Ultra-High-Speed Core Transport to Handle Rapid Growth in Traffic

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There has recently been a speed up of mobile traffic, spread of optical access and increase in speed and capacity of communication between data centers for purposes such as cloud services. This has caused a rapid increase in traffic in the core transport network and handling it is becoming an urgent challenge. Including international submarine networks, the core transport network is transitioning from 40 Gb/s to 100 Gb/s WDM. In these circumstances, Fujitsu has successfully developed digital coherent technology which is expected to dramatically improve frequency utilization efficiency compared to the existing technology. This new technology has been applied to an optical transport system for terrestrial FLASHWAVE 9500 and submarine FLASHWAVE S660, and released as a product. This paper gives an overview of technology that is expected to help solve problems caused by the continuous increase in the amount of traffic.

1. Introduction

Along with the sophistication of optical networks that support cloud services and smart devices and the diffusion of broadband services such as Long Term Evolution (LTE), trunk line traffic demand is on an explosively increasing trend exceeding an annual rate of 30%. In addition, routers, which are central to core networks, are rapidly shifting to 100 GbE as the trunk line traffic demand has been growing. The transmission capacity per commercially installed fiber in FY 2010 was around 1.6 Tb/s (40 Gb/s × 40 wavelengths) for terrestrial backbone networks and 1.2 Tb/s (10 Gb/s × 120 wavelengths) for submarine ultra-long haul networks; but obviously transmission capacity at these levels cannot meet the future traffic demand. To increase the transmission capacity, the method used up to now has been to increase the multiple number of wavelengths by dense wavelength division multiplexing (DWDM). While this method is reliable, it unavoidably involves an increase in power consumption due to the need to increase the scale of equipment. Therefore, it is difficult to satisfy the demand of energy-saving to help prevent the recent global warming.

With these situations in the background, Fujitsu has been working on technological research and development to realize an ultra-high-speed transport system, targeted for launch in 2012, which provides at least three times as much transmission capacity as the 2010 level. We have been focusing on digital signal processing technology as a way to increase the amount of information contained in each signal.

This paper presents the digital coherent technology adopted for an ultra-high-speed transport system and the pieces of equipment with the technology applied—FLASHWAVE 9500 for terrestrial systems and FLASHWAVE S660 for submarine systems.

2. Technological paradigm shift

In general, to increase the transmission speed, one issue to overcome is how to improve the waveform distortion (group delay) compensation performance and the noise tolerance from the transmission paths. In the optical fiber-based transmission systems, the optical signals are influenced by the chromatic dispersion which results from the dependence of the propagation speed on the wavelength, and polarization mode dispersion caused by stress on optical fibers. The optical signals affected by these factors generate a waveform distortion, and it causes signal quality degradation. The effect of waveform distortion becomes more conspicuous as the transmission speed increases. For example, increasing the transmission speed to 100 Gb/s from 40 Gb/s requires a noise tolerance improvement of 4 dB. The conventional technique which relied on the performances of the optical components has already reached its critical limit, because those components cause the problem of high volume and high cost of the equipment.

It became possible to overcome these problems by achieving a digital coherent technology[1] with the digital signal processing on an LSI circuit, and it has thus brought about an innovation that can be called a technological paradigm shift in optical transmission. One representative technological innovation is the realization of a digital signal processing algorithm with dual-polarization quadrature phase shift keying (DP-QPSK) (**Figure 1**).[2] DP-QPSK uses a combination of two technologies, named polarization multiplexing and quadrature phase shift keying, to reduce the baud rate to 25% of the transmission rate. For 100 Gb/s signals, the baud rate is reduced to 25 Gb/s with DP-QPSK modulation; this baud rate is congruous to the most advanced CMOS circuits.[3] And also this baud rate is suitable for the existing 50 GHz spacing WDM transmission equipment.

