Recent Status and Trends in Optical Submarine Cable Systems

Optical submarine cable systems are essential telecommunication infrastructure for the worldwide broadband networks. This paper introduces overviews of the optical submarine cable systems including their key technologies, and also discusses their technical trend toward the next generation.

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1 Introduction

The submarine cable system has a very long history. Since the installation of the world's first submarine cable at Dover Starait in 1850, it has been an important telecommunications infrastructure for interconnecting countries worldwide. NEC entered into the submarine cable system business in 1968, and has installed a large number of submarine cable systems.

Fig. 1 shows the evolution in the submarine cable system technologies since 1970. Submarine cables systems in the 70's employed the coaxial cable that carries the electrical signals. A large number of repeaters, which amplify the electrical signals periodically, were installed with a narrow spacing of a few kilometers. The transmission capacity of the coaxial cable system was as small as some tens of Mbps. The optical submarine cable systems with using the optical regenerator became the mainstream after the fiber optics and the semiconductor lasers were put to commercial use in the 80's. The optical submarine cable systems achieved large-capacity transmissions beyond a several hundreds Mbps utilizing the fiber optic's advantage such as low loss and wide bandwidth characteristics. In the 90's, the transmission capacity has been increased dramatically by adopting both the optical amplification and wavelength-division multiplexing (WDM) transmission technologies. The optical submarine cable systems have been essential for the global broadband network. This paper describes the recent status and future perspectives of the optical submarine cable system.

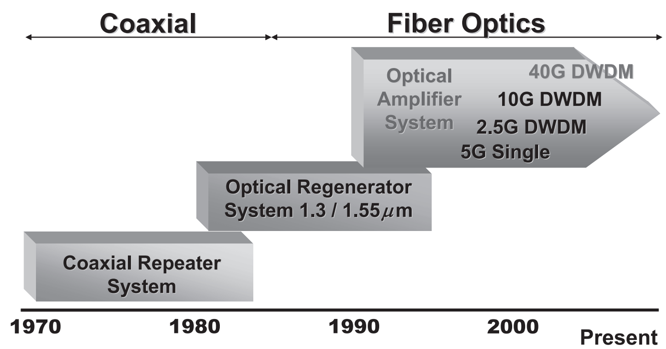

Fig. 1 Evolution of the submarine cable system technologies.

2 Overview of the Optical Submarine Cable System

Fig. 2 shows an overview of the optical submarine cable system. The optical submarine cable system is classified into two categories. One is the repeatered system for the transoceanic applications such as in the transpacific and transatlantic

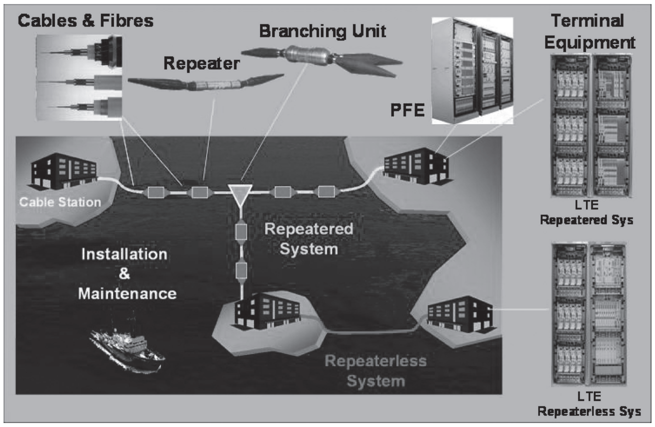

Fig. 2 Overview of the optical submarine cable system.

systems. The other is the repeaterless system for short-distance applications, e.g. between a continent and island or between islands.

The repeatered system, which transmit the optical signals over several thousands kilometers, installs submarine repeaters on the submarine cables at a constant interval in order to amplify the optical signals that are attenuated by optical fiber loss during transmission. Landing stations accommodate the terminal equipment handling the optical signals for the service traffic, the power feeding equipment for the submarine repeaters, and the element monitoring system for each equipment as well as the entire network. Branching units installed on the submarine cables are used to branch the optical fibers accommodated in each submarine cable. These optical fibers are branched to other submarine cables of various routes in order to enable the efficient connection of multiple stations.

The repeaterless transmission system installs submarine cables only in the submarine section and features land terminal equipment capable of handling high-power optical signals at the landing station. NEC has already constructed a large number both of repeatered and repeaterless systems, and we are capable of performing in house all of the necessary work from development to the manufacture of all of the requisite system elements, including the submarine cables.

3 Recent Status of Optical Submarine Cable Systems

Most of the current optical submarine cable systems employ WDM signals with a bit rate of 10 Gbps. Very large capacity transmission of over 1 Tbps per one fiber-pair is available for commercial systems, thanks to the significant advancements in the fields of optical transceivers, wavelength division multiplexing, optical amplification and optical fiber technologies.

