Recent Advances and Deployments in the Asia-Pacific Region

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Abstract *This paper reviews the Tb/s capacity trans-oceanic transmission technologies and relevant advanced equipment, as applied to the latest 10Gbps DWDM system deployments. It also discusses the higher capacity and global IP-based networking, including 40Gb/s, TCP engine and OADM meshed design.*

Introduction

The transmission capacity of submarine cable systems has dramatically increased since early 1990's by adopting optical amplifier repeaters as well as dense wavelength-division-multiplexing (DWDM) technology [1]. The first generation of optical amplifier submarine systems has been deployed and put into commercial service at 5 Gb/s single channel in 1995, then soon evolved to 2.5Gb/s WDM and 10Gb/s DWDM systems [2-5]. The 10Gb/s DWDM systems have been implemented worldwide in the last ten years, serving as an infrastructure for international communication and global network. Consequently it is recognized that more than 99 % of the current international traffic is carried by means of the submarine cable system.

The international traffic and network are rapidly evolving towards a data-centric configuration, in which Ethernet data based on TCP/IP protocol, for a high speed and high capacity Internet connectivity environment, are transmitted and distributed worldwide through trans-oceanic submarine cable links. For such application, multiple route diversity will become more vital, as well as minimization of latency. The optical add/drop multiplexing (OADM) branching configuration could offer meshed and direct connections among many stations, and thus it is considered to play a dominant role. Furthermore, as the demand on capacity rapidly increases, higher bit rate transmission with high spectral efficiency, such as advanced 40Gb/s modulation formats [6-11], is explored for deployment in the next generation submarine systems.

This paper firstly reviews trans-oceanic distance, over 1 Tb/s capacity transmission technologies and relevant equipment, as applied for the latest 10Gbps DWDM submarine cable system deployments, covering advanced submarine plants of broadband repeaters and dispersion managed fibers (DMFs). It also touches on the terminal equipment technologies such as return-to zero differential phase-shit-keying (RZ-DPSK) modulation. Secondly we discuss OADM submarine network technologies and equipment, and the way to alleviate the negative effect of latency on the TCP performance, which may induce a problem in the future high-speed TCP communication. Also, we discuss 40Gb/s long-distance transmission technologies for the near future deployments.

10Gb/s DWDM Repeatered System

The transmission capacity per fiber pair of 10Gb/s based WDM submarine cable system has successfully been increased by various technical advancements such as advanced forward-error-correction (FEC), RZ-DPSK, and DMF.

Figure 1 explains the details how the transmission capacity have evolved and how has been established: The-state-of-the-art submarine cable systems can cope with over 128 channels of 10Gb/s DWDM signal with over trans-Pacific distance. The key technologies and advancement on each network element (NE) are as follows:

Submarine Repeater: repeaters with very high power of more than +16dBm and wide gain bandwidth over 36nm are achieved by using high power 980 nm pumping LDs. Extremely flat average gain with less than 0.01 dBp-p is also achieved by the use of periodic residual gain equalizers.

Submarine Cable*:* In addition to conventional non-slope matched fiber, DMF is deployed for long distance systems, where single mode fiber (SMF) with approx. +20ps/nm/km and dispersion compensation fiber (DCF) with approx. -40ps/nm/km is combined with the ratio of 2:1 in each cable span. In this configuration, flat dispersion is achieved with dispersion slope fairly less than +/- 0.01 ps/nm2/km over entire transmission gain bandwidth.

Submarine Line Terminal Equipment (SLTE): RZ-DPSK modulation scheme, which achieves about 2.5 dB improvement in the receiver performance compared with the conventional RZ, is commercialized. This scheme allows to reduce the channel spacing down to as narrow as 25 GHz due to compact spectral width. It has also contributed to wider tolerance against chromatic dispersion (CD) and fiber nonlinearity. The adoption of tuneable LD and tuneable dispersion compensation module in the transponders is a typical advancement in the actual deployments.

Power Feeding Equipment (PFE): The maximum PFE output has been boosted up to 15, 000 volts, enabling single-end feeding with trans-Pacific distance.

In all the systems, the long-distance transmission performance is diagnosed prior to actual deployment through simulation test-bed facility, where fiber-loop configuration is usually adopted as established

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technology.

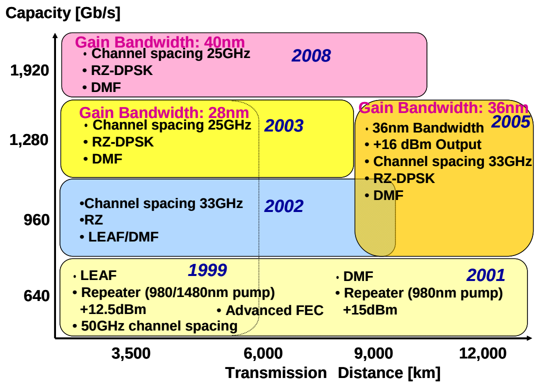

Fig.1: 10 Gb/s DWDM technology development in NEC for submarine cable systems.