In order to apply polarization multiplexing, following polarization fluctuation was the major issue to be resolved. It is generally known that commercially installed fibers have a polarization fluctuation in the order of a few tens of kHz due to vibration and so on, and it has been said that this is difficult to follow entirely with an optical compensator. In a coherent technology, following polarization fluctuation was achieved by real-time digital signal processing, and it has allowed for an adequate performance of a commercial operation quality. Quadrature phase shift keying has reduced the spectrum spread on the frequency axis. As a result, the occupied bandwidth has become narrower than the conventional 40 Gb/s, and it has made it possible to further increase the transmission capacity in a fiber.

Furthermore, digital signal processing has made it possible to compensate the large amount of chromatic dispersion sufficiently covering the terrestrial metro networks (a few tens of thousand ps/nm) without transmission quality degradation caused by waveform distortion, and optical dispersion compensators have become unnecessary.

3. Effects of digital coherent technology

Fujitsu has applied digital coherent technology to an ultra-high-speed transport system to achieve a transmission capacity per-fiber of 8.8 Tb/s (100 Gb/s × 88 wavelengths) for terrestrial trunk line networks, five times larger than the FY 2010 level, and 3.6 Tb/s (40 Gb/s × 90 wavelengths) for submarine ultra-long-haul networks, three times greater than the FY 2010

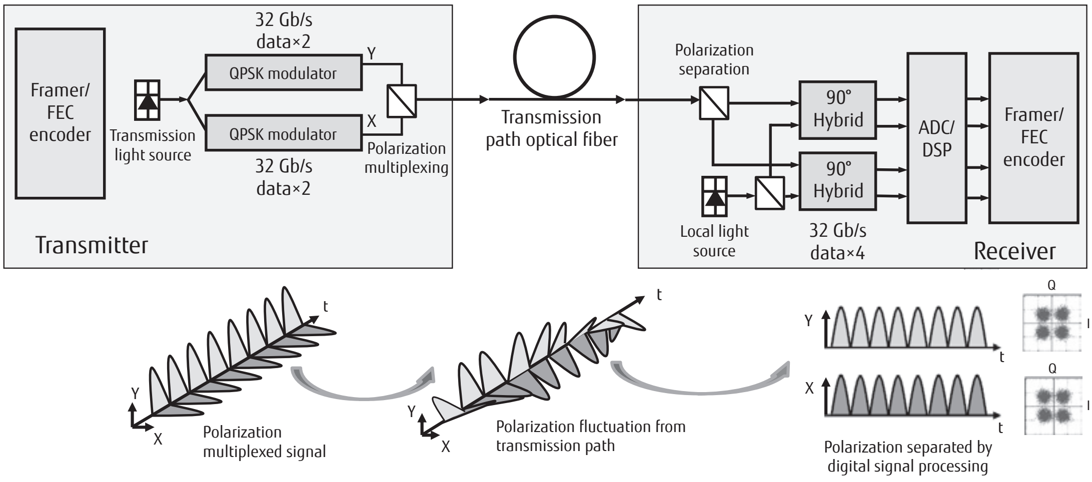


Figure 1
Configuration of digital coherent transmitter and receiver.

level. In this way, we have met the ever-increasing trunk line traffic demand.

Along with the realization of improved transmission capacity, as a result the optical signal distortion has been compensated for at the electrical signal level by digital processing, and so new effects are generated in terms of network operation.

Since the recent Great East Japan Earthquake, the issues of network flexibility and redundancy have been examined again. It is becoming essential to restore lines quickly without manual operation when a line failure has occurred. Digital coherent technology provides a function that can automatically estimate and compensate for the chromatic dispersion generated in transmission lines, and the dispersion compensation value is optimized in the order of ms. Therefore, even if there is a rapid change of the chromatic dispersion value caused by a switching of the fiber route when a failure occurs, the signal is instantaneously restored (**Figure 2**).

Previously network design has been restricted by the difference in the optimum dispersion compensation value between rerouting sections; but digital coherent technology has eliminated the dispersion limitation and improved the flexibility of the network design. This improvement of flexibility in network design has eliminated the need for strict management of the characteristics of transmission lines, which was conventionally required when installing networks, and reduced management costs and network construction terms.

