EFFICIENT AND EXPEDITED UPGRADING OF EXISTING SUBMARINE CABLE SYSTEMS

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Abstract: Submarine cable systems with optically amplified repeaters were first deployed with a design capacity of 2.5Gb/s and/or 5Gb/s per fiber pair. If we compare these older systems with the latest 10Gb/s Dense Wavelength Division Multiplexed (DWDM) systems, there will not be a striking difference observed in terms of their traffic carrying capacity despite having a rested lifetime of more than 10 to 15 years. Due to the recent advancements in transmission and terminal equipment technologies, it is now possible for these older systems to be upgraded by utilizing the 10Gb/s DWDM scheme.

In this paper we shall describe our process for determining upgrade feasibility as well as the potential maximum capacities achievable by upgrading existing systems. In addition, technologies and terminal equipment to be newly developed for upgrading applications will be presented with upgrade implementation examples from actual projects.

1 TECHNOLOGY INNOVATION ON OPTICAL AMPLIFIED SUBMARINE REPEATER SYSTEM

In spite of its 25 year design life, the traffic capacities of earlier constructed submarine cable systems with optically amplified repeaters in mid 90’s are near full capacity these days due to the fact that the recent growth in traffic demand around the world has been fast and furious beyond expectations.

Figure 1 shows the growth of maximum capacity per fiber pair of a constructed major optical amplified submarine repeater system. The optical amplified submarine repeater systems, which were first deployed with a designed capacity of 2.5Gb/s or 5Gb/s single wavelength per fiber pair, has brilliant advantages in its simple repeater configuration, providing extremely high reliability and cost efficiency in comparison to the hitherto known 3R regenerating submarine repeater systems mentioned herein.

As technology progressed their capacities were increased through the introduction of 2.5Gb/s WDM systems, which was developed by adopting Dense Wavelength Division Multiplexed (DWDM) Technologies such as gain shape equalization of Er-doped Fiber Amplifier (EDFA) in the submarine repeater, accurate wavelength control on transponder and the dense wavelength multiplexing/de-multiplexing.

From year 2000 to 2002, great achievements were made in developing 10Gbit/s optical transponders with high coding-gain Forward Error Correction (FEC), low noise, wide-band optical submarine repeater enabling construction of large capacity submarine cable system over 100Gb/s capacity per fiber. Bringing the maximum capacity per fiber pair to reach approximately 1Tb/s within as few as just seven years from the construction of the first optical amplified submarine repeater systems, the maximum capacity has hit the roof by collapsing the asset-inflation bubble there after.

On the other hand, since traffic demands have been steadily growing at slightly slower pace than the explosive expansion for developing maximum capacity, the capacities of many earlier installed 2.5G or 5G single wavelength submarine cable system has begun to fill up in the past few years. Therefore, the planning and execution for expanding the capacity of such existing optical amplified submarine repeater systems, some still having for more than the 15 years of design life, became an attractive option in comparison to the construction of new submarine cable systems.

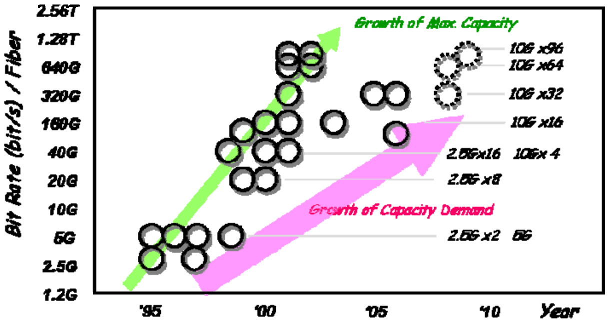


Figure 1 Growth of maximum capacity per fiber pair on constructed optical amplified submarine repeater systems

2 TECHNOLOGIES FOR ENSURING CAPACITY UPGRADE

Due to the recent advancements in transmission and terminal equipment technologies, it is now possible for these older systems to be upgraded utilizing 10Gb/s DWDM schemes and achieving capacities that are much higher than their original design capacities. This upgrade can now be done irrespective of which supplier installed the original system. This is very good news for existing system owners that seek to extend the life and capacity of their existing systems.