Figure 2 shows an example of Q performance of 10Gb/s RZ-DPSK x 132 DWDM transmission with 25 GHz channel spacing, as a function of transmission distance. The dotted line is simple Q or theoretical value with no transmission penalty, while the solid line with dots corresponds the measured values. As it is clearly seen from this figure, the transmission penalty is very small with less than a few dB, and almost linear transmission is achieved even over 10000 km distance region.

To our best knowledge, the deployed system is so far up to 10Gb/s x 128 channels but higher counts of channels reaching 200 is considered to be feasible from technical point of view.

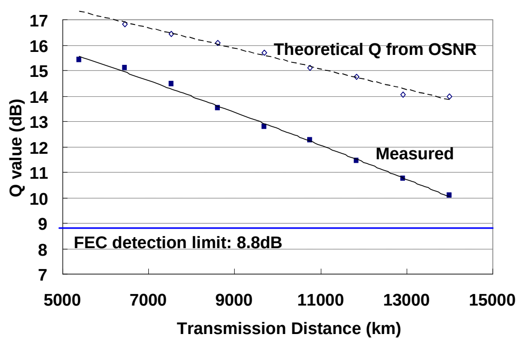

Fig.2: Q values v.s. transmission distance for 10Gb/s x 132 DWDM transmission.

OADM Meshed Submarine Network

The submarine cable systems with optical add-drop multiplexing branching units (OADM-BUs) have been contemplated since the earliest WDM in the mid-1990's, and a few systems have so far been commercially deployed. In those systems, the number of wavelengths per fiber pair was limited to 8 or 16 waves at 2.5Gb/s, and only a few channels were branched for local stations. With the improvement of optical filtering technology and optical line design, the incorporation of OADM BU's into the 10Gb/s DWDM submarine networks is widely considered as it can offer very cost-effective and flexible network configurations for various traffic demand patterns. This scheme enables us to share the DWDM traffic on the same fiber pair not only between the high capacity trunk nodes, but also between the trunk and branch nodes, or between the intermediate branch nodes themselves.

Figure 3 shows an example of physical and logical configurations of OADM-BU system, compared with the conventional non-OADM or fiber-BU system. The OADM-BU system has primarily been considered as a fiber-sharing WDM methodology to reduce the system cost. As it is clearly indicated in this figure, however, it enables to configure a meshed network with direct connection for all the stations.

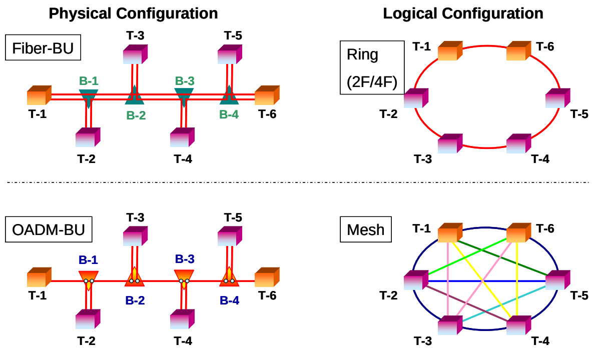

Fig.3: Comparison of physical and logical configurations between non-OADM and OADM systems.

The current OADM BU design uses optical couplers and fixed wavelength optical filters with band-pass / high-pass / low-pass types, permitting to add or drop a set of wavelengths. Typical example of OADM BU with optical band pass filter is shown in Fig. 4.

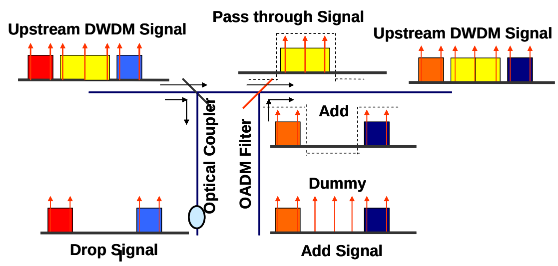

Fig.4: Optical add/drop branching architecture.

In this example, a part of upstream DWDM signals, which includes the drop signals, are tapped to the branch by an optical coupler, and the pass-through signals are transmitted to the trunk by eliminating the drop signals with a band-pass OADM filter, while the add signal is combined with the pass-through signals by the OADM filter. The arrows show the dummy lights incorporated in each wavelength sub-band for signal level compensation. The guard band with appropriate width is secured between the pass-through signals and the add-drop signals to sufficiently prevent the cross talk degradation.

