Demonstration of All-Optical CDMA with Bipolar Codes

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Abstract — Using a fiber-based testbed, we experimentally verify that the advantageous correlation properties of bipolar spread-spectrum codes can be preserved in an optical channel using direct detection and all-optical encoder/decoders. The power spectrum of an erbium-doped super-fluorescent fiber source is encoded, the codeword correlations are verified and rejection of multiple-access interference is demonstrated.

I. INTRODUCTION

One of the challenges of fiber optic networks is to design methods of supporting a large pool of subscribers, not all of whom require access to the network at the same time, while providing access to many simultaneously active users. All-optical code division multiple access (CDMA) using bipolar codes developed for the radio-frequency domain is an attractive approach to meeting this challenge [1, 2, 3]. The primary problem is to design a coding technique that can preserve the advantageous correlation properties of bipolar codes using a direct detection, unipolar optical channel.

Our basic scheme has been reported previously [1]. In summary, for each length- N bipolar code X , we form a unipolar sequence U by replacing each -1 with 0. The unipolar super-code J of length $2N$ is then formed as the concatenation of U and its complement, $U \oplus \bar{U}$. In the same way, the bipolar code $-X$ can be transformed into the unipolar super-code $\bar{J} = \bar{U} \oplus U$, the binary complement of J . ON/OFF modulation of J and $\bar{J}$ forms the information symbols "1" and "0". The key to system performance depends on constructing a decoder that implements a true bipolar correlation using only unipolar signals and intensity detection. This can be accomplished using two unipolar correlations, followed by a subtraction [1]. Consider two bipolar codes X and Y and their super-codes $J = U \oplus \bar{U}$ (the pattern of light incident at the decoder) and $K = V \oplus \bar{V}$ (the pattern for receiving at the decoder). The zero-shift crosscorrelation of X and Y can be expressed as

$$\theta_{XY} = X \cdot Y = J \cdot K - J \cdot \bar{K}. \quad (1)$$

The operations $J \cdot K$ and $J \cdot \bar{K}$ are unipolar correlations and therefore can be performed optically. In this paper, we present experimental results that demonstrate the effectiveness of this coding technique using a fiber-based system with modulated signals.

Our experimental apparatus performs spectral encoding and decoding of a superfluorescent fiber source (SFS) using a bulk grating and amplitude mask as shown in Fig. 1. At the encoder, portions of the spectrum transmitted by the amplitude mask represent the super-code

J , while portions reflected represent $\bar{J}$. At the decoder, the SFS input is replaced by the signal from the network channel, and the amplitude mask represents the super-code K . The two beams produced are therefore proportional to $J \cdot K$ and $J \cdot \bar{K}$. The decoder outputs are de-

Fig. 1: The geometry for the grating based encoders. The spectral patterns of the two outputs, J and $\bar{J}$ are complements of one another, and are used to transmit a One and Zero respectively. The decoder has exactly the same geometry, but the SFS input is replaced by the signal from the network channel, and the outputs are focused onto a balanced receiver.

tected with a balanced receiver, so the resulting signal is proportional to the bipolar correlation θ_{XY} .

II. EXPERIMENT

Figure 2 shows a diagram of the experimental setup for these measurements. We used a SFS consisting of 40 m of highly doped erbium fiber pumped by a 150 mW, 980 nm pigtailed diode. About 22 mW of randomly polarized SFS power was divided with a fiber polarization splitter, forming broadband light sources for two encoders. We encoded about 9 nm of the bandwidth centered around the 1530 nm peak using Walsh codes. These codes, which have zero crosscorrelations in theory, were used to simplify comparison between theory and experimental results. Three codes of length $N = 16$, which we shall denote as super-codes J_A , J_B , J_C , and their complements, were etched on aluminum-coated glass substrates for each mask of the encoders and decoder in the testbed. The two outputs of each encoder, formed according to the selected bipolar code, are ON/OFF modulated with 2×1 interferometric optical switches according to the information symbol b . The modulated outputs are combined to form the network channel sent to the decoder. The mask of the decoder performs the bipolar correlation according to the code selected for receiving, and the output is detected with a balanced receiver and monitored with a spectrum analyzer.

Fig. 2: Experimental setup of the spectral amplitude CDMA testbed; showing superfluorescent fiber source SFS, isolator/wavelength division multiplexer IWDM, fiber splitters and combiners BS and PBS, polarization controllers PC, and reflection and transmission outputs R and T.

III. RESULTS

The correlations between the codes were measured with a single encoder and decoder. With the decoder adjusted to receive a particular code, the encoder mask was positioned in successive measurements to transmit any one of the available code patterns. This procedure was repeated for each of the codes at the decoder, while the optical switch was driven by a 20 MHz sine-wave. As shown in Fig. 3, for the same code (a, b, or c) at encoder and decoder a large autocorrelation power is detected (one

Fig. 3: Correlations of the codes measured on the spectrum analyzer.

each for positive and negative receiver currents). For mismatched codes, the crosscorrelation signals are 15 dB or more below the autocorrelations, showing that a binary information symbol can be recovered by an appropriate threshold operation. The non-zero crosscorrelations and the variation of the autocorrelations are due to a combination of mask fabrication tolerances and the optical properties of the system.

Multiple-access interference rejection was evaluated using two encoders and one decoder. While one encoder and decoder were adjusted to matched codes, the second encoder sent the other codes in successive measurements. Figure 4 summarizes these measurements, showing the change in signals measured at the decoder when an inter-

Fig. 4: The change in signals measured at the decoder when an interference signal is present.

ference signal is present. The degradation of the desired signal is less than 1.7 dB in all cases, demonstrating the capability of the decoder to reject multiple-access interference.

In conclusion, our experimental results demonstrate the successful application of bipolar codes for spectral encoding and decoding in an optical CDMA communications testbed. The use of fiber-based components and optical switches allowed the correlation properties of the bipolar equivalent codes to be tested with modulated signals. Additional experiments are underway to measure the bit-error-rate performance of this coding scheme.

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