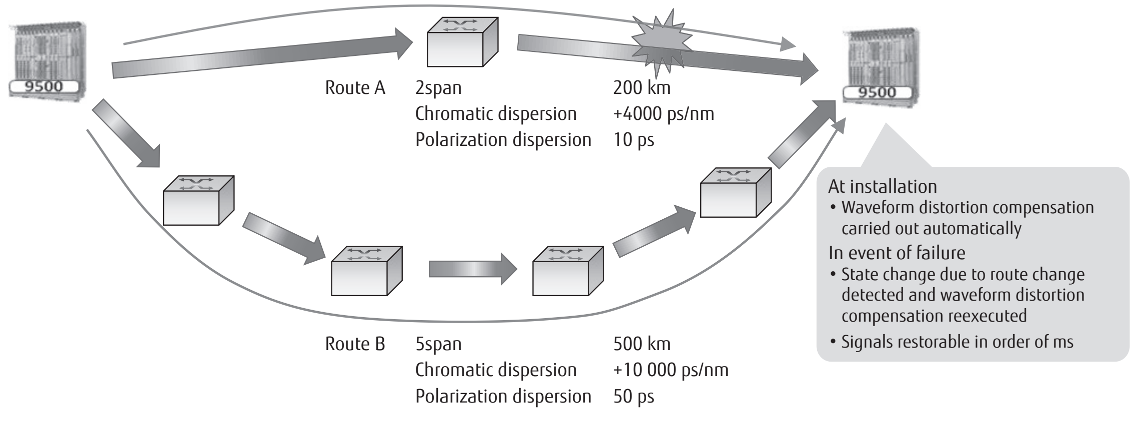
Furthermore, the conventional high-speed transport systems had some dispersion compensation equipment located in the network, such as compensators and optical amplifiers to compensate for the losses. In ultra-high-speed transport systems with digital coherent technology, the number of pieces of equipment has been dramatically reduced. As a result, there has been a structural change of optical network systems to give them simpler configurations and reduce the total costs.

4. Product development

Fujitsu has put digital coherent technology with these functions to practical use and developed ultra-high-speed transport system products.

4.1 FLASHWAVE 9500 for metro networks

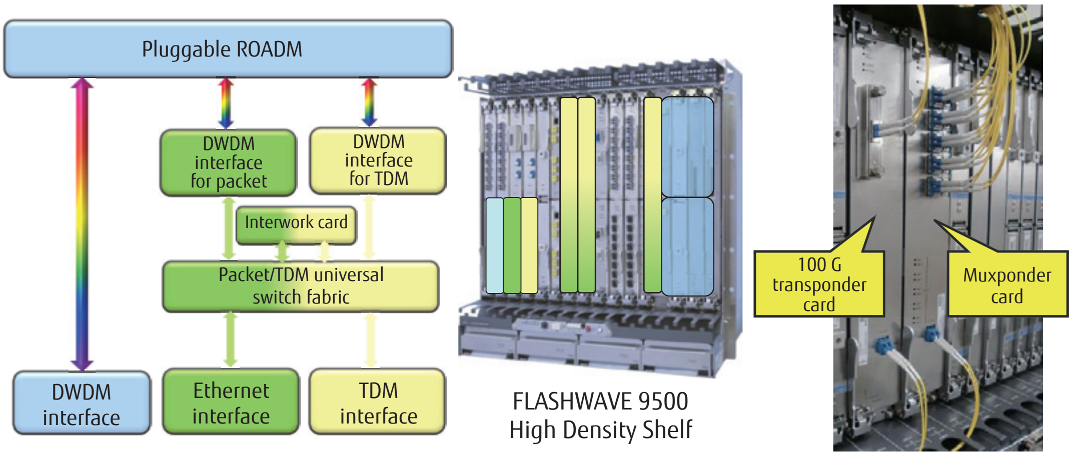
FLASHWAVE 9500 (**Figure 3**) has been designed and developed based on a product concept of a packet optical networking platform that efficiently integrates the existing and next-generation networks. Various functional blocks can be combined according to the application to offer the optimum system for the existing Internet Protocol (IP) network, Synchronous Optical NETwork/Synchronous Digital Hierarchy (SONET/SDH) and DWDM networks. This not only allows existing networks to be seamlessly migrated to higher-speed, higher-capacity next-generation networks while they are still maintained but also helps conserve space and energy by simplifying complicated circuit operation and management across IP, SONET/SDH and DWDM and by consolidating devices that constitute the networks.



