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Propagation of 2.5 Gb/s Asynchronous, Concurrent, Optical CDMA Signals Through a 214 Kilometer Fiber Optic Link

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ABSTRACT: The propagation of optical CDMA signals was studied by computer simulation. Group velocity dispersion produces the worst impairment. With dispersion management, the decoder successfully recovers the signals, even in the presence of severe multi-access interference.

OCIS codes: (060.2330) Fiber optics communications; (060.4230) Multiplexing; (060.5530) Pulse propagation and solitons; (999.9999) Optical CDMA.

1. Introduction

Optical Code Division Multiple Access (O-CDMA) is a true "tell and go" protocol [1], suitable for "just-in-time" transmission strategies [2]. O-CDMA supports multiple asynchronous, concurrent users which occupy the same time slots and frequency domain. Historically, it has been considered as suitable mainly for local area networks [3,4,5], using a star network topology. Since the mid-1990s, O-CDMA has been explored for future telecommunication applications [6]. In 1999, successful field trials of O-CDMA (eight codes or users, each at a data rate of 155 Mb/s), over an installed 40 Km fiber base with a tree topology, were reported [7].

In this paper we describe a set of eight O-CDMA pseudo-orthogonal "Flattened Matrix" codes designed to be used with Lucent Technologies Multifrequency Lasers (MFLs), for operation at 2.5 Gb/s data rates. Measurements were made on the MFLs to characterize their output, which was then used to define the O-CDMA encoding and computer simulation. The computer simulation was used to predict the propagation, correlation, and detectability of these eight asynchronous, concurrent, encoded data streams through a 214 Km link (LLNL to Burlingame, CA) of the National Transparent Optical Network, NTON [8]. A split-step Fourier method was used in conjunction with the non-linear Schroedinger's equations. Dispersion and nonlinear effects were considered. The computer simulations show that the propagation of these matrix codes is severely impaired (primarily) by the group velocity dispersion, but that the codes can be recovered with high fidelity, and the decoder can discriminate against multi-access interference, if fiber optic dispersion compensation is used to preserve the pseudo-orthogonal (PSO) features of these codes.

2. Technical Discussion

O-CDMA is a collision-tolerant protocol by virtue of the codes assigned to each user and the correlation and thresholding means assigned to the receivers (which detect a particular code in the presence of the other users or interfering codes). The codes are impressed on each bit in a message launched by a user into the common transmission medium (e.g., a single mode or multi-mode fiber-optic link, free-space, or wireless link). The various approaches to O-CDMA are subdivided into bipolar and unipolar codes. We use unipolar codes which can be physically represented by narrow signal pulses (return-to-zero, "RZ", modulation) and fiber-optic delay line arrays [3,9]. A major architectural advantage of the unipolar coding approach is the mature computational techniques for generating PSO sets of arbitrary size and arbitrary code weight, while guaranteeing that the autocorrelation side-lobes and the crosscorrelation peaks never exceed unity. But unipolar codes are too bandwidth-inefficient because they derive their PSO characteristics from a very long code length (the code signature consists of a few "1" chip symbols and a much larger number of "0" chip symbols). MRDA has solved the bandwidth efficiency problem

[10,11,12] by distributing the code over two or more orthogonal dimensions (i.e., space/time; wavelength/time; space/time/wavelength; etc.).

The Lucent Technologies MFLs consist of eigth (or more) individual gain sections coupled through a wavelength grating router (WGR) to an output port. These eight (or more) independent cavities may be coupled to the output fiber by means of a semiconductor optical amplifier (SOA). The MFLs produce ITU wavelengths, each with an output power of 0 dBm [13]. MRDA has designed a set of eight O-CDMA flattened matrix codes (weight four, code length four) based on these wavelengths. The encoder selects four specific wavelengths ("quartets") from the MFLs to produce the encoded bit stream. The electrical-to-optical conversion is performed with the SOA (direct modulation) for data rates less than 1 Gb/s, and with external modulation for higher data rates. A block diagram of the O-CDMA electrical-to-optical conversion, encoders, and decoders is shown in Figure 1.

The propagation of these O-CDMA codes over the 214 Km (=161.5 Km SMF-28 + 52.5 Km Corning LEAF) was evaluated by means of the computer simulation. The test data was the nibble "1101", encoded as a flattened matrix code and "transmitted" over the link. The evaluation criterion was the recovery of the correlated signal by the decoder and, before correlation, the preservation of the "color" and alignment of the code time slots.

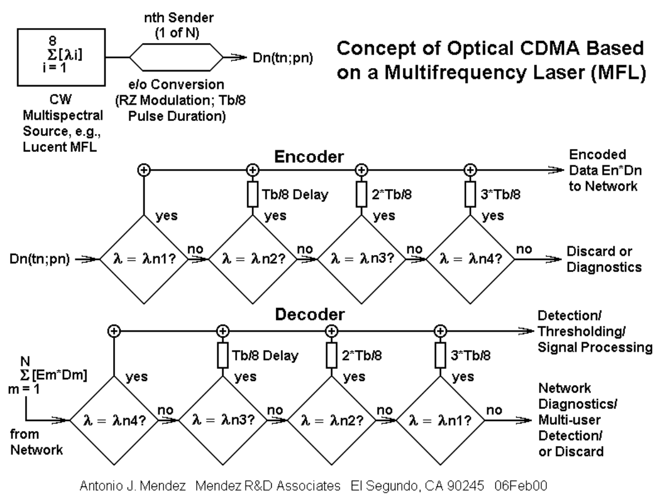

Fig. 1. Block Diagram of MFL/O-CDMA System Concept.