Submarine repeater and cable for the OADM system are basically the same as those for non-OADM BU system, but dedicated design is applied for the SLTE and the management system as follows:

OADM SLTE: The SLTE for OADM systems incorporates the dedicated cw lights (Dummy Lights), corresponding to each sub-band, as well as a set of Dummy Lights for non-service channels. It is also designed to recognize the loss of the incoming DWDM signal on each sub-band basis for automatic optical level adjustment in case of cable/fiber failures.

OADM Management System: In addition to the standard element management system (EMS) at local stations, management system for OADM network is provided to support overall submarine network monitoring and controlling functions as well as local NE supervision. In particular, OADM management system equips submarine network view for each OADM path connection for easier maintenance

Latency Unaware TCP Transmission

Recently large-scale Data Centers (DCs) are rapidly spreading worldwide for growing IP Traffic and cloud computing. This implies that large files will be transmitted back and forth among the DCs through submarine cable links.

TCP is defined as a connection-type communication protocol and the window-size is valuable depending on end-to-end packet loss rate (end-to-end transmission quality) and the buffer memory size at end receivers. Due to this, TCP throughput is sensitive to “latency“ and predicted dramatically degraded with increase of transmission distance or round trip time (RTT), as indicated in Fig. 5.

In order to solve this issue, we propose to apply smart TCP booster engines at both submarine ends, as shown in Fig. 6**,** which are combined with SLTEs to optimize the TCP parameters based on submarine link performance, which eventually enables to boost the TCP performance.

The smart TCP Booster terminates and relays TCP connections at the submarine link ends, and a unique and advanced TCP is dedicatedly applied for the submarine link on each 10Gbps signal (10GbE) base, which performs ACK and rate control for higher performance. Note that although the advanced TCP is terminated between the ends of each submarine link, transparency between DC end-hosts is supported as in the conventional TCP links.

The proposed solution is expected to enable unaware connection of link length of submarine systems and contributes to latency-unaware IP global network for worldwide cloud computing with the Data Centers.

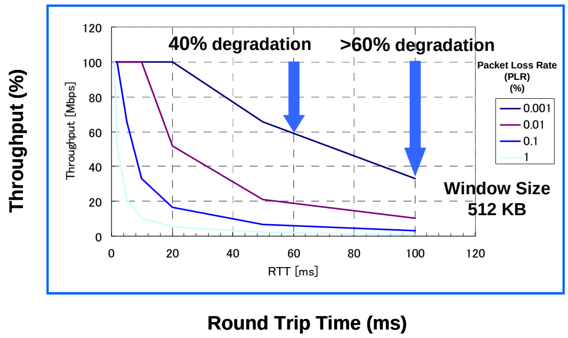

Fig.5: An example of TCP performance degradation by round trip time or line latency.

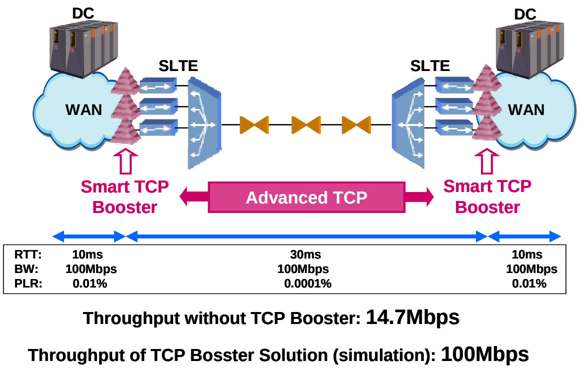

Fig.6: Smart TCP Booster concept for latency unaware TCP transmission and its performance simulation example.

10Gb/s DWDM Non-Repeatered System

Non-repeatered systems have been deployed for local areas to link continent to island, and between islands, etc. The transmittable length is up to approx. 450 km for 10Gb/s DWDM system, depending on the channels counts and the cable routes. In the SLTE for non-repeatered application, +30dBm booster amplifier and up to 1000 mW pumping sources for remote post/pre-amplification are supported.

Future 40Gb/s DWDM Technology

We have been pursuing R&D of 40Gb/s technology for submarine application since late 1990, and long-distance repeatered transmission over 9000 km of 40Gb/s x 32 DWDM signal is demonstrated by using DMF and fiber amplifier repeaters [12,13]. Also demonstrated is transmission of 40Gb/s x 50ch over 6,175km [14]. In order to make the 40G DWDM system attractive, however, we suppose that 40G system must be advantageous compared with the 10G DWDM system in terms of either the performance or the system cost, or both. As the latest 10Gb/s DWDM technologies can support approximately 2Tb/s (200 DWDM channels with 25GHz spacing in C band) over trans-Pacific distances, total capacity by 40Gb/s introduction should exceed this criteria by keeping the same distance. Also crucial will be the OSNR tolerance or receiver sensitivity, comparable to the 10Gb/s RZ-DPSK signal.