At installation
- Waveform distortion compensation carried out automatically

In event of failure
- State change due to route change detected and waveform distortion compensation reexecuted
- Signals restorable in order of ms

Figure 2
Operational benefits of digital coherent technology.



Integration of network devices
(packet optical networking platform)

Optimum system can be provided by combining various functional blocks according to application

Appearance of FLASHWAVE 9500

* Transponder card supports 100 G Ethernet and OTU4 signals
* Muxponder card supports 10 channels of 10 Gb/s (10 G Ethernet, etc.) signals

Figure 3
Basic concept and appearance of FLASHWAVE 9500.

The DWDM functional block of this system, which is a reconfigurable optical add/drop multiplexer (ROADM) that supports up to 88 wavelengths and can add or drop arbitrary wavelengths, is capable of hub connection in up to eight directions and realizes 1200 km transmission with a configuration of up to 24 nodes. In addition, it adopts hybrid switching, which combines time division multiplex (TDM) switching in SONET-SDH networks and Layer 2 (L2) switching in IP networks in one system, and allows for the construction of a new IP network while maintaining a SONET/SDH network; it is also capable of more efficient Ethernet over SONET (EoS) or DWDM transmission of Ethernet services.

As mobile services including smartphone and LTE services become widespread and grow in capacity, communication carriers are demanding a reduction in the cost per transmitted bit as well as a solution to expand capacity in a cost-efficient way. Many of the existing carrier networks are built with DWDM based on 10 Gb/s signals. To address the rapid increase in bandwidth demand, they have been introducing 100 Gb/s transponders and muxponders on a full-scale basis since 2012 and these are capable of expanding the network bandwidth tenfold without expensive overlay networks.

The latest digital coherent optical transmission technology used in the 100 Gb/s transponder and muxponder of FLASHWAVE 9500 has eliminated the need for a dispersion compensation design, which was traditionally required for network construction, and made it possible for existing networks to adapt to 100 Gb/s signals without making any change. In addition, there is now no need to measure the optical fiber characteristics of the trunk line and have a dispersion design, which makes it possible to reduce the construction, maintenance and operation costs.

In addition to TDM-IP hybrid switches, Fujitsu is now working on development of Optical Transport Network (OTN) switches, which are expected to be the mainstream device in next-generation networks, and increasing switch capacity (960 Gb/s for TDM, 1.2 Tb/s for packet and 2.4 Tb/s for OTN) to help further reduce network costs.

4.2 FLASHWAVE S660 for submarine long-haul transmission

FLASHWAVE S660 has useful features which are similar to the existing FLASHWAVE S650 and it is capable of ultra-long-haul transmission exceeding 9000 km and high-capacity transmission. Moreover, it is a highly reliable piece of submarine terminal equipment that can realize easy operation and maintenance.

Up to 3.6 Tb/s with 40 Gb/s × 90 waves per fiber can be achieved by using digital coherent technology. In addition, the redundant configuration is applied for the main components and functions which affect transmission quality to achieve high reliability. In order to realize the long-haul transmission with WDM signals (i.e., 90 waves × 40 Gb/s), the accumulated chromatic dispersion (CD) value caused by the transmission fiber should be compensated for at each wavelength. Until now, such CD value was compensated at each wavelength by using an optical fiber and/or optical device. By using digital coherent technology, the accumulated CD value can be compensated for at the receiver side by high-speed digital signal processing. As a result, individual CD compensation by optical fiber and/or device is not required and so a simple equipment configuration, which means small size and low cost, can be achieved.

In the case of submarine systems, the required initial equipage is often a small number of wavelengths compared with design capacity. In order to realize stable and high-quality transmission even when only one wavelength is equipped, a function of dummy light that keeps the signal power per wavelength constant independently from the equipped number of wavelengths, is provided.