One of key-factor for extending the capacities of existing optical amplified submarine repeater systems is to maximize the number of wavelengths while increasing the bit-rate on a single wavelength.

For maximizing the number of wavelengths, it is not possible to extend the wavelength bandwidth of submersible repeaters unless replacing the repeaters themselves. However, the fact that most of the existing repeaters for single wavelength systems had been designed to keep the features of EDFA's gain-wavelength characteristics brings us expectations for transmitting additional wavelengths into the existing bandwidth.

For increasing the bit-rate, it becomes possible to replace the existing 2.5Gb/s or 5Gb/s signals with 10Gb/s signals without a reducing in the number of wavelengths by adopting high gain Advanced FEC (AFEC) which provides approximately 3dB higher coding-gain than the Conventional FEC (CFEC), and by changing the modulation format from "Non-return to Zero (NRZ)" to "Return to Zero (RZ)" which brings approximately 2dB of additional gain.

In addition, Differential Phase Shift Keying (DPSK) which has been recently brings an additional 2dB gain enhancement to the system power budget.

By utilizing these technologies, enhancements once only dreamed about like for extending the existing system capacities for over ten times of its original capacities, have now become a reality.

3 CAPACITY UPGRADE DESIGN AND EVALUATION

We begin generic analyses of the existing 2.5Gb/s and 5Gb/s system in order to address to what extent of the capacity upgrade is feasible by utilizing today's 10Gb/s technology choices. Since each existing system is unique it will require a specific upgrade solution in order to derive the maximum possible capacity. In this desk-top study, we can estimate the expected signal performances after 10Gb/s DWDM upgrades, such as the optical signal noise to ratio (OSNR), Q values and transmission penalties generated from chromatic dispersions and non-linear effects in the fibers by entering system key parameters of Repeater Gain, Output Power and Noise Figure, Repeater Spacing, Dispersion Map and Transmission Fiber Type into our simulation tools.

The optical signal to noise ratio (OSNR) and expected Q value is calculated based on the following formula.

$$Q_{line}\,(db) = 20\log\left(\frac{\dfrac{2SNR_o(1-ER)\sqrt{\dfrac{B_o}{B_e}}}{DR+(2-DR)ER}}{\sqrt{1+4ER\left(\dfrac{SNR_o}{DR+(2-DR)ER}\right)}+\sqrt{1+4\left(\dfrac{SNR_o}{DR+(2-DR)ER}\right)}} \right)$$

Where,

Qline: Line Q value

SNR0: Optical SNR in the bandwidth B0

B0: Optical Bandwidth of receiver

Be: Electrical Bandwidth of receiver

ER: Extinction Ratio

DR: Duty Ratio

The transmission penalties of 10Gb/s signal due to the chromatic dispersion and non-linear effect in the fiber have also been simulated by changing the parameters of the channel power level launched into transmission fiber and the chromatic dispersion compensation values at terminal equipment. Figure 2 shows an example of simulation results of transmission penalties for upgrading an existing 2,600km length of submarine cable system with 10Gb/s DWDM scheme. In this example, in order to minimize the transmission penalty, the channel power should be adjusted less than +1dBm, and the total chromatic dispersion should be adjusted to +300 ps/nm. As shown here, we can clearly predict how we should configure the upgraded system by utilizing our simulation tools.

In order to gain further confidence for the upgrade purchasers we normally conduct on-site measurements of the longest segment and then compare the actual measurements with the predictions obtained from the desk-top study. This comparison process assures that there are no unpleasant surprises later on.