The main factors restricting the transmission distances and capacities of optical submarine systems include the degradation of optical signal waveforms due to the wavelength dispersion and nonlinear optical effects, both of which occur in the optical fibers. Also of concern is the S/N ratio degradation due to the accumulation of ASE noise emitted by the optical amplifiers incorporated in the submarine repeaters. NEC has been tackling the technological development of the 10-Gbps WDM system in order to overcome these restriction factors for more than a decade. Below are described the main technologies that have thus been developed.

(1) Optical Transmitter/Receiver Technology

In the optical submarine cable systems, it is important to obtain high-quality transmission characteristics even for the optical signals with distorted waveform and degraded S/N ratio during transmission. To solve this issue, we apply an optical modulation/demodulation technology with an excellent S/N ratio tolerance and a high-gain forward error correction technology.

While the optical modulation/demodulation technology used generally in the terrestrial systems is the NRZ (Non-Return-to-Zero) format. the one used widely by submarine systems is the RZ (Return-to-Zero) format. The RZ format is used because it can increase the theoretical peak power by 3 dB, compared to the NRZ format of the same average power and therefore an excellent transmission quality is obtained even if the S/N ratio is low. More recently, NEC has developed and implemented an optical transceiver, adopting the RZ-DPSK (Return-to-Zero Differential Phase Shift Keying) format based on the phase-shift keying that mounts information in the light phase. The RZ-DPSK format has now become an indispensable modulation technology for the ultralong-distance systems such as the transpacific systems thanks to its excellent OSNR tolerance and chromatic dispersion tolerance.

The forward error correction (FEC) based on the Reed-Solomon code was widely employed for earlier optical amplifier systems. NEC has developed and implemented the Advanced FEC LSI featuring an improved error correction capability. This LSI applies a BCH concatenated code and achieves a greater than 3 dB higher error correction capability compared to the conventional correction applying the Reed-Solomon code.

(2) WDM Technology

In general, the terrestrial systems adopt 100 GHz or 50 GHz channel spacing for the WDM system. On the other hand, with the optical submarine cable system, which is restricted in the number of optical fibers accommodated per cable (max. 16

fibers), it is important to increase the number of the WDM signals in each optical fiber as large as possible. As a result of developments in the optical filtering technology for WDM and the wavelength stabilization technology of the laser diode used as the light source for the optical transmitters, NEC has put to commercial use the ultrahigh-density WDM technology with a minimum channel spacing of 25 GHz.

(3) Optical Amplification Technology

The optical amplifier incorporated in submarine repeaters employs the Er^{3+} doped optical fiber amplifier (EDFA), which is composed of an Er^{3+} doped optical fiber for amplifying signal light of the 1.55μm band and an pumping laser for exciting the Er^{3+} doped optical fiber. Thanks to its simple configuration it features excellent optical characteristics including wide gain bandwidth, high output power, low noise figure and high reliability. The EDFA is positioned as one of the critical technologies employed in the optical submarine cable systems. NEC has long been developing technologies for enhancing EDFA performance. To increase the gain bandwidth, we have established a gain equalization technology for optical amplification bandwidths with high accuracy. This technology offers excellent gain flatness characteristics below 0.1 dB over a bandwidth of 36 nm or more. In order to enable increased output power and a reduction in noise figure, we have implemented a high-power 980 nm band pumping laser that features optical amplification characteristics with an output of +16 dBm or more and a noise figure of 4.5 dB or less.

(4) Optical Transmission Line Technology

The optical submarine cable systems employs optical fibers as the transmission paths. Optical fibers have excellent features such as low loss and wide bandwidths. However, from the viewpoint of increasing both transmission speed and WDM density, it is important to design an optical fiber transmission line so that the optical signal waveform distortion, which is caused by both the chromatic dispersion and the nonlinearity, is suppressed. NEC has established the optical transmission line design technology that is capable of selecting and placing optimum optical fibers to meet the demands for longer transmission distances and the larger capacity taking all the optical fiber properties into consideration. For example, in the case of high capacity transpacific system over 9,000km distance, our system applies the dispersion-managed fiber with a flat chromatic dispersion characteristics over all the signal wavelength band in order to achieve the high quality in all the signal wavelengths.

By applying the results of the technical developments described above, NEC can offer an optimum solution for any system from small-scale ones for regional system to transoceanic or large-scale ones for international system.

4 Future Perspectives

Future trends in optical submarine cable systems are expected to enhance the network configuration flexibility as well as the transmission capacity. **Fig. 3** shows the advancement of transmission capacity together with the contributory applied technologies. As shown in this figure, the transmission capacity of the current 10G system has already reached the theoretical bandwidth limitation of around 2 Tbps, and then commercial implementation of the 40G system is now expected in order to increase the capacity further. Nevertheless, to exceed the current 10G system from the viewpoint of frequency utilization efficiency, it would also be important to develop the multilevel-modulation and the polarization multiplexing technologies for the commercial use. NEC has already completed the research-stage verification of a transpacific-class 9,000 km transmission system using 40G signals, and is currently advancing technological developments to enable its commercial implementation.