In long-haul submarine cable systems such as those over 9000 km, a hundred or more submerged repeaters are required in order to compensate for the loss of transmission fiber. After transmission in such system, the large power deviation of WDM signals caused by the accumulated gain ripple and tilt of gain characteristics of individual repeaters at the entire gain bandwidth is observed at the receiver side. To compensate for this power deviation, a pre-emphasis function that fine-tunes the transmission power for each wavelength on the transmitter side is also provided.

The interface of the client has a multi-rate structure and is capable of handling various types of signals including IP and SONET/SDH in addition to OTN. High compatibility with the FLASHWAVE 9500 mentioned earlier is ensured and a seamless network integrating submarine and terrestrial systems can be constructed (**Figure 4**).

Furthermore, this equipment helps realize a system featuring a low transmission delay, which is considered important in international financial transactions.

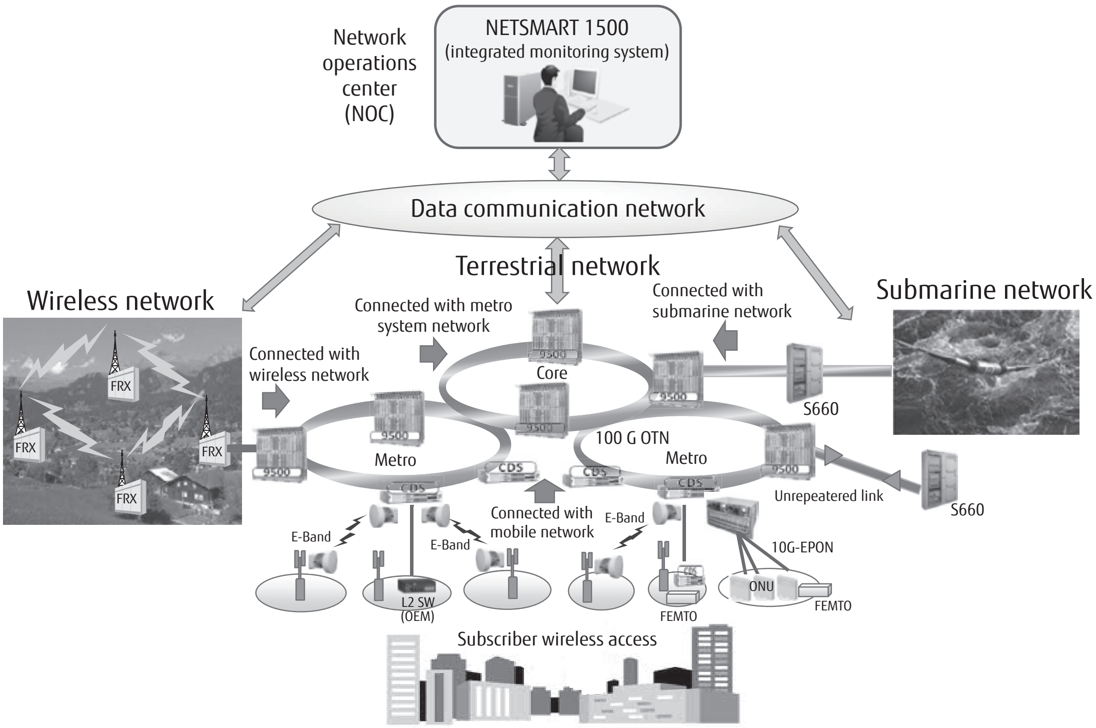


Figure 4
Fujitsu's seamless terrestrial and submarine networks.

5. Future outlook

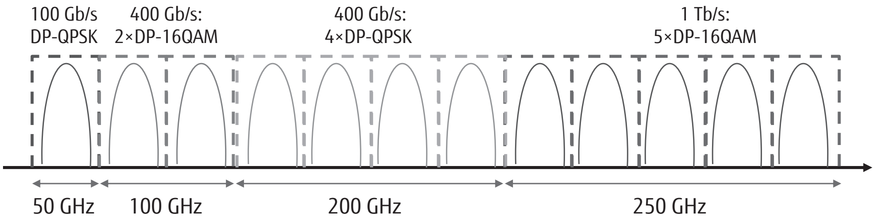
As a technological trend towards transmission capacity expansion, there are two technological axes to improve frequency utilization efficiency: further multi-level modulation technologies and spectrum bandwidth narrowing technologies (**Figure 5**).

