3-2 1000 Channel WDM Transmission and Grouped Wavelength Path Routing Experiments using JGNⅡ Test Bed

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A 1000 channel WDM transmission experiment based on a supercontinuum multi-carrier source as well as a group-wavelength path routing experiment utilizing simultaneous WDM wavelength conversion on a JGNⅡ test bed are reported.

Keywords

WDM transmission, Multi-carrier source, Grouped-wavelength path routing, Simultaneous wavelength conversion, JGNⅡ test bed

1 Introduction

The communication traffic on the Internet is rapidly increasing, and this is due mainly to services dealing with audio and broadband image data. In the future ubiquitous network society, it will be expected to exchange information smoothly among computers, electric household appliances, tags, sensors, and other devices via networks. Such communication networks will require wide band capacity, flexibility, and security. In order to satisfy these demands, research and development of photonic network technologies based on wavelength division multiplexing (WDM) transmission and optical switching technologies has been carried out.

In order to realize the broadband photonic networks and all-optical end-to-end networks, WDM transmission technologies utilizing over 1,000 wavelengths are required. Furthermore, grouped wavelength conversion technologies will also be needed so that 1,000-wavelength networks can operate efficiently.

This paper reports on over 1000 channel WDM transmission experiment, and wave conversion and grouped-wavelength conversion experiments using the JGNⅡ optical network testbed and the NICT Keihanna Info-Communication Open Laboratory; these technologies in particular will be essential for efficient, all-optical broadband photonic networks.

2 Over 1000 channel WDM transmission technologies

An ultra-broadband optical transmission technology can generally be expected to increase the flexibility and reduce the cost of photonic networks; thus broadband devices (such as WDM sources, optical amplifiers, and optical filters) are important issues.

A supercontinuum multi-carrier source (SC-MCS) can simultaneously generate more than 100 channels of optical carriers with a high SNR, aligned precisely on an optical frequency axis; such a source can be expected to contribute to make WDM sources simple and reduce cost and improve wavelength controllability. Previously we have reported that SC-MCS can be applied to multi-span WDM transmission systems, specifically through a 124-nm broadband seamless transmission experiment in the S-, C-, and L-bands using the SC-MCS (313 channels, 160 km)[1] and through a long-span optical transmission experiment (≥100 channels, ≥1,000 km)[2]. The applicability of over 1000 channel wavelength-division multiplexing was also confirmed.

This paper will first evaluate the technologies for multi-wavelength generation exceeding 1,000 channels and optical frequency stabilization using the SC-MCS, and report on a 1,000-channel WDM transmission experiment using the JGNⅡ optical network testbed.

2.1 High-accuracy optical multi-carrier generation technology

We examined high-accuracy optical multi-carrier generation using the SC-MCS.

A multi-carrier with a 6.25-GHz channel spacing was generated by injecting optical pulse trains with repetition frequencies of 6.25 GHz into an SC fiber. Figure 1 shows the generated SC spectrum. The optical spectrum of the pump light source is converted into an ultra-broadband spectrum of over 170 nm in the SC fiber [Fig. 1 (a)]. Figure 1 (b) indicates that the optical carriers are aligned precisely at 6.25-Ghz intervals around 1,560 nm. Thus we confirmed that optical carriers were generated in the wavelength range of from 1,490 nm to 1,660 nm.

Furthermore, the frequency of the optical carrier produced by the SC-MCS was stabilized by locking the carrier to an optical-frequency-stabilized source[3]. As a result, we were able to generate multi-carriers with an optical frequency accuracy of within ±1 MHz, as shown in Fig. 2.

