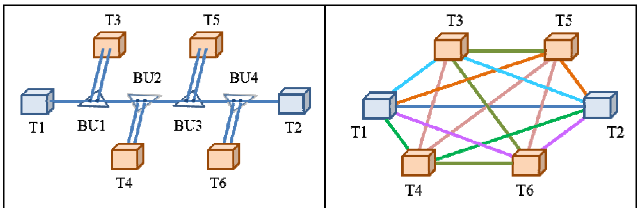
Abstract: This paper describes the flexible connectivity of advanced submarine cable systems using fully-tunable ROADM branching units. Key features of fully-tunable submarine ROADM systems are discussed and compared with conventional and terrestrial ROADM systems. The transmission performance of a fully-tunable submarine ROADM system is demonstrated using a prototype ROADM branching unit and long distance straight line test-bed.

1. INTRODUCTION

Due to the rapid growth of digital communication links, network flexibility has become one of the important factors for recent undersea networks, in addition to capacity expansion. In order to enhance network flexibility, Optical Add/Drop Multiplexing (OADM) functionality has been employed in branching units (BUs) over the last 5 years.

The first generation of OADM-BUs used fixed optical filters, which provide improved wavelength-based connectivity in the multiple links connected through OADM BUs in one fiber pair, as shown in Figure 1.



(a) Physical connection | (b) Optical signal path

Figure 1: OADM connectivity

Subsequently, to cope with the strong demand for re-configurability of optical signal paths and capacity reallocation, submarine OADM systems evolved from a pre-determined OADM architecture to a selectable ROADM architecture based on optical switches and multiple optical filters [1], in which the add/drop wavelength allocation can be dynamically changed after submarine cable installation. However, the flexibility is still limited to the pre-installed optical filter selections.

For the further improvement of flexibility and connectivity in submarine OADM systems, fully-tunable ROADM systems based on Wavelength Selective Switch (WSS) technologies [2-4] has become one of the most promising candidates for advanced submarine cable systems. This paper discusses the main features of submarine ROADM systems based on WSS technology, compared with conventional submarine ROADM system and terrestrial ROADM system. Key functionalities of submarine ROADM systems are demonstrated using a fully-tunable ROADM BU prototype and long distance transmission test-bed.

2. SUBMARINE ROADM SYSTEM

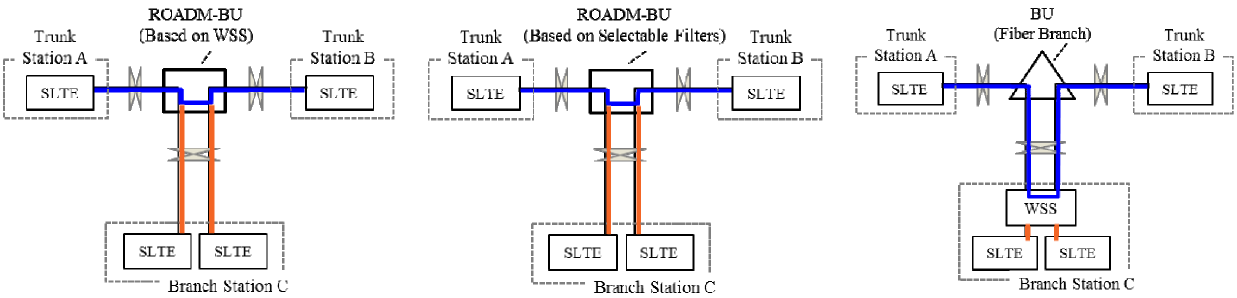
Figure 2 shows three candidates for submarine ROADM systems. All systems consist of a BU, trunk stations A, B and a branch station C. The SLTEs in each station communicate with the other two stations using a dedicated wavelength band.

Figure 2(a) shows the fully-tunable submarine ROADM system, in which a ROADM-BU based on WSS technologies is integrated into the submersible plant. Figure 2(b) shows a convention submarine ROADM system, in which a ROADM-BU based on the combination of fixed optical filters and switches is provided in the submersible plant. In these submarine ROADM systems, the ROADM-BU performs the add/drop function in the submersible plant.

Figure 2(c) shows another configuration using terrestrial ROADM equipment. In this case, the WSS-based ROADM function is accommodated in the branch landing station and a fiber branching type BU is accommodated in the submersible plant. All WDM signals from the trunk line go through the branch line via the BU. After the add/drop function is performed by the WSS circuit in the branch station, the WDM signal is returned to the trunk line.

There are different features among these three ROADM configurations. One is flexibility of signal add/drop ratio. In the conventional submarine ROADM system shown in Figure 2(b), multiple add/drop ratios can be selected by switching between pre-determined filters. However this flexibility is limited to the number of the optical filters installed in the ROADM-BU. In addition, a guard band of a few nanometers between neighbouring wavelength sub-bands is indispensable due to the shape of add/drop optical filters. On the other hand, for the cases of the fully-tunable submarine ROADM system and the terrestrial ROADM system, the add/drop ratio can be changed with fine resolution, and excess guard-bands between neighbouring sub-bands are not required thanks to sharpness of the filtering characteristics of the WSS device. Furthermore, the add/drop ratio can be changed without traffic interruption in the wave-bands unaffected by this add/drop switching.

