Ultrafast Hierarchical OTDM/WDM Network

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ABSTRACT

Ultrafast hierarchical OTDM/WDM network is proposed for the future core-network. We review its enabling technologies: C- and L-wavelength-band generation, OTDM-WDM mutual multiplexing format conversions, and ultrafast OTDM wavelength-band conversions.

KEY WORDS

Photonic network, Fiber optic communications, Wavelength division multiplexing, Optical time division multiplexing, Photonic processing, Nonlinear optics

I. Introduction

The rapidly increase in demand for bandwidth from end-users forces network infrastructure to be agile and flexible. Expansion of WDM channels results in increase of the complexity of optical cross-connect. The grouping of wavelengths, that is, layered structure of optical path, is a way to reduce this complexity.

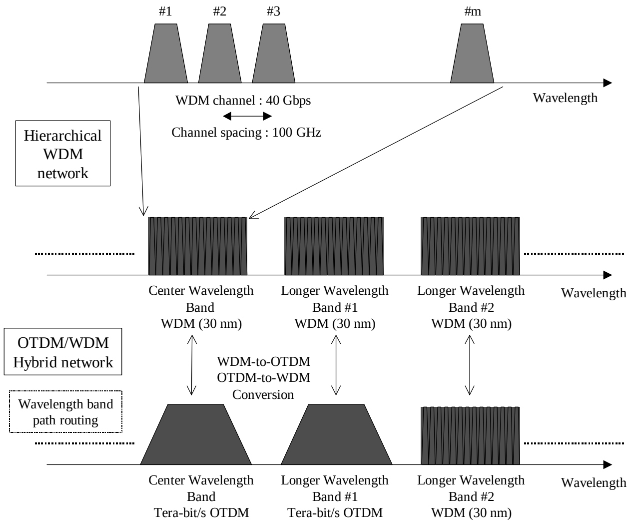

Fig. 1: Layered structure of hierarchical OTDM/WDM network.

Accordingly, hierarchical OTDM/WDM networks, as shown in Fig. 1, have been proposed as future core networks [1,2]. After grouping WDM channels as wavelength-band, the high-level traffic is converted to tera-bit/s OTDM, which is cut through the low-level nodes with guarantee for error-free transmission using a single optical carrier signal monitoring [1,2]. The hierarchical structure suggests a natural method of using wavelength-band routing to achieve a high degree of spectrum reuse.

In such networks, wavelength-band generation [3], multiplexing format conversions [4], and wavelength-band conversions [5] will be key technologies.

In this paper, we review the enabling technologies for the ultrafast hierarchical OTDM/WDM networks. We report experimental demonstrations of a frequency standardized 3.24 Tbit/s C- and L-wavelength-band generation in Section 2, a 40 Gbit/s OTDM-WDM mutual multiplexing format conversion in Section 3, and a 640 Gbit/s OTDM wavelength-band conversion in Section 4.

II. C+L-Wavelength-band generation

We propose a simple configuration of frequency standardized simultaneous wavelength-band generation using a single supercontinuum (SC) source [6], which is directly pumped by an optically multiplexed carrier suppressed return-to-zero (CS-RZ) signal [3]. Figure 2 shows the operational principle of frequency standardized simultaneous wavelength-band generation in SC-RZ format using SC generation. A 10 Gbit/s RZ signal is optically time-delayed

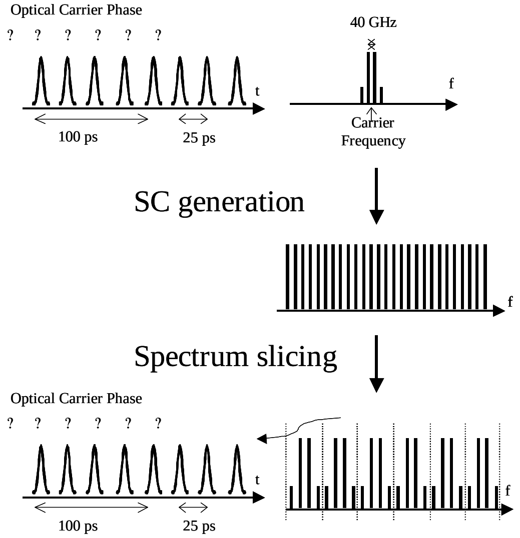

Fig. 2: Simultaneous wavelength-band generation of frequency standardized CS-RZ DWDM signal.