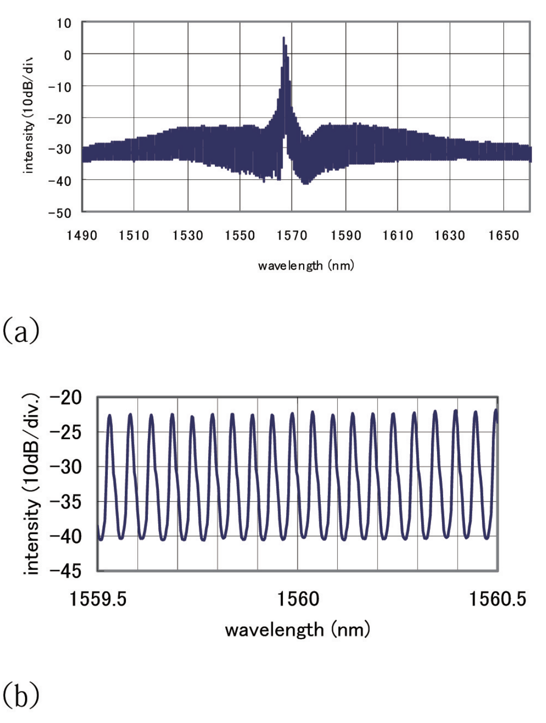

Fig.1 *Output spectrum of SC-MCS*

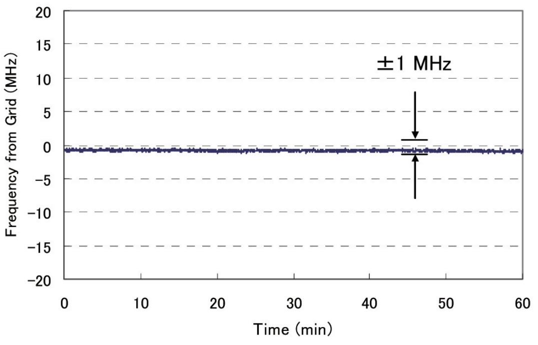

Fig.2 *Frequency stability of the optical carrier*

2.2 1,000 channel WDM transmission experiment

Next, we conducted a 1,000-channel WDM transmission experiment using the JGNⅡ optical network testbed and the NICT Keihanna Info-Communication Open Laboratory (Fig. 3)[4]. The transmitter and receiver were set up in the Keihanna Info-Communication Open Laboratory and the optical amplifier was set up in Dojima, Osaka (NICT Keihanna Center). The transmission fiber is 126 km of field-installed fibers (SMFs) in the JGNⅡ testbed between the Keihanna Laboratory and Dojima. From the ultra-dense multi carriers generated by the SC-MCS with a channel spacing of 6.25-GHz, approximately 1,000 channels between the wavelengths of 1539 nm to 1600 nm were used. After modulating these

