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Multiple access interference elimination with enhanced chromatic dispersion tolerance in SAC OCDMA

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Abstract: We demonstrate a direct decoding scheme to eliminate multiple access interference in optical spectral-amplitude-coded, multiple access networks. By detecting only the non-overlapping spectrums, our scheme shows a better BER of eight orders of magnitude over the conventional complementary subtraction scheme, when 16 simultaneous channels with 10 Gbps bit rate per channel are transmitted over a simulated 70 km dispersion-compensated fiber span. Our direct decoding technique is also tolerant to chromatic dispersion, where the maximum achievable distance of 67 km was obtained in a dispersion limited system with standard 16 ps/nm.km dispersion of single mode fiber.

Keywords: optical CDMA, multiple access interference, chromatic dispersion

Classification: Photonics devices, circuits, and systems

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1 Introduction

Multiple access interference (MAI) is the main source of performance degradation in optical code division multiple access (OCDMA) systems [1]. Hence, several techniques have been developed to cancel such an effect especially at the receiver side of the system. In spectral-amplitude-coded (SAC) OCDMA, balanced detection using the complementary subtraction (CS) technique has been widely used to cancel MAI [2, 3, 4]. This technique requires two decoders at a single receiver. The upper decoder has the same structure as the encoder at the transmitter side, while the lower decoder is the complement of the upper decoder. The decoded signals are detected by a balanced receiver for cancellation of MAI. Let the incoming signal be $S(\lambda) = x(\lambda)+y(\lambda)$, where $x(\lambda)$ being the desired signal and $y(\lambda)$ being the interferer. The upper and lower decoders detect the desired code, $x(\lambda)$ and its complement, $\bar{x}(\lambda)$, respectively. The mutual in-phase cross-correlation between two code sequences $x = (x_1, x_2, \ldots, x_v)$ and $y = (y_1, y_2, \ldots, y_v)$ is defined as $R_{x,y} = \sum_{n=1}^{v} x_n y_n$. Intended signal should be obtained as the cancellation between signals with the correlation properties of $R_{x,x} + R_{x,y}$ and $R_{\bar{x},y}$ will result in a signal with correlation of $R_{x,x}$ provided that $R_{x,y} = R_{\bar{x},y}$.

The received signals utilizing this technique can be improved further using our proposed direct decoding (DD) scheme, as shown in our results. Our scheme also reduces the number of filters and photodetectors at the receiver [5, 7]. In addition to the detrimental effects of MAI, dispersion is another major contributing factor to performance degradation of OCDMA system. In high bit rate system, signals travelling through an optical fiber will be severely degraded by chromatic dispersion (CD) effects. Hence, it is very important to observe the inevitable effect of CD in addition to MAI.

2 Direct Decoding Scheme

In this letter, we propose a new decoding scheme that circumvents MAI, thus improving signal quality. In our proposed scheme, only the non-overlapped chips are detected, thus avoiding the MAI. This differs from CS where all chips are detected including the overlapping chip(s) for further cancellation. This technique is different from the direct detection technique used in wave-

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length division multiplexing (WDM) whereby the number of chips detected in DD depends on the number of the non-overlapped weights where it is always code weight divided by two ($W/2$) for the case of our code [5, 6, 7]. On the other hand, WDM only detects one wavelength. Thus, the transmission quality of DD can be improved as the number of non-overlapped weights increase, whereas in WDM it is fixed. In DD scheme, the decoder detects the desired signal $x(\lambda)$ without the overlapped spectra, $x(\lambda) \cap y(\lambda)$, thus the filtered signal is represented by $x(\lambda) - [x(\lambda) \cap y(\lambda)]$. Fig. 1 depicts the simulation setup for DD scheme.