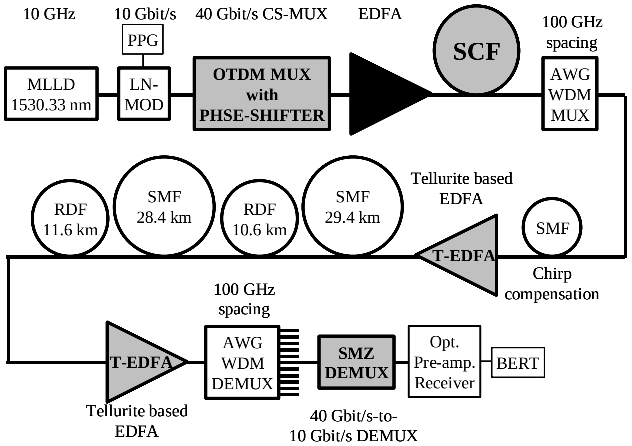

Fig. 3: Experimental setup of frequency standardized simultaneously generation and transmission of 3.24 Tbit/s (81 WDM x 40 Gbit/s) wavelength-band CS-RZ signal.

multiplexed into a 40 Gbit/s signal. The optical carrier phase of each delayed adjacent pulse is shifted by ? using optical phase shifters in the time domain. Simultaneous multi-wavelength 40 Gbit/s CS-RZ multiplications are performed by SC generation directly pumped by a 40 Gbit/s CS-RZ signal.

Figure 3 shows the experimental setup of 3.24 Tbit/s (81 WDM x 40 Gbit/s) CS-RZ generation and transmission. The generated 40 Gbit/s CS-RZ induced SC signal was spectrum sliced and recombined by AWGs with a 100 GHz channel spacing to generate multi-wavelength 40 Gbit/s CS-RZ signals. Tellurite-based erbium-doped fiber amplifiers (T-EDFAs) were used for amplification of the continuous signal band in the C- and L-bands [7]. The transmission line was two pairs of a single mode dispersion fiber (SMF) and a reversed dispersion fiber (RDF). Signals were wavelength demultiplexed by a 100 GHz spacing, 81 channels of AWG (ch. 1: 1535.04 nm – ch. 81: 1600.60 nm). Then, the resulting WDM DEMUX 40 Gbit/s CS-RZ signal was optically TDM demultiplexed into 10 Gbit/s by using a Symmetric Mach-Zehnder (SMZ) all-optical switch [9].

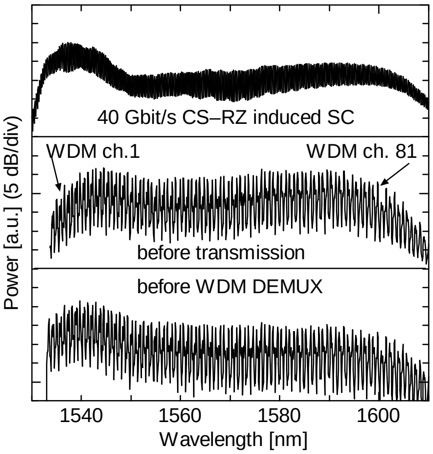

Fig. 4: Measured optical spectra

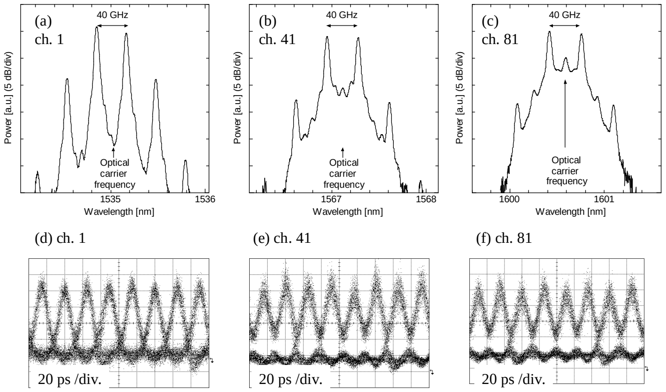

Fig. 5: Measured optical spectra and eye diagrams of ch. 1 and ch. 81.