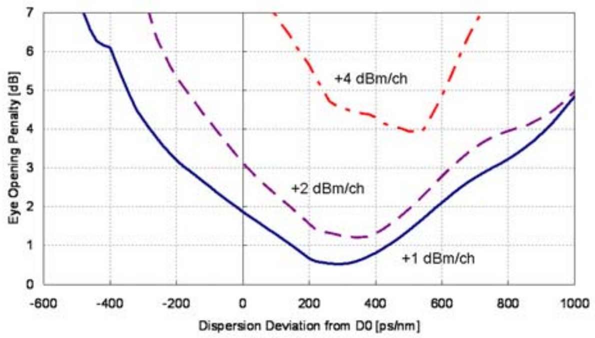


Figure 2 An example of simulation results for upgrading an existing 2,600km system with 10Gb/s DWDM

Figure 3 shows an example of relation between the estimated Q values and actually measured Q values of upgraded 10Gb/s DWDM signals which were taken from our recent upgrade project on existing 2.5Gb/s and

5Gb/s systems. The measured Q values turned out to be slightly better than our expected results and, it assures that our upgrade design process is conservative enough for designing the capacity upgrade project.

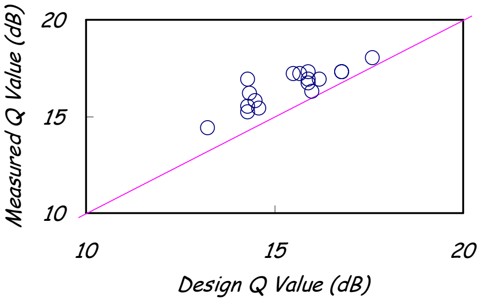


Figure 3 An example of estimated Q values vs actual measured Q values of upgraded 10Gb/s DWDM system

Based on our extensive experience with recent upgrade projects, we have learned that by completing an accurate characterization of the existing system through the completion of a desk-top study, we are able to accurately predict the upgrade feasibility as well as the maximum capacity achievable. From our recent experiences of upgrade projects, we have learned that most of the existing 2.5Gb/s or 5Gb/s single wavelength system can be upgraded to several wavelengths of 10Gb/s DWDM system.

4 SLTE FOR CAPACITY UPGRADE

The terminal equipment to be utilized for upgrading must be the most flexible and most efficient in terms of its configuration and its installation capability. Since it is usually very desirable to be able to achieve high capacities both in the initial upgrade and any subsequent upgrades; systems that can be upgraded without further traffic interruption are indispensable.

By considering these technical requirements, we have developed and deployed terminal equipment which has increased flexibility, reduced foot print, and power requirements and is modular in nature. The equipment is configurable with functional elements such as 10G transponders, optical amplifiers and dispersion compensators, etc. and each element can be flexibly combined, subject to system requirement.

Figure 4 shows a picture of modular type SLTE. A most unique feature of this submarine terminal equipment is that each functional element is designed as a stand alone module and operated by supplying only DC-48V station power.

The SLTE consists of Submarine Line Terminating Module (SLTM) as 10G transponders, Level Compensation Module (LCM) as optical amplifier, Line Stabilizer Module (LSM) as dummy CW light source and Termination Module (TRM) to accommodate wavelength multiplex/ de-multiplex (MUX/DMUX) modules and dispersion compensators.

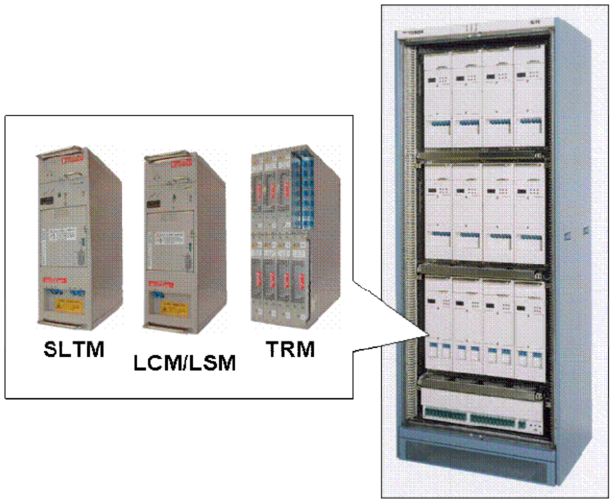


Figure 4 Submarine Line Terminal Equipment (SLTE)

The SLTM provides STM-64 or OC-192 optical signal interfaces, and realizes high-quality transmission performance by using Advanced FEC (AFEC) to improve the receiver sensitivity for approximately 8 dB, compared with the case without FEC. The modulation format can be optimized, pursuant to the existing system condition, by choosing from the line-up of NRZ, RZ and DPSK-RZ.

