100 km Field Trial of 1.24 Tbit/s, Spectral Efficient Asynchronous 5 WDM×25 DPSK-OCDMA using One Set of 50×50 Ports Large Scale En/Decoder

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Abstract: Field trial of Terabit payload capacity (1.24 Tb/s), spectral efficient (SE>0.41 bit/s/Hz) asynchronous WDM/DPSK-OCDMA system is demonstrated for the first time with a set of large scale (50×50 ports, 500 Gchip/s) multi-port en/decoder and FEC.

OCIS codes: (060.2330) Fiber optics communication; (060.5060) Phase modulation; (060.4230) Multiplexing

Introduction By combining optical code division multiple access (OCDMA) with wavelength division multiplexing (WDM) technique, high capacity in access networks can be achieved, which in prospective can enable gigabit-symmetric FTTH [1~2]. In a multi-user coherent OCDMA system, the major noise sources that limit the system capacity are the beat noise and multiple-access-interference (MAI) [2~5]. In synchronous coherent OCDMA, proper timing coordination is required to carefully avoid the overlaps between signal and interferences [4~5]. This is a kind of hybrid TDM/OCDMA scheme. Combining time gating, optical thresholding, polarization multiplexing and forward-error-correction (FEC), up to 320 Gb/s capacity has been demonstrated in synchronous OCDMA [5].

However, the asynchronous capability is essential in practical OCDMA systems [1~3]. In asynchronous OCDMA, signal and interferences are received with random overlap, therefore the system suffers from more severe beat noise and MAI comparing to synchronous ones. Employing ultra-long optical codes (OC) [2], multi-port encoder/decoder (E/D) with high power-contrast-ratio (PCR) [3] and optical thresholding [2] can effectively suppress these noises in asynchronous environment to enable multi-user OCDMA [3]. Using differential phase shift keying (DPSK) modulation with balanced detection [6] and FEC [7] can also effectively enhance the noise tolerance of the system. The multi-port E/D [8] also has periodic spectral response and it can process multiple OCs in multiple wavelength bands simultaneously. Using a multi-port encoder in the central office, and a low cost decoder in the ONU makes the WDM/OCDMA system very flexible and cost-effective [3]; it is very desirable to employ a large-scale multi-port E/D, whose cost can be shared by all the subscribers. Using 16×16 ports, 200 Gchip/s E/D, up to 385 Gbit/s capacity asynchronous WDM/DPSK-OCDMA system has been demonstrated with spectral efficiency of 0.32 bit/s/Hz [3].

In this paper, we demonstrate the field trial experiment of a Terabit payload capacity (1.24 Tb/s) asynchronous WDM/DPSK-OCDMA transmission with a large scale (50×50 ports, 500 Gchip/s) multi-port E/D and FEC. The multi-port E/D is used in a novel multi-dimensional configuration to best fit the WDM/OCDMA system. Payloads of 5 wavelengths (600GHz spacing)×25-OCDMA users at 9.95328 Gbps/user have been successfully transmitted over 100 km field fiber in Tokyo with bit-error-rate (BER)<10^{-9} and spectral efficiency (SE) of ~0.41 bit/s/Hz for payload.

Experiment description and results Figure 1 shows the experimental setup. We employed two super-continuum (SC) sources as WDM light sources. Each of them is composed of a mode-locked laser (MLLD), an EDFA and 2 km dispersion-flattened-fiber (DFF). The central wavelengths of the MLLDs are 1569.5 nm and 1565 nm, respectively. The MLLDs were driven by two independent synthesizers at 10.71 GHz. The spectra of the SC signals are shown in insets $\alpha 1$ and $\alpha 2$. Two pattern generators were used to generate independent data streams. The data stream for BER measurement was optical transport Network (OTN) frame generated by Anritsu Network Performance Tester. The frame contains 2^{31}-1 pseudo random bit sequence (PRBS) payload and FEC parity. The FEC is Reed-Solomon code (RS(255, 239)). The data rate is 10.71 Gbps (10 G for payload+7% FEC overhead). These data were encoded by DPSK encoder and drove the Lithium Niobate phase modulators (LN-PM). The SC signals were splitted into 5 branches and 5 band-pass filters (BPF) with 4 nm bandwidth and center wavelengths of $\lambda 1$(1540.16 nm), $\lambda 2$(1544.92 nm), $\lambda 3$(1549.72 nm), $\lambda 4$(1554.54 nm), and $\lambda 5$(1559.39 nm) were used to generate 5 WDM channel. The WDM channels fit to the ITU grid and channel spacing is 600 GHz. Insets $\beta 1$~$\beta 5$ in Fig. 1 show their spectra.