Figure 4 shows the optical spectra of generated and transmitted wavelength-band signal. Figure 5 shows the measured optical spectra and eye diagrams of WDM ch. 1 (1535 nm) and ch. 81 (1601 nm). Transmission of frequency standardized simultaneously generated 3.24 Tbit/s (81 WDM x 40 Gbit/s) CS-RZ over 80 km dispersion compensated link are experimentally demonstrated using T-EDFAs with 66 nm continuous signal in C- and L-wavelength band with bit-error rates (BERs) less than 10^{-9}.

III. OTDM-WDM Multiplexing format conversion

We propose an efficient scheme of photonic multiplexing format conversion and reconversion of OTDM and WDM by wavelength interchange using optical time-gating of highly chirped SC and high speed pulse trains [4]. Figure 6 shows the operational principle of multiplexing format conversion. When 40 Gbit/s OTDM signals are used to control the time-gating ON/OFF window, the 10 GHz repetition rate SC pulses are converted to 4 x 10 Gbit/s WDM signals, since the center wavelengths of four WDM channels depend on the time-gating position. WDM-to-OTDM conversion is achieved by controlling the time-gating widow using WDM signals. Four time-aligned 10 Gbit/s WDM signals are used for controlling the time-gating ON/OFF window, 40 GHz repetition rate pulse trains are converted to 4 x 10 Gbit/s OTDM signals.

Figure 7 shows the experimental setup of 40 Gbit/s photonic conversion. 10 GHz SC pulses are optically time-gated in semiconductor saturable absorber [10] pumped by amplified 40 Gbit/s OTDM data. The time-window opens while the pump pulse saturates the absorber and its duration is 10 ps. The center wavelengths of time-gated SC pulses depend on the time position of time-gating. Then, it is WDM demultiplexed using an AWG having channel spacing of 350 GHz (?$_1$: 1544.1 nm -??$_4$: 1552.5 nm). For WDM-to-OTDM conversion, the 40 GHz pulse trains, which are generated by four times time-delayed optical multiplexer from 10 GHz MLLD pulse trains, are optical time gated by using the 40 Gbit/s WDM data. The converted 40 Gbit/s OTDM data are time demultiplexed into 10 Gbit/s by optical time-gating.

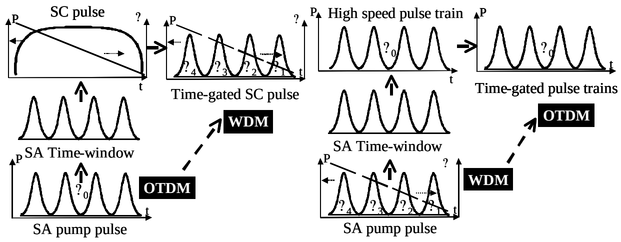

Fig. 6: Operational principle of the photonic conversion of (a) OTDM-to-WDM, and (b) WDM-to-OTDM by using optical time-gating.

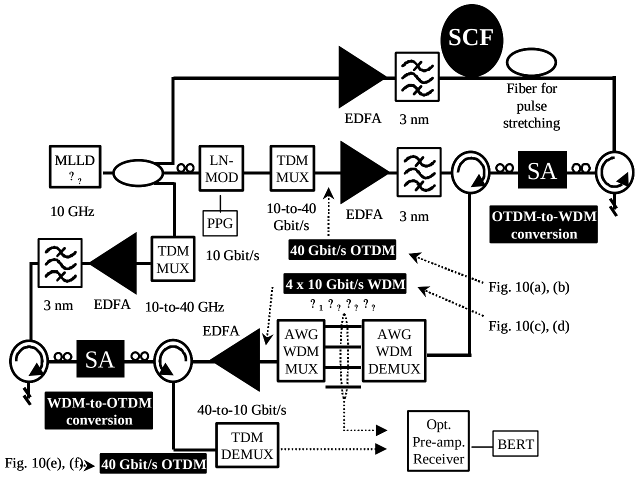

Fig. 7: Experimental setup.

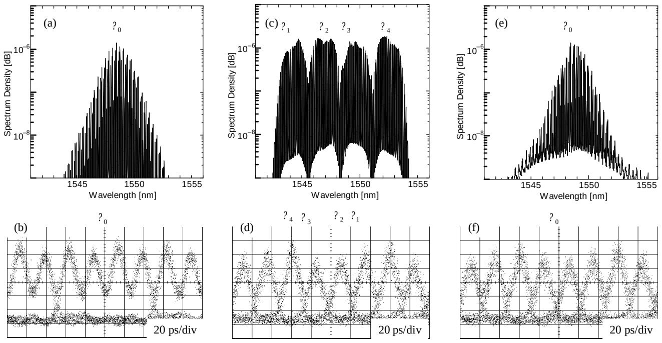

Fig. 8: Measured (a),(b) 40 Gbit/s OTDM, (c),(d) converted WDM, and (e),(f) reconverted OTDM.