The second key feature is transmission performance. In a terrestrial ROADM system, trunk traffic between station A and station B cannot avoid the excess transmission path for the branch line section. So, the terrestrial ROADM system causes excess OSNR penalty and excess latency for the trunk traffic according to the length of branch line. On the other



(a) Fully-tunable submarine ROADM system

(b) Convention submarine ROADM system

(c) Terrestrial ROADM system

Figure 2: Fiber connectivity of ROADM systems for submarine networks

hand, in submarine ROADM systems, the OSNR penalty and latency of the trunk signal can be minimized since the trunk traffic directly passes through the BU in the submersible plant and does not traverse the branch.

Considering these ROADM features, the configuration with fully-tunable submarine ROADM BU is advantageous compared to the other two configurations.

3. ASSESSMENT OF ROADM-BU FUNCTION AND PERFORMANCE IN LONG DISTANCE TRANSMISSION

In order to assess the fully-tunable ROADM-BU in submarine cable systems, we have experimentally evaluated its functionality and performance using a prototype. Figure 3 shows the configuration of the prototype ROADM-BU. The add/drop wavelength bandwidth of this ROADM-BU is controlled by the remote control signal from the trunk or branch line.

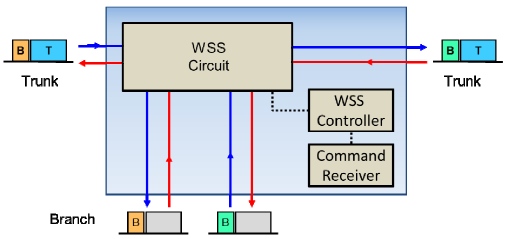


Figure 3: Prototype of fully-tunable ROADM-BU

3.1. FLEXIBLE ADD/DROP FUNCTION

Firstly, we confirmed the add/drop functionality of the fully-tunable ROADM-BU with a long distance transmission line. Figure 4 shows the experimental setup.

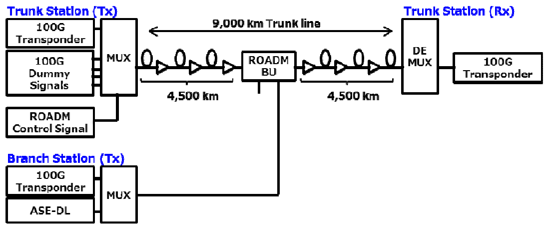
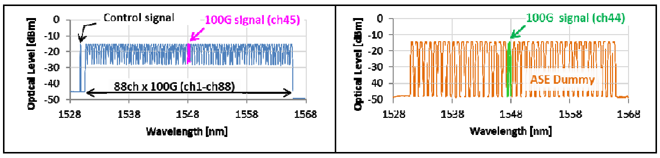


Figure 4: Experimental setup

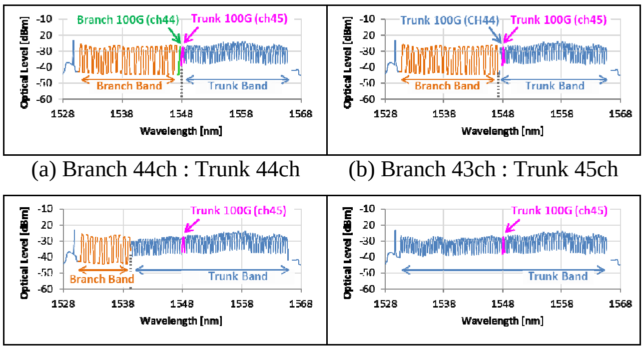
The transmitter side of the trunk station consists of 100Gb/s transponders for the measurement channel and dummy signals. The modulation format of the measurement signal and dummy signals is dual polarization-quadrature phase shift keying (DP-QPSK). Those optical 100Gb/s signals are combined by a multiplexer (MUX) and have 50GHz channel spacing. The remote control signal to operate the ROADM-BU is also combined by the MUX. The transmitter side of the branch station consists of one 100Gb/s transponder and ASE (Amplified Spontaneous Emission) dummy lights. Optical 100Gb/s signals from the trunk station are injected to a 9,000km straight transmission line which consists of 60km SMF spans and EDFAs. We set the output power of the EDFAs to +17.0 dBm. One ROADM-BU is inserted in the middle of 9,000km transmission line. The optical signals from the trunk station and branch station are multiplexed at the ROADM-BU. At the receiver side, the transmitted signal to be measured is selected by a 50 GHz de-multiplexer (DEMUX) and detected by a 100 Gb/s DP-QPSK Transponder.

Figure 5 shows the spectrum at the transmitter side of the trunk station and the branch station. Figure 6 shows the received spectrum after 9,000km transmission by changing the add/drop bandwidth ratio from 44ch (branch) : 44ch (trunk) to 0ch (branch) : 88ch (trunk). The blue peaks show 88 x 100Gb/s signals with 50GHz-spacing from the trunk station. CH45 of these trunk signals is indicated by the pink color. The green channel shows the branch 100Gb/s signal allocated on CH44. The orange peaks show the branch ASE dummy lights allocated with 100 GHz spacing. Add/drop bandwidth control with a step size of a single channel was achieved as shown in Figure 6.