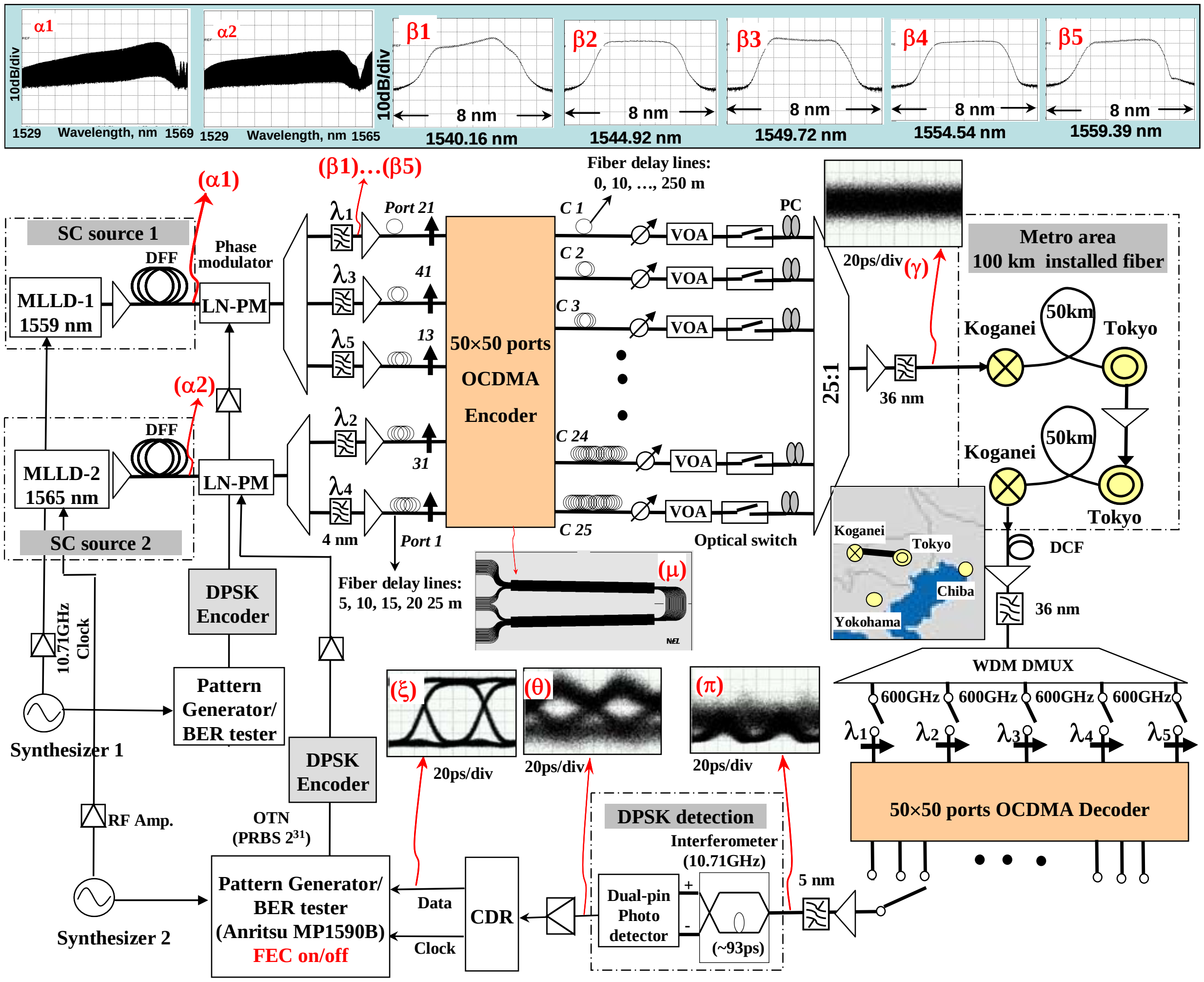

Fig. 1. Experimental setup

The 50×50 port E/D that can generate 50 coherent time-spreading OCs with 50 chips and 500 Gchip/s for this application was fabricated by NEL. Inset μ shows its basic configuration. Since a WDM/OCDMA system suffers also from WDM inter-channel cross-talk, in addition to the OCDMA multi-user interference, and in order to maximize the spectral efficiency of the system, it is essential to suppress the inter-channel cross talk to enable the WDM channel spacing close to the free-spectral-range (FSR) of the E/D. In the experiment, we adopted a multi-dimensional (Multi-D) configuration to minimize the WDM cross-talk, where, signals from different WDM channels go into different input ports of the encoder; therefore the multi-port encoder functions as both WDM multiplexer and OCDMA encoder simultaneously. By properly choosing the input ports among the 50 ports available of the encoder, we were able to minimize the WDM cross-talks. Figure 2 shows the comparison of crosstalk levels of between the conventional [3] and Multi-D configurations for λ3. The maximum crosstalk levels from the two adjacent channels have been significantly suppressed by 7.5 dB and 11dB respectively in the Multi-D case and the deviation range of crosstalk level has been significantly reduced >10 dB.

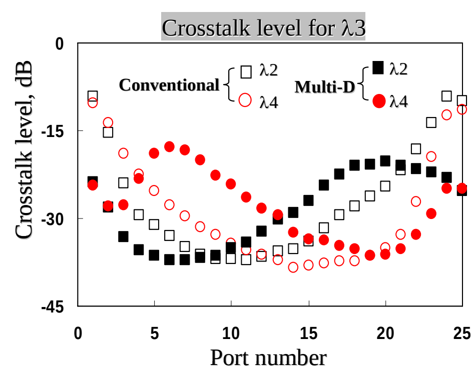

Fig. 2 Comparison of crosstalk level between conventional and Multi-D configurations (for λ3)