The TRM supports optical multiplexing and de-multiplexing functions by incorporating associated optical devices. Depending on the system design, the TRM can adaptively accommodate passive optical components required for interconnecting the existing SLTE.

The LCM achieves optical amplification function by incorporating highly-reliable optical fiber amplifiers. This is used to boost single-wavelength and DWDM signals in order to compensate for the loss of optical components and dispersion compensation fiber.

Dispersion Compensation Module (DCM) is to accommodate dispersion compensation devices such as dispersion compensation fiber.

The LSM provides a Continuous Wave (CW) light insertion function. As shown in Figure 2, optimization of channel power for 10Gb/s signal is significant to achieve the highest signal performances. The LCM is applied to launch wavelength-stabilized light to the existing wet plant, which enables channel power optimization without modifying the repeater output powers of the transmission line.

Element Management Systems (EMS) based on Web technology also provide abundant flexibility by supporting create/delete functionalities with unique GUI. The EMS provides various management functions for the SLTE such as Fault Management, Performance Management, Configuration Management, Log Management and Security Management.

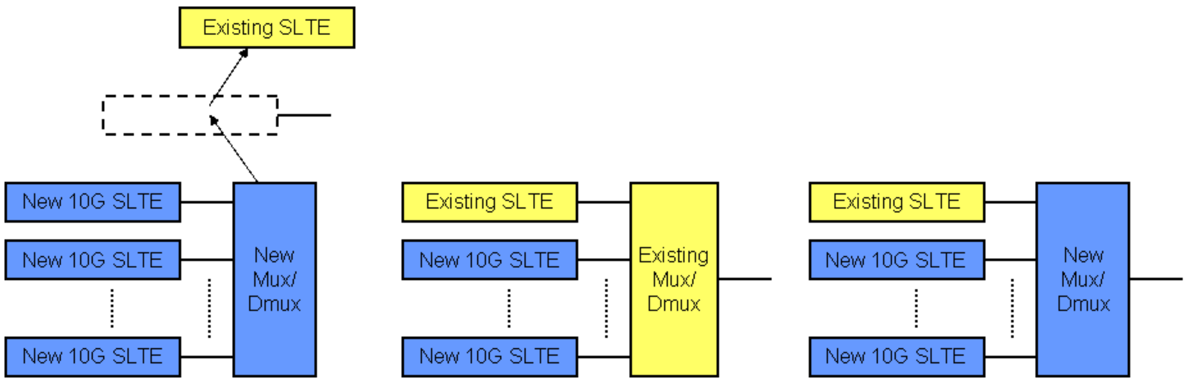
The ways of upgrading the existing system are mainly categorized in those types as shown in Figure 5; (a) replacement, (b) inserting new 10Gb/s wavelength into existing MUX/DMUX and (c) adding new 10Gb/s wavelength together with new MUX/DMUX. In either of each situation, the combination of our SLTE and EMS can be configured with optimum combination of appropriate modules.

5 CONCLUSION

In spite of its design life of 25 years, the traffic capacities of earlier constructed submarine cable systems with optically amplified repeaters are nearly full at many locations. We have presented the design process for expanding the capacity of existing optical amplified submarine repeater systems, by adopting the recent DWDM technologies.

Fortunately, most of such existing systems for single wavelength systems can accommodate additional wavelengths into the existing bandwidth. In addition, high gain AFEC and RZ modulation techniques have been realized to replace the existing 2.5Gb/s or 5Gb/s transponder with the 10Gb/s transponder without reduction in wavelengths.

We have also presented our process for determining the upgrade feasibility, our extensive experience with recent upgrade projects as well as our new terminal equipment which can be applied to any type of existing systems.



(a) (b) (c)

Figure 5 System Upgrade Methods