Improved Phase Matching by Paired-Fiber Coherent Matched Detection for Time-Frequency Domain Demultiplexing

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Abstract: We investigate coherent matched detection with paired fiber configuration, which improves phase matching between received time-frequency domain multiplexed signals and multicarrier local oscillator, giving a tolerance to residual dispersion.

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So much attention is paid on high-capacity and high-spectral-efficiency transmission, including orthogonal frequency division multiplexing (OFDM) [1][2]. A difficulty revealed in OFDM and other approaches is that Fast Fourier Transform (FFT) or equivalent precise filtering circuits are required to achieve multiplexing and demultiplexing, which are hard to be implemented. Recently, we have demonstrated another optical multiplexing technique called orthogonal-time division multiplexing (OTFDM), which enables ultra-high-speed and ultra-high-spectral-efficiency transmission with less complexity [3]. In this approach, optical channels are orthogonally multiplexed into time-frequency domain by using time-domain signal processing techniques, without relying on FFT or optical filter circuits (Fig. 1(a)). This simple optical multiplexing technique offers the following merits: 1) the spectral efficiency is as high as OFDM because all channels can be optimally multiplexed without necessity of time-domain/frequency-domain guard band; 2) the data rate is as high as optical time division multiplexing (OTDM) because the multiplexing/demultiplexing is optically achieved without restricted by electrical processing speed.

To demultiplex and demodulate a target channel from such ultrafast OTFDM signals, coherent matched detection is an effective approach, which has less complexity in its structure comparing to other optical demultiplexer based on optical filter or FFT circuits. Fig. 1(b) shows the principle of optical coherent matched detection for demultiplexing and demodulating ultrafast and high-spectral-efficiency OTFDM signals. In the scheme, the received OTFDM signal is homodyne mixed with a locally generated multi-carrier local oscillator (i.e. a local comb), which has the same amplitude and phase characteristics as the carriers of the OTFDM signals. With this coherent matched detection, one target tributary channel is orthogonally demultiplexed and demodulated from the ultrafast OTFDM signal when the local comb exactly matched with the OTFDM carriers. Under the situation, no crosstalk between neighboring channels are appeared, so that tributaries are orthogonally separated and independently demultiplexed.

To achieve perfectly orthogonal demultiplexing, the pair of signal and local comb should be matched well; otherwise, the mismatch between them causes crosstalk to neighboring multiplexed channels. For example, a residual group velocity dispersion (GVD) in a transmission line causes the mismatch. To achieve a good phase mismatch even if the transmission line has any residual GVD, we propose a novel method called “paired fiber” configuration, as shown in Fig. 1(b). In this setup, another optical fiber is placed on the local port side, where a transfer function same as that of the transmission line is given in order to keep the phase matching between the received OTFDM signal and local comb. Contrast to conventional dispersion compensation schemes, we can simply install two fibers with the same length and same amount of GVD to cancel out the phase mismatching, without using dispersion compensation fibers that usually gives a negative GVD to the transmission line. Another advantage of this approach is that the paired fiber can compensate for higher-order GVD as well. In addition, we can concentrate on controlling the optical phase at the discrete frequencies of the comb lines, which is also a good point if we consider applying tunable compensators to cancel the phase mismatch. (Conventionally, dispersion compensators need to continuously cover wide wavelength range to prevent signal distortion. For example, phase ripples in FBG, and limited resolution of diffraction in grating gives compensation errors.)

Here, through cross-correlation analysis, we prove that the paired fiber configuration will keep phase matching between the OTFDM signals and local multicarriers in the coherent matched detection. In this analysis, we numerically investigate a 160-Gb/s OTFDM-QPSK transmission system, where 8-channels, 10-Gbaud QPSK are multiplexed in time-frequency domain; the setup is descript in Ref. [3].
Figs. 2(a)-(c) show cross-correlation traces between the tributary (the target channel for demultiplexing) and the local comb, where the received power is calculated as a function of timing delay ($\tau$) between them. In the analysis, the power at $\tau = 0$ was normalized to 1. In each cross-correlation trace, the extinction ratio at the null points stands for crosstalk to neighboring channels. For example, in the back-to-back case shown in Fig. 2(a), the crosstalk to the neighboring channels is kept < -25 dB, and the total crosstalk from other channels to the target channel is estimated to be -18.8 dB. If the phase mismatch between the received signal and local comb becomes larger, the extinction ratio of the cross correlation trace becomes degraded as shown in Fig. 2(b), where we assume residual GVD, $\Delta \beta_2 L = 40 \text{ [ps}^2\text{]}$ in this example. Under this condition, the total crosstalk is increased to be -8.8 dB; demodulated QPSK constellations, shown in the subset of the plot, are highly degraded due to the huge amount of the crosstalk. As shown in Fig. 2(c), the crosstalk is kept as low as -19.6 dB, where $\Delta \beta_2 L = 40 \text{ [ps}^2\text{]}$ is given to the local side, achieving paired fiber configuration.

Figs. 2(d)(e) show the BER characteristics of the received 160-Gb/s OTFDM-QPSK signals. (d) and (e) corresponds to the cases for w/ and w/o paired fiber configuration, respectively. Not a little penalty appears w/o paired fiber configuration, which is mainly due to the inter-channel crosstalk caused by the phase mismatch. With paired fibers, almost no OSNR penalty appears in the range of $\Delta \beta_2 L < 40 \text{ [ps}^2\text{]}$, which means that tributaries can be orthogonally demultiplexed; i.e., this is another proof of the perfect phase matching.

In conclusion, optical coherent matched detection with paired fiber configuration has been proposed. It has been shown that the paired fiber compensates for the phase mismatch in the coherent matched detector to keep orthogonality between the tributaries in OTFDM systems.

References