We used all the odd output ports of the encoder to generate 25 different OCs (C1~C25). The 5 WDM×25 OCDMA signals were multiplexed in an asynchronous manner [2~3] with random delays and random polarization states (uniformly distributed for C1~C25), and then launched into 100 km field fiber installed in Tokyo area [3]. Inset γ in Fig. 1 shows the waveform of this signal. Low noise figure (NF<4) EDFAs were used before and after the

100 km field transmission. The received signal was separated by the WDM demultiplexer and decoded by the multi-port OCDMA decoder. In an actual system, the decoder could be replaced by a fixed low cost decoder [3]. A fiber based interferometer and balanced detector perform the DPSK detection. The clock-data-recovery (CDR) circuit regenerates the data and clock signals and forwarded to the BER tester. Insets π, θ and ξ in Fig. 1 show the eye diagrams of the signals after the decoder, detector and CDR, respectively.

Figure 3 shows the BER performances of all the 5 WDM channels and all 25 OCDMA users for back-to-back (B-to-B) and field transmission. In the B-to-B case with FEC, error free ($<10^{-12}$) has been achieved for all the users in all the channels. The figure at the lower corner in Fig.3 is a captured picture of the measurement result with Anritsu MP1590B. After field transmission, most of the users have also achieved error free except 3 users in λ1. These three users appeared BER floor at $\sim 10^{-10}$. Compared to B-to-B case, the power penalty after field transmission is about 1.6 dB in average. The SE (for payload) is 0.41 bit/s/Hz, that is a recode value in asynchronous OCDMA.

Conclusion Field trial of Terabit capacity, high spectral efficiency asynchronous WDM/DPSK-OCDMA system is demonstrated for the first time with a large scale multi-port E/D and FEC.