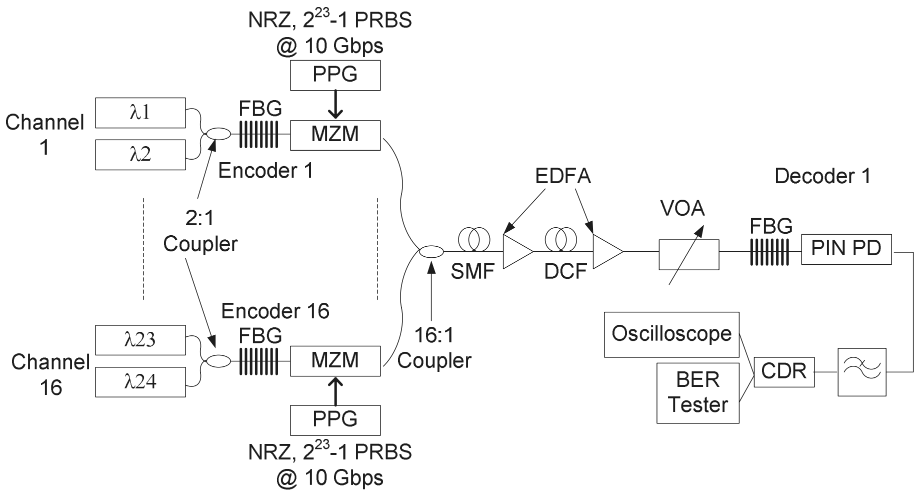

Fig. 1. Simulation setup of our proposed direct decoding scheme for 16 channels at 10 Gb/s rate per channel

This system accommodates 16 simultaneous channels which are represented by 16 SAC codes with code weight, $W = 2$ and code length, $N = 24$. The number of channels was chosen merely as an example to demonstrate the detection mechanism, as our proposed system is not limited to small numbers of channels [7]. The codes are chosen based on the construction algorithm in [5, 6, 7], which has the cross-correlation property of 1. The main significance of this code is that it can exist for any natural number; hence the cardinality is not limited [5]. As chip ones of our codes always occur in pairs, only one filter is needed at the encoder with twice the bandwidth of a single chip [7]. This reduces the total number of filters at the encoder by half.

A total of 24 wavelengths, with spacing of 100 GHz ranging from 193.1 THz to 195.4 THz are utilized to build the codes. Distributed feedback lasers (DFB) lasers are chosen due to their capability to support higher bit rate and longer transmission distance [8], as in core and metro networks. In the case of access networks, broadband source (BBS) might be preferable due to its cost effectiveness. Code 1 which is assigned to Channel 1 is the desired code, while the remaining 15 other codes are the interfering channels. The overlapping wavelength of Code 1 is λ2. The combined wavelengths are then encoded using a fiber Bragg grating (FBG) to form the desired code before being modulated with a $2^{23} - 1$ PRBS sequence at OC-192 transmission

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rate per channel using a Mach-Zehnder modulator (MZM). Single mode fiber (SMF) of 70 km is used together with 12.4 km dispersion compensating fiber (DCF) to mitigate the chromatic dispersion effect. The dispersion coefficient of the SMF is set to 16 ps/nm.km, while the DCF has a negative dispersion profile of -90 ps/nm.km at 194.25 THz optical frequency. Two EDFAs are placed after the SMF and DCF to compensate the losses due to fiber attenuation. In DD scheme, detection of the non-overlapped spectrum ($\lambda 1$) of the intended user, i.e. Channel 1 is performed using one FBG with 30 dB signal rejection. To simulate the CS scheme, two FBGs representing the actual and complementary decoders of Code 1 are used with further MAI cancellation using balanced receiver. The system is modeled with the presence of non-linear (NL) effects and polarization mode dispersion (PMD), where the PMD coefficient is 0.1 ps/$\sqrt{}$km.

3 Results and Discussion

The results are depicted in Fig. 2-3, simulated using VPItransmissionMaker® software. Fig. 2 (a) shows the bit error rate (BER) performance against received optical power (ROP) when 16 different channels are present in the system. In this simulation, the input power of all lasers is fixed at 0 dBm.