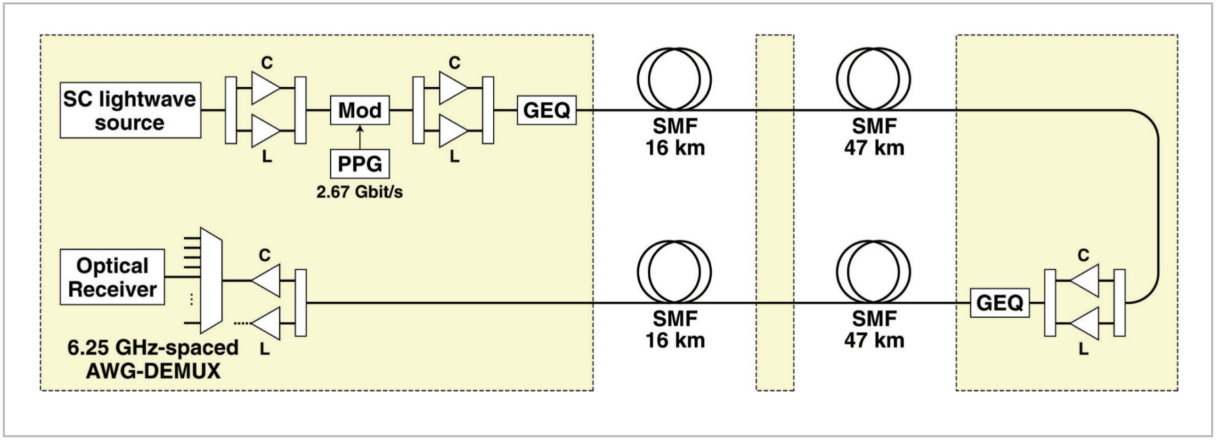

Fig.3 *Transmission experiment setup*

multi-carriers with a 2.67-Gbit/s signal (2^{31}–1 PRBS) using an intensity modulator, the C- and L-bands were amplified and injected into the SMF transmission fibers. The wavelengths of the optical signals were 1539.07–1564.68 nm in the C-band, and 1,572.01–1,600.01 nm in the L-band. The transmission fibers consist of two spans, with a total length of 126 km (63 km × 2). The signal power into the transmission fibers was set at –15 dBm per channel to reduce the influence of FWM 1 within the transmission fibers.

After transmission, the WDM signals were demultiplexed using a 6.25-GHz-spacing demultiplexing filter; the Q-factor values were then measured (Fig. 4). The measured Q-factor values were all above 11.1 dB (corresponding to a bit error rate (BER) using FER < 10^{-12}) for the 1,046 channels.

From these results, we confirmed that ultra-dense, 1,000 channel WDM transmission with a 6.25-GHz channel spacing is feasible.

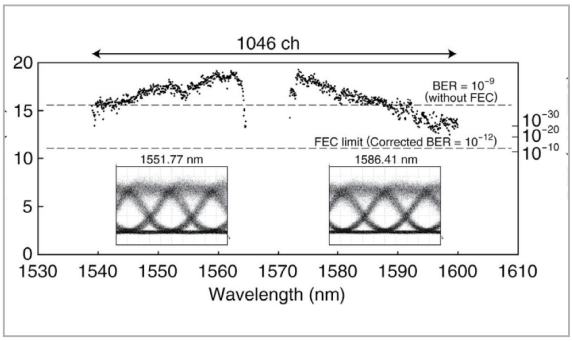

Fig.4 *Q-factor value of WDM signals after transmission*

In the future, we will extend the transmission distance by improving the SNR of the signal source, gain flatness of the optical amplifiers, and optimization of the transmission fiber characteristics.

3 Wavelength conversion and grouped-wavelength conversion

To respond to the demand for high-speed, large-volume inter-user connections, it is necessary to investigate the operation and node configuration methods of grouped-wavelength paths consisting of multiple channels. For dynamic operation of a grouped-wavelength path, devices are required that can perform simultaneous wavelength conversion of multiple channels. Parametric wavelength conversion is one technique that can be effective for this purpose. In this study, a quasi-phase-matching lithium niobate (QPM-LN) waveguide was used as the nonlinear material to realize parametric wave conversion. The virtual grouped-wavelength path routing experiment was conducted using the JGNⅡ optical network testbed and the NICT Keihanna Info-Communication Open Laboratory.

Figure 5 shows the experiment setup for the 25-GHz, 8-channel grouped-wavelength path routing experiment [Channel 1 (1,555.4 nm) to Channel 8 (1,556.8 nm), NRZ 10 Gbit/s (PRBS: 2^{31}–1)][5]. The modulated signals were divided into two paths to form two