References

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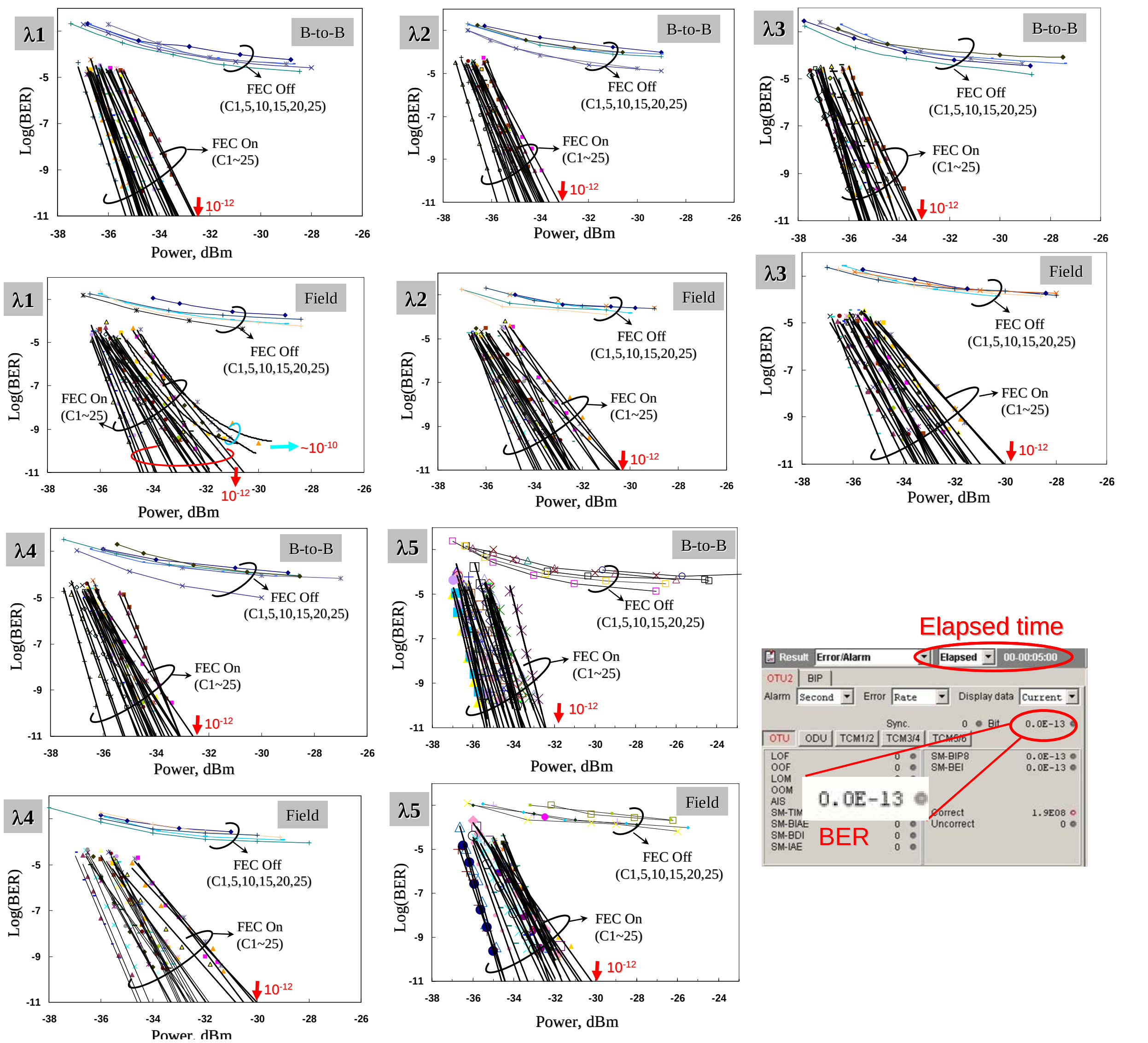

Fig. 3. BER performances