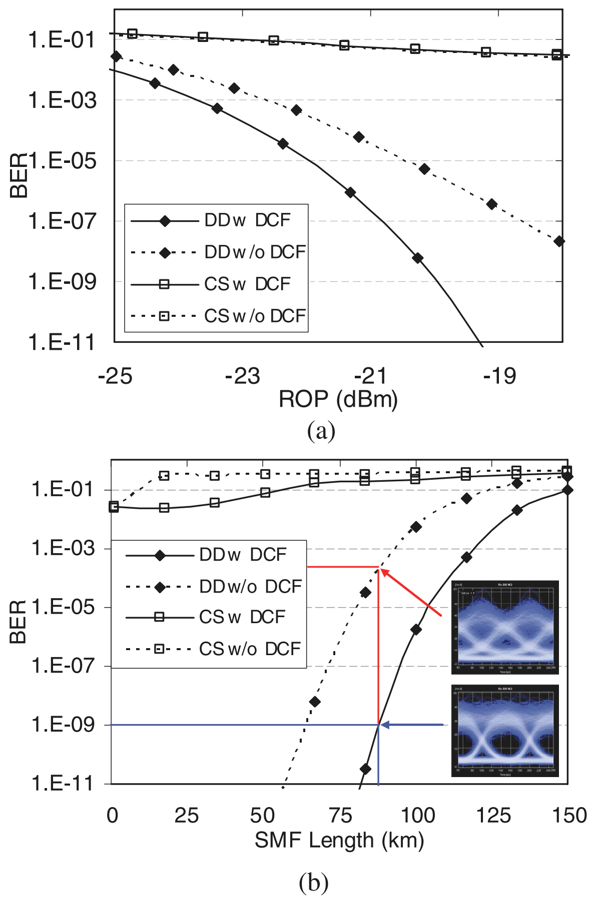

Fig. 2. BER plot for CS and DD schemes with and without dispersion compensation against (a) ROP and (b) SMF length

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A SMF length of 70 km is used for all cases; with an added 12.4 km DCF for CD compensated system. DD with CD compensation shows a power advantage of 3 dB at BER of 10^{-9} over the dispersion limited system. For both detection schemes, the BER for system with CD compensation are better than uncompensated system due to the mitigated CD effect and signal amplification by the two EDFAs per fiber link.

Fig. 2 (b) depicts the effects of varying the SMF length on BER for both decoding schemes. For each plotted SMF length, an associated DCF length is given by $L_{DCF} = D_{SMF} \times L_{SMF}/|D_{DCF}|$, where L and D denotes the fiber length and the dispersion coefficient, respectively. At BER of 10^{-9}, the required SMF length for DD scheme is 90 km and the corresponding DCF length is 16 km. At the same distance, BER obtained using the CS scheme is only 10^{-1}. The BER values for both schemes are almost the same over a SMF length of 150 km when lines of both schemes started to converge. For the uncompensated system, DD gives a BER of 10^{-9} over 67 km of SMF. This demonstrates the tolerance of our system to chromatic dispersion effect. The SMF length is also extendable by 23 km for one fiber span of DD scheme with added dispersion compensation mechanism. Distance extension is limited due to the residual dispersion (RD) that remains in the detected wavelength, which is 193.1 THz. The reference frequency for both SMF and DCF is 194.25 THz, where the dispersion is fully compensated, resulting in zero RD. At the detected wavelength, which is the farthest from the reference frequency, hence highest RD (±97.15 ps/nm) at 90 km SMF length, the performance is still considered good with 23 km advantage.

The insets of Fig. 2 (b) show the eye diagrams for DD scheme at 10^{-9} BER, for the dispersion-limited and –compensated system. For a dispersion compensated system, a better BER of 4.28×10^{-9} is obtained at 90 km of SMF while for the uncompensated system, the BER is 4.2×10^{-4}. For CS scheme, BER at the same distance are 1.86×10^{-1} and 3.37×10^{-1}. Imperfect reflection responses of the FBGs have detrimental influences in CS. The unequal power levels contained in the chips lead to imperfect MAI cancellation as perfect cancellation can only be obtained if the power contained in each of the spectral bands of the different codes is the same [1]. Dispersion also results in pulse broadening which lead to imperfect cancellation in CS scheme. In the case of DD, this is not a problem since the overlapping wavelengths are not detected and no further cancellation is required.