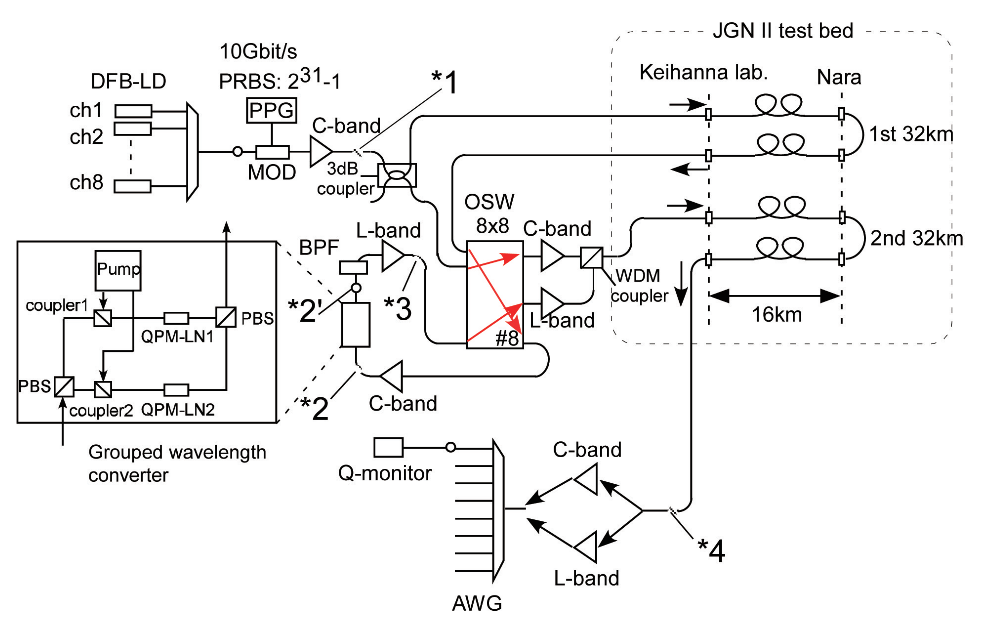

Fig.5 *Setup for 8-channel grouped-wavelength collision avoidance experiment*

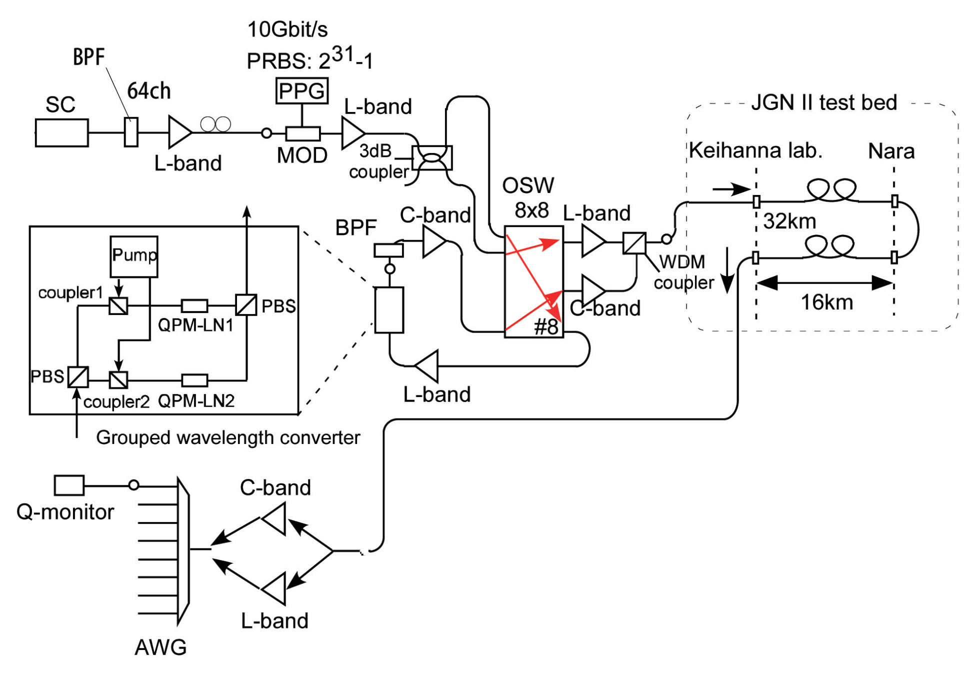

Fig.6 *Setup for 64-channel grouped-wavelength switching experiment*

wavelength groups, and we circumvented collision in the fiber on the output side of the switch using a polarization-independent wavelength conversion circuit and an optical switch. The transmission fibers used were those of field-installed SMFs in the JGNⅡ test bed between NICT Keihanna Info-Communication Open Laboratory and Nara (Nara Institute of Science and Technology). Two 16-km fibers to and from Nara were used to form a 32-km path. Figure 6 shows the setup for the grouped-wavelength path routing experiment with a 64-channel wavelength group[6].