In order to achieve these targets, a variety of optical modulation formats are being studied and two of them, i.e. RZ-DPSK and RZ-DQPSK, have been implemented in 40Gb/s transponders for the near future deployments.

40G RZ-DPSK Transponder: this can support 100GHz channel spacing. 50GHz channel spacing is also possible with reduced transmission performance. Compared with other 40G modulation schemes, 40G RZ-DPSK has the best transmission performance. Since the RZ-DPSK signals have relatively limited tolerance to residual chromatic dispersion (CD) and polarization mode dispersion (PMD) distortions, both tunable dispersion compensator for CD and electrical dispersion compensator (EDC) [15, 16] for PMD are incorporated in the equipment.

40G RZ-DQPSK Transponder: this can support 50 GHz or narrower channel spacing. Due to its lower symbol rate of half the bit rate, RZ-DQPSK signals show better tolerance to PMD even without EDC compensation.

We also consider as extremely competitive for 40G RZ-QPSK with polarization multiplexing and digital coherent receiving schemes, because its symbol rate is at 10G and thus it is expected that the system can support 25 GHz channel spacing as well as better sensitivity and tolerance to CD.

Long distance transmission of the equipment has been tested by using simulation test-bed facility and Figure 7 shows Q value performance as a function of distance for 40G/s x 32 DWDM RZ-DPSK and 40G/s x 64 DWDM RZ-DQSK signals. It is confirmed that over 6000 km and 3000 km transmissions for RZ-DPSK and RZ-DQPSK 40Gbps DWDM signals, respectively, are feasible and ready for commercial use.

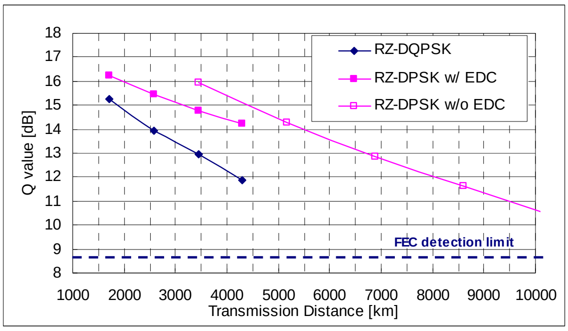

Fig.7: Q values v.s. transmission distance for 40 Gb/s x 32 DWDM, RZ-DPSK and 40Gb/s x 64DWDM RZ-DQPSK transmissions.

With the RZ-DPSK and RZ-DQPSK, the introduction of 40Gb/s has a constraint regarding the system cost due to less equipment performance. Thus, further R&D is still needed to enable the 40Gb/s system superior to the latest 10Gb/s systems in terms of cost and performance, and to put trans-oceanic 40Gb/s systems into practical use.

Conclusions

Most of the current optical submarine systems are deployed with 10Gb/s DWDM technologies and thanks to continued technical advancements, it can carry over 1Tb/s capacity per fiber pair at trans-Pacific distances. Cost-effective submarine networks utilizing OADM-BU are developed and being deployed to meet the market demands for flexible add/drop traffic. The OADM system will open a new era for global IP submarine networks because it can achieve meshed connection with reduced system cost as well as minimized latency.

The 40Gb/s systems are feasible for trans-oceanic application, but their introduction to new cable constructions may need more time due to higher wet plants cost. Never the less, it is likely that 40 Gb/s system deployments should be accelerated in the next couple years for seamless connection to terrestrial networks.

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References

1 See for examples, S, Akiba and S. Nishi, “Submarine Cable Network Systems”, published by NTT Quality Printing Service co. (Tokyo, Japan), 2001.
2 B. Bakhshi et al, OFC’03, PD27(2003).
3 G. Vareille et al, OFC’03, PD20(2003).
4 R. Yokoyama et al, Suboptic’04, Tu B1.5(2004).
5 D.G. Foursa et al, OFC’07, PDP25(2007).
6 See, for examples, Lei Xu, “Advanced Technologies for High-Speed Optical Communications”, published by Research Signpost (2007).
7 C. Ramussen et al, OFC’03, PD18(2003).
8 G. Charlet et al, ECOC’05, Th4.1.3(2005).
9 J.-X. Cai et al, OFC’06 PDP33(2006).
10 G. Charlet et al, ECOC’08, TH3.E.3(2008).
11 J. Yu, et al, OFC’09, OThR3(2009).
12 Y. Inada, et al, Photon. Tech. Lett., 14, p.1366 (2002).
13 H. Sugahara et al, OAA’03 (2003).
14 Y. Inada et al, ECOC’04, Th.3.5.4(2004).
15 K. Fukuchi et al, CLEO’07, ThD1-1(2007)
16 T. Ito et al, OECC’07, 10B1-3(2007)