Regarding the enhancement of network configuration flexibility, it is expected that development of a technology for configuring the mesh network will be an essential step. As shown in **Fig. 4** , while a ring network connects stations along a single ring, a mesh network interconnects stations directly. At present, most of the large-sale optical submarine cable systems adopt the ring network configuration, as shown in the upper row of Fig. 4. With this configuration, the submarine cable accommodates the optical fibers both for direct routes and those for branch routes. The submarine optical fiber branching units simply distributes the fibers of the direct routes and those of the branch routes to configure a ring network in which the stations are connected in sequence via the optical cables. The ring network configuration secures the communications via backup routes even when a fault occurs between certain stations. However, there are some restrictions in the traffic capacity design flexibility and the redundancy priority design in the ring network configuration because all the optical signals trip across the stations.

On the other hand, by adopting the optical add/drop multiplexing (OADM) technology that branches optical signals in the wavelength domain instead of by physical branching on a per-optical fiber basis, it is possible to configure a mesh network that can set the branching destination per individual wavelength and connect the stations directly as shown in the lower row of Fig. 4. The commercial implementation of the mesh network is expected to enhance the flexibility with respect to the

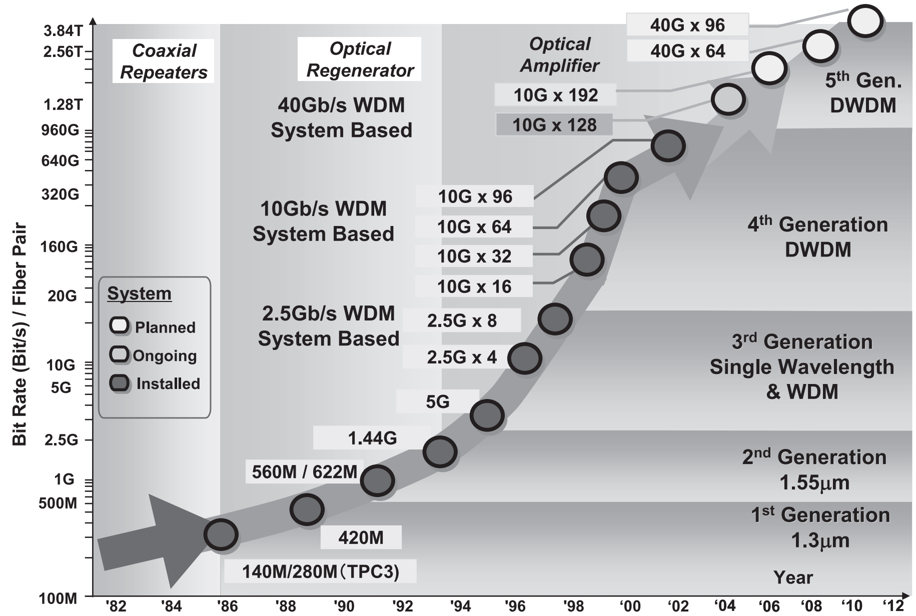

Fig. 3 Advancement of transmission capacity and applied technologies.

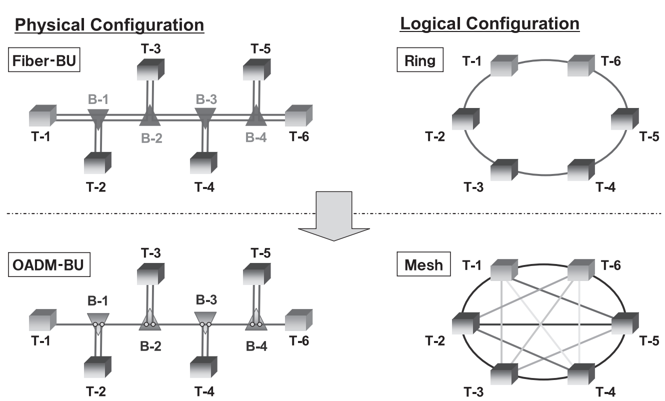

Fig. 4 Network advancement.

capacity demands and the redundancy priority of each landing country. NEC is putting practical fundamental technologies, including the OADM branching unit and the network management equipment, to commercial use to configure the mesh network systems. NEC is aiming to provide the optical submarine cable systems that feature both large capacity and flexibility.

5 Conclusion

The optical submarine cable system is now an essential telecommunication infrastructure for the global broadband network. Based on experience and achievements accumulated over nearly four decades, NEC will contribute to the advancement of telecommunication networks for connecting countries worldwide by paying efforts further on R&D for the optical submarine cable system industry.