Figure 7 shows the spectrum and eye-pattern of 8-channel grouped-wavelength (shorter wavelength: without conversion; longer wavelength: with conversion) after transmission through the 32-km fibers. A uniform wavelength conversion characteristic was obtained through the use of a polarization-independent wavelength conversion circuit. No variations in conversion efficiency were observed during the experiment. All output signals were confirmed to have Q values > 15.6 dB (BER < 10^{-9}). Figure 8 shows the spectrum for the 64-channel wavelength group after transmission through the 32-km line. As indicated in the figure, the polarization-independent wavelength conversion circuit features a wavelength conversion bandwidth of 70 nm. The slope of the signal power of the grouped wavelength after wavelength conversion is due to the gain profile of the L-band optical amplifiers. We confirmed a Q value ≥ 15.6 dB (BER ≤ 10^{-9}) in all channels. Note that no variations in Q values were observed with a change in polarization and that wavelength conversion was stable.

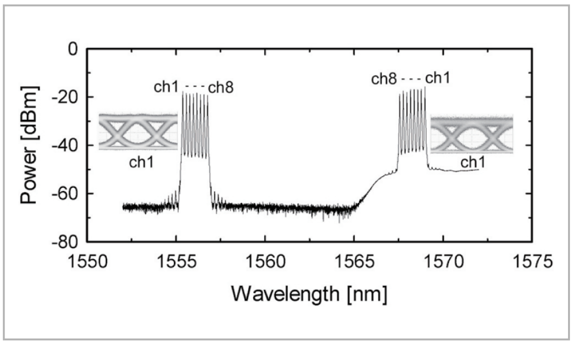

Fig.7 Node output spectrum after 32-km transmission

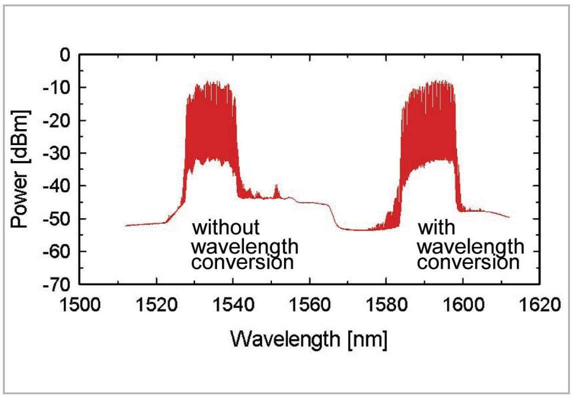

Fig.8 Spectrum after 32-km transmission

4 Conclusions

We conducted a successful ultra-dense WDM signal transmission experiment using field-installed fibers in the JGNⅡ optical network testbed and the NICT Keihanna Info-Communication Open Laboratory (bit rate: 2.5 Gbit/s; 1,046 channels; distance: 126 km). These results indicate the feasibility of over 1,000 channel WDM transmission using a single optical fiber line. This ultra-broadband optic transmission technology using SC-MCS not only offers extremely simple design but also enables simultaneous transmission over wider bandwidth range. It is expected that this technology will contribute to the realization of high-performance, low-cost optical communication networks in the future.

A virtual grouped-wavelength path routing experiment was also conducted using the JGN Ⅱ optical network testbed and the NICT Keihanna Info-Communication Open Laboratory. Using two different wavelength group configurations (8-channel and 64-channel), we have successfully demonstrated stable operation of a polarization-independent wavelength conversion circuit and simultaneous multi-wavelength switching of OSW.The feasibility of grouped wavelength switching with a throughput of 5 Tbit/s was thus confirmed.

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