The analysis of the accumulated group velocity dispersion (GVD) of the transmission link of our system is depicted in Fig. 3. Fig. 3 (a) shows the GVD value in ps/nm for a total distance of 106 km, where the first 90 km is SMF followed by 16 km DCF. The differences in GVD of the 16 channels are illustrated by the different colored lines. The accumulated GVD is at its maximum, i.e. 1550 ps/nm at 90 km distance and down to near 0 ps/nm after 16 km DCF. Fig 3 (b) is the enlarged version of red box A in Fig. 3 (a), where it can be seen that the CD is not fully compensated at all wavelengths. The RD values depend on the spacing between the desired wavelength and the zero dispersion wavelength, which is 194.25 THz in this case. The farthest

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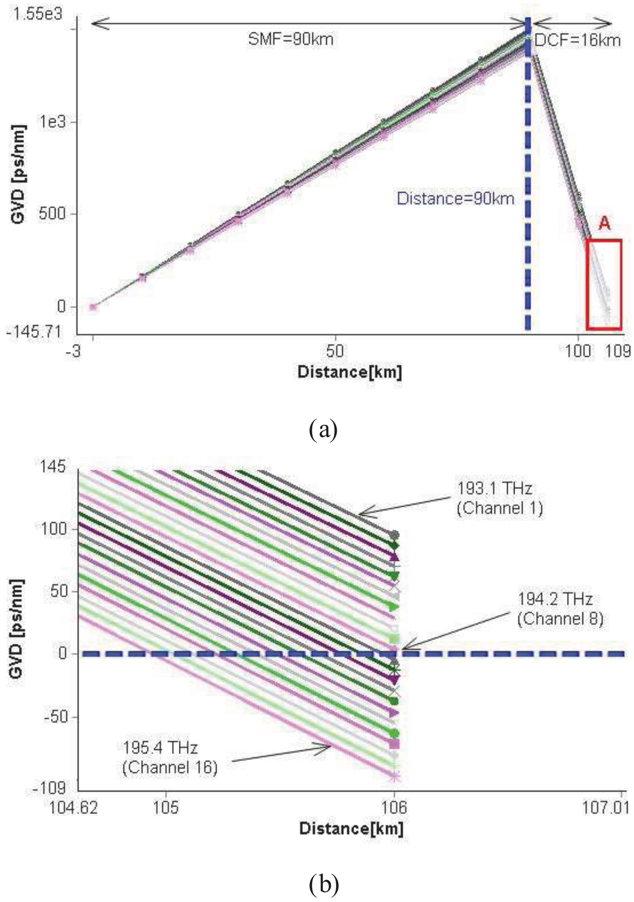

Fig. 3. Group velocity dispersion (a) for entire fiber link and (b) after dispersion compensation using DCF at 106 km distance

wavelengths which are 193.1 THz and 195.4 THz have the highest RD which is ±97.15 ps/nm. However, the problem of large RD can be reduced by narrowing the chip spacing among the codes to smaller gaps, for example 50 GHz or 25 GHz.

4 Conclusion

It is shown that, with the presence of 16 simultaneous users, our direct decoding scheme was able to avoid the MAI effect and still maintain a good BER of 10^{-9} at 90 km SMF length with dispersion compensation. DD shows better performance than CS scheme in all cases where wider eye opening were obtained. DD scheme also demonstrates a better tolerance to fiber imperfection due to chromatic dispersion as the power penalty of uncompensated system is 3 dB less than the system with CD compensation, while the attainable distance is 67 km for 10 Gbps bit rate per user. It is also illustrated that with dispersion compensation, the SMF length for system employing DD scheme is extendable up to 23 km for a single fiber span. Our GVD analysis had reported the effect of CD in OCDMA system, hence offering a new research direction in the field. In conclusion, our proposed direct decoding technique provides a new detection scheme for OCDMA technology, which is capable

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of eliminating MAI with improved tolerance to chromatic dispersion effect, hence offering significantly better signal quality.

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