(a) Trunk station (b) Branch Station

Figure 5: Spectrum at transmitter side



(a) Branch 44ch : Trunk 44ch (b) Branch 43ch : Trunk 45ch

(c) Branch 22ch : Trunk 66ch (d) Branch 0ch : Trunk 88ch

Figure 6: Received spectrum after 9,000km transmission with fully-tunable ROADM-BU

3.2. TRANSMISSION PERFORMANCE

We have also measured 100G transmission performance with the fully-tunable ROADM-BU. The experimental setup with the long distance test-bed is shown in Figure 4.

Figure 7 shows the Q variation of the trunk 100Gb/s signal CH45 by changing the ROADM add/drop wavelength ratio among 6 representative cases. In this evaluation, CH45 remains as trunk traffic. A stable Q performance of less than 0.1dB is confirmed. Error-free operation is also confirmed, including during the transient time of ROADM switching.

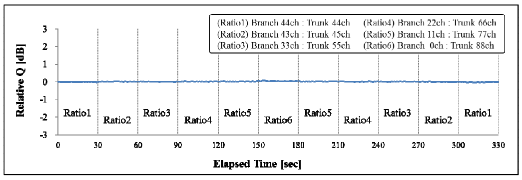


Figure 7: Q variation of CH45 by changing the add/drop ratio

Figure 8 shows the long term Q performance stability with the fully-tunable ROADM-BU. 100Gb/s DP-QPSK signals from the trunk and branch station achieved very stable Q performance with a standard deviation of less than 0.1dB over long distance transmission.

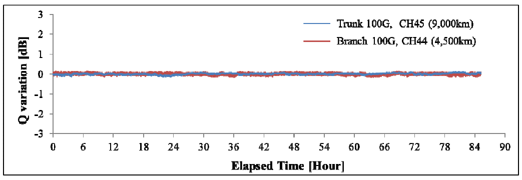


Figure 8: Q time variation through the fully-tunable ROADM-BU

3.3. FILTERING PENALTY WITH ROADM CONCATENATION

Finally, we have evaluated the penalty which may be induced by the optical shape of the fully-tunable ROADM under the condition of ROADM concatenation during long distance transmission. Figure 9 shows the experimental setup. The fully-tunable ROADMs are located in each sub-segment which consists of approximately 30 repeaters, and up to four ROADMs are inserted in the 9,000km transmission line. 88 x 100Gb/s signals with 50GHz spacing are injected to a 9,000km straight transmission line. In order to confirm the filtering penalty of ROADM concatenation, only one measurement channel of 100Gb/s signal is passed through each ROADM as shown in Figure 10. The WDM signals are divided by optical coupler and are re-inserted to ROADM as the add channels.

Figure 11 shows Q penalty as a function of ROADM filter concatenations. The penalties under conditions of one ROADM concatenation and four ROADM concatenations are 0.04dB and 0.15dB respectively. The penalty is increased by ROADM concatenation number in a linear manner as shown in this figure.

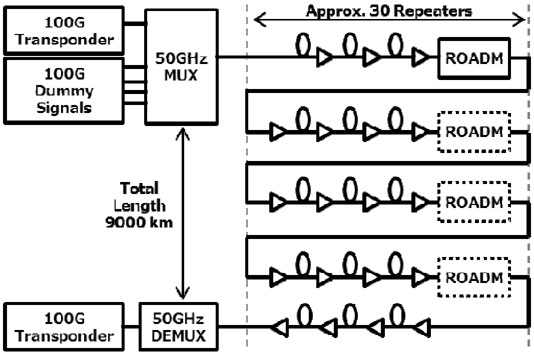


Figure 9: Experimental setup

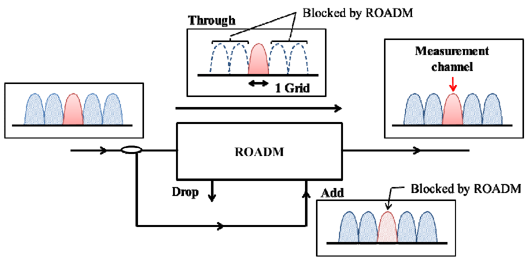


Figure 10: ROADM multiplex configuration

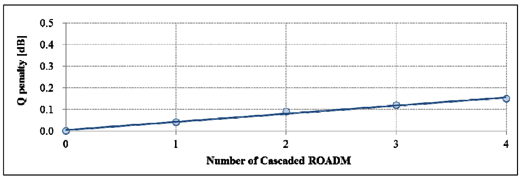


Figure 11: Q penalty vs ROADM concatenation

4. CONCLUSION

Submarine fully-tunable ROADM systems are discussed and compared with conventional submarine ROADM system and terrestrial ROADM system. The transmission performance of Submarine ROADM-BU system is demonstrated by using fully-tunable ROADM BU prototype and long distance straight line test-bed. This technology provides further connectivity and flexibility for advanced submarine networks.

5. REFERENCES

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