3. Simulation Description, Detailed Results, and Concluding Remarks

The O-CDMA code propagation evaluation was carried out on the fiber optic link simulator developed by LLNL and UCD [8]. The link has four EDFAs placed at strategic locations. The simulation included: power attenuation due to scattering and absorption; group velocity dispersion (GVD); 3rd order dispersion (dispersion slope); nonlinear refractive index; Raman effect; gain dispersion and gain saturation in the EDFA; and amplified spontaneous emission (ASE) produced at the EDFAs. GVD was found to be the dominant impairment for O-CDMA transmission. Therefore, dispersion compensation modules (44 Km of single mode fiber with opposite sign of GVD) were inserted in the link to null the effect of GVD at 1555 nm (the center wavelength of the MFLs). Then the O-CDMA codes propagated with sufficient fidelity, with some residual distortion and timing jitter due to the higher order effects.

Figure 2 shows that code propagation is severely impaired without dispersion compensation and that dispersion compensation preserves the encoded nibble: Fig. 2a depicts the encoded nibble at the input to the fiber; Fig. 2b shows the effect of impairments on the output; Fig. 2c shows that dispersion management reduces the impairments; Fig. 2d depicts a more severe test, the transmission of an encoded signal together with seven asynchronous interferers; Fig. 2e shows that the signal is recovered (with multi-access interference, MAI, quite evident), if dispersion management is used; finally, Fig. 2f shows that signal processing (an early-late gate filter) enhances the signal over the interference and reduces the thresholding dynamic range. In summary, Fig. 2 shows that asynchronous, concurrent, O-CDMA encoded signals can be propagated and recovered effectively and suggests that O-CDMA can support data rates much greater than 2.5 Gb/s and/or more than eight concurrent users.

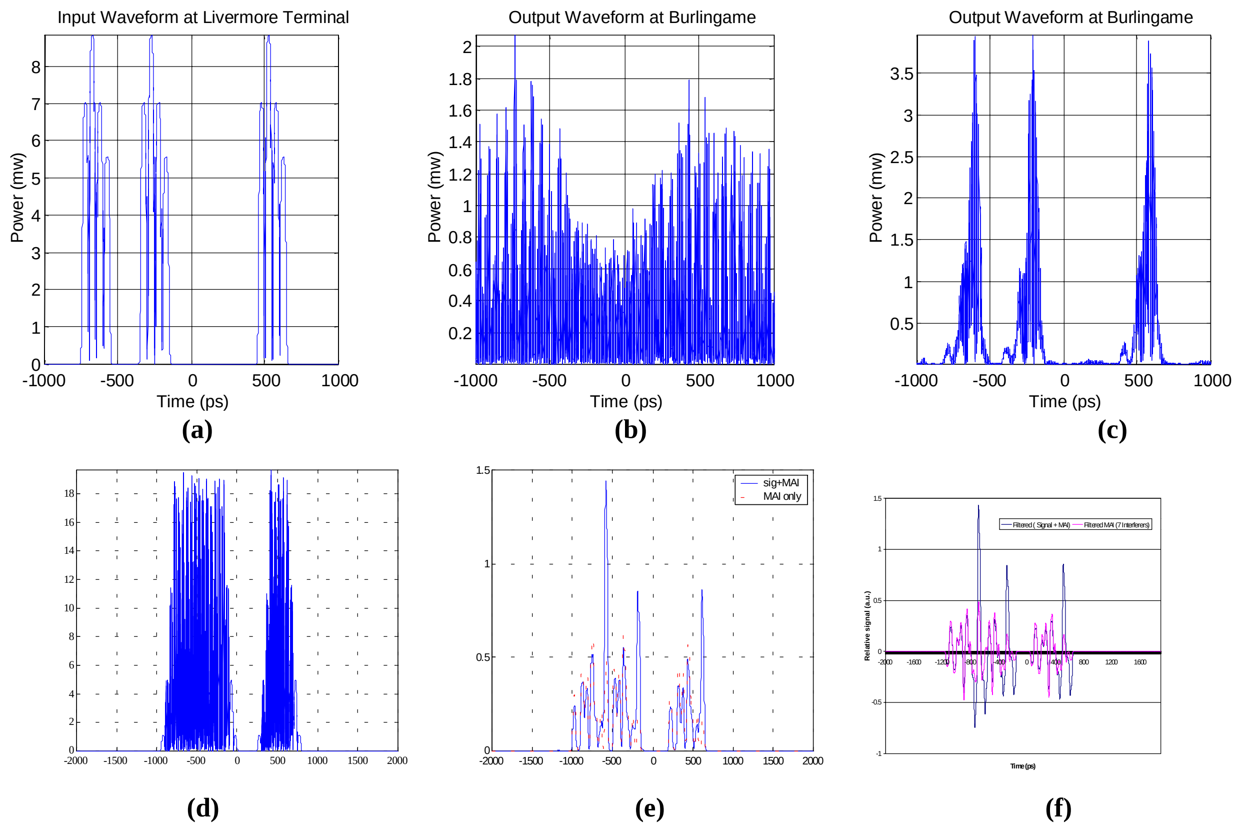

Fig. 2. Simulation test cases and results: (a) Encoded input bit pattern “1101”; (b) Effect of impairments; (c) Effect of GVD compensation; (d) Multi-access input; (e) Decoder output; (f) Early-late gate filtering.

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