Figure 8 shows the experimental results. 40 Gbit/s OTDM-to-4 x 10 Gbit/s WDM-to-40 Gbit/s OTDM conversions in series are experimentally demonstrated based upon ultrafast photonic processing with BERs less than 10^{-9}.

IV. 640 Gbit/s Wavelength-band conversion

We propose wavelength-band conversion of ultrafast OTDM signals to establish wavelength-band path routing [5]. By use of highly nonlinear dispersion-shifted fibers, (HNL-DSF) almost pulse broadening-free, highly efficient wavelength-band conversions can be obtained.

Figure 9 and Fig. 10 respectively show the

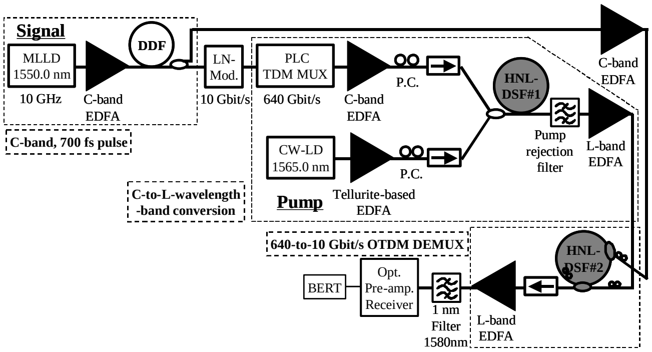

Fig. 9: Experimental setup for C-to-L wavelength-band conversion of 640 Gbit/s OTDM signal.

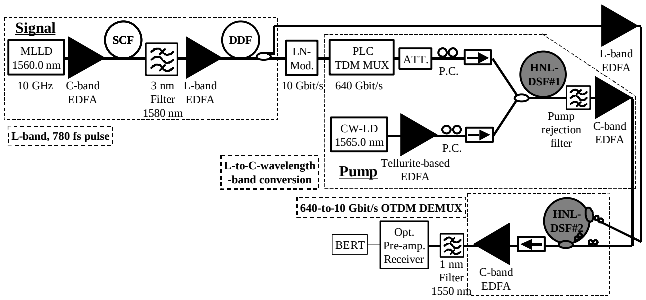

Fig. 10: Experimental setup for L-to-C wavelength-band conversion of 640 Gbit/s OTDM signal.

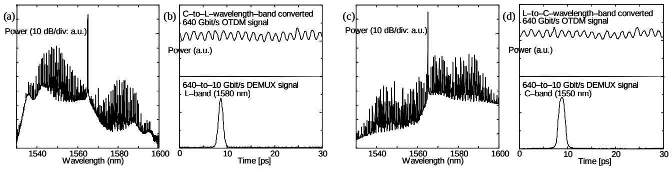

Fig. 11: Experimental results of 640 Gbit/s OTDM signal (a),(b) C-to-L wavelength-band conversion, and (c),(d) L-to-C wavelength-band conversion.

experimental setup of C-to-L and L-to-C wavelength-band conversion. For C-to-L wavelength conversion, a 640 Gbit/s OTDM signal in the C-band is wavelength converted to L-band in a HNL-DSF by four-wave mixing. After that, the converted L-band signal is demultiplexed into 10 Gbit/s using a HNL-DSF based optical switch. For L-to-C wavelength conversion, the opposite wavelength allocation was used.

Figure 11 shows the experimental results of 640 Gbit/s sub-pico second OTDM signals wavelength-band conversions of C-to-L-wavelength-band and L-to-C-wavelength-band accompanied by 640-to-10 Gbit/s OTDM demultiplexing. In both experiments, wavelength conversions were done with BERs less than 10^{-9}

V. Conclusion

Key technologies for hierarchical OTDM/WDM network, that is, 3.24 Tbit/s frequency standardized C- and L-wavelength-band generation, 40 Gbit/s OTDM-WDM mutual multiplexing format conversions, and 640 Gbit/s OTDM wavelength-band conversions are reviewed. The proposed schemes based upon ultrafast photonic processing would become crucial in the future hierarchical OTDM/WDM network.

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