For further multi-level modulation, such as from practical DP-QPSK (two polarizations × four levels) to 16QAM, we introduce high-level modulation technologies used in wireless communication into optical communication, by having further multi-leveling through full use of the phase, amplitude and polarization axes. Multi-leveling is an extremely effective technology for increasing the frequency utilization efficiency while restraining the expansion of spectrum bandwidth per signal.

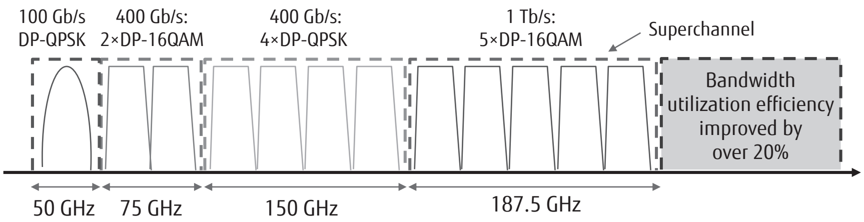
A Nyquist filtering technology (a technology to narrow the signal spectrum shape) is one way to limit the bandwidth of the spectrum. This can narrow the spectral width occupied by each signal, and compress the intervals between each signal, which leads to an increase in spectral density. These filtered channels can be a sub-carrier channel which composes the so-called super channels, for instance, 100 Gb/s × 4 channels to 400 Gb/s, and 200 Gb/s × 5 channels to 1 Tb/s.[4] To realize the operation of this high-density channel allocation, it is essential to develop a new gridless optical add/drop multiplexer (OADM).

The technology for improving frequency utilization efficiency will be a trade-off against transmission distance performance. Accordingly, in order to limit the cost increase while continuing to increase the capacity, it is necessary to keep or improve transmission distance performances which were achieved with the existing bit-rate channels operated up to now. For example, in the near future we can expect to adopt such technologies as enhanced error correction technologies for improved receiver performance and nonlinear compensation algorithms for recovering from transmission waveform degradation.

Furthermore, high-capacity transmission technologies are being studied with the aim of having exabit-level optical transmission infrastructure exceeding the bandwidth of a single optical fiber,[5] which includes space division multiplexing by multi-core transmission fiber and mode multiplexing by



(a) Capacity increase by different multi-level modulation technologies in existing-wavelength grid (50 GHz)



(b) Example of improving efficiency of frequency utilization with high-density grid using bandwidth throttling with Nyquist filter

Figure 5
Improvement of frequency utilization efficiency.

multi-mode transmission fiber.

As described above, we have commercialized 100 Gb/s transmission technology and are confronted by a rapid expansion of network scale. Therefore, it is important to promptly establish technology for the next transmission capacity expansion and put it to practical use.

6. Conclusion

As there is a pressing need to address the expansion of the volume of traffic into core networks, Fujitsu has developed digital coherent technology and commercialized an ultra-high-speed transport system offering 100 Gb/s for terrestrial systems and 40 Gb/s for submarine systems. Digital coherent technology has brought an innovation that can be called a technological paradigm shift in optical transmission. Along with the realization of improved transmission capacity, the technology has improved the network operability dramatically and reduced the total costs.

For the future, to correspond to the continuously expanding traffic, we will accelerate the development of multi-layer integration equipment for domestic systems, and apply a 100 Gb/s ultra-high-speed transport system to submarine long-haul transmission. We also plan to develop enhanced high-capacity networks that will be required in next-generation services, such as 400 Gb/s and 1 Tb/s, in pursuit of even greater frequency utilization efficiency.

Fujitsu's digital coherent transmission technology presented in this paper uses the outcomes of the technological development in the "Research and Development on High Speed Optical Transport System Technologies" and "Research and Development on Ultra-high Speed Optical Edge Node Technologies" commissioned by Japan's Ministry of Internal Affairs and Communications.

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