Non-uniform spectral encoding for enhanced multi-user performance in optical CDMA networks

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Abstract: We propose a novel non-uniform spectral coding scheme in an Optical-CDMA system that utilizes Spectral Phase EnCoded Time-Spreading (SPECTS). The new method achieves lower multi-user-interference and twice network capacity for Gaussian spectral shape optical pulses.

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1. Introduction

Optical-CDMA based on spectral phase encoded time spreading (SPECTS) of ultra-short optical pulses was first proposed by Salehi, Weiner and Heritage [1] in 1988. This technique achieves all-optical encoding and decoding by optical pulse shaping. The original SPECTS optical CDMA was studied with the assumption of utilizing optical pulses with flat spectral shapes, which lead to near orthogonality between multiple access users and near perfect MUI suppression. To deal with a more realistic pulse spectrum, this paper proposes a new coding scheme that adjusts the width of each frequency “chip” according to the actual non-flat spectral shape of such optical pulse in the OCDMA system. Further, it demonstrates that this new coding method significantly improves the orthogonality in the optical phase coding and reduces the impairments due to the MUI, resulting in reduced bit-error-rates for a given number of simultaneous users or in increased number of users for a given acceptable bit-error-rate.

2. Uniform vs. Non-Uniform Phase Coding in SPECTS Optical CDMA

In SPECTS OCDMA, the optical pulse spectrum is divided into different spectral components, known here as “chips”. The number of the “chips” is chosen to be the length of the selected phase code. This paper considers an example employing a 31-bit m-sequence as the basic spreading code. Each user then employs a cyclically-shifted version of such a binary code as its phase code, where “1” and “0” represent phase shifts of 0 and π accordingly. Fig. 1 (a) illustrates the induced phase shift across the spectrum according to the selected m-sequence.

Fig. 1 (b) illustrates that the encoded pulse is transformed into a time-spread pulse with lower peak power after the encoding compared to the original pulse, while maintaining the same optical pulse energy.

![Fig. 1. (a) Phase encoding with the 31-bit m-sequence across the pulse spectrum and (b) the time domain optical pulse of the original and the encoded pulses.](image)

When applying decoding phase shifts that are conjugate to the encoded phase shifts for all frequency chips, all phase shifts introduced by the encoder will be completely compensated, resulting in the reconstruction or correct decoding of the original ultra-short pulse. If wrong phase codes are applied at the decoder, then the correct decoding will not occur. Limiting the set of codes to within the family of nearly orthogonal codes, the incorrectly decoded output will remain low peak power and widely spread in time. Even though multiple users share the optical channel over a common fiber link, only the desired receiver can receive the correctly decoded signal while, to all other users, incorrectly decoded signals will behave like noise.

A very important consideration in OCDMA networks is MUI. Previous investigation in this area has concentrate at an ideal situation where the optical pulse poses a flat spectrum[2,3]. In such case, orthogonal coding can minimize the interference yielding 100% spectrum efficiency (means when 31-bit code length is selected, 31 users can be accommodated in the same OCDMA network) with error-free performance. In a more realistic case where the
optical pulse spectrum is non-flat, a similar coding method yields poor orthogonality and MUI becomes much more severe. Our proposed new coding method will adjust frequency chip intervals so that the total energy of each frequency "chip" under the spectral shape is approximately the same. Fig 2 (c) illustrates this coding scheme in contrast to the traditional uniform spectral coding scheme shown in Fig 2 (a).

3. Performance Comparison of Uniform coding vs. Non-uniform coding SPECTS Optical CDMA

Simulations on the two coding methods adopted a Gaussian-shaped pulse with a pulse width (defined as full-width at the 1/e of the peak field amplitude) of 300 fs as our signal pulse. The phase codes are cyclically-shifted 31-bit m-sequence. In our simulation, first uniform phase coding scheme is adopted. By incorporating a non-linear threshold detector (responding more sensitively to high peak power pulses than low-peak power pulses), we were able to randomly test the bit error rate of such a system and our resulting BER shows such a system can achieve bit-error-rates of less then 1E-9 for 8 simultaneous users.

We also simulate the non-uniform coding scheme. A complete spectral equalization within each “chip” will require each chip to have different spectral width adjusting to the power level of each chip. This paper implement a much simpler case which only contains three different "chip" sizes. The center 2/3 of the spectrum has the smallest "chip" size, the next perimeter 1/6 of the spectrum has twice the chip size, then the edge 1/6 has three times the chip size. The number of chips remains at 31. Fig 2 (b) and (d) show the properly decoded pulse (solid line) vs. worst-case MUI from 15 other users (dotted line) for uniform coding and non-uniform coding schemes respectively. The comparison of the two figures indicate that the MUI is suppressed much more effectively when non-uniform “chip” size is utilized in the coding scheme. Fig 2(e) compares the BER for uniform and non-uniform coding schemes, and shows that the OCDMA system can accommodate 16 simultaneous users in the non-uniform coding case as compared to only 8 for the uniform case.

Fig. 2. (a)(b)(c) Illustration of the uniform coding and corresponding interference power from 15 simultaneous users vs. original pulse power (c)(d) Illustration of the non-uniform coding and corresponding interference power from 15 simultaneous users vs. original pulse power (e) BER comparison for uniform and non-uniform coding scheme.

4. Conclusion

This paper proposed and demonstrated a new coding scheme employing non-uniform frequency chips for optical CDMA using SPECTS. Simulations of the non-uniform phase coding indicate a significant improvement in the spectral efficiency by accommodating twice as many users in the OCDMA network compared to the case of uniform phase coding.

5. References


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