An Optical CDMA Network Using Incoherent Optical Processing and Bipolar Spreading Sequences

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Code Division Multiple Access (or CDMA) is a multiple access technique based on spectral spreading that has been tremendously successful in the wireless domain. The effectiveness of CDMA in applications like cellular networks, satellite systems and Wireless Local Loop systems has strongly contributed to maintaining the application of CDMA to the optical domain, also known as Optical CDMA, an active area of research and has promised more efficient optical networks. More flexible and efficient spectral allocation, asynchronous and high-speed connectivity, no need of centralized control and simpler protocols are some issues that Optical CDMA networks claim as advantages over other multiple access techniques, specially for LANs [1].

In the wireless domain, the use of bipolar spreading codes is widespread but using such codes on the optical domain is not a straightforward task. Coherent optical systems are still expensive, complex and unstable if compared to non-coherent optical systems. Several possible ways of using spreading sequences in the optical domain have been proposed, including using families of spreading sequences which could naturally adapt to the incoherent optics environment (unipolar codes), as in [2]. The use of optical processing for encoding/decoding with unipolar codes in Optical CDMA was proposed in [3]. With optical processing, much higher processing gains can be reached, avoiding therefore the bottleneck imposed by electrical processing when spreading the baseband signal.

Unipolar codes, however, have a limiting factor: the number of possible codes is usually much smaller than the number of bipolar codes of the same size. Since the number of active users is a fundamental issue in any network, several attempts to adapt bipolar codes to the incoherent optical systems domain have been made. Examples can be seen in [4] and [5], where different schemes of Optical CDMA using bipolar sequences and optical processing were proposed, each using different features for coding or/and decoding the baseband signal. Also, in [6], an all-optical CDMA scheme with bipolar sequences is presented.

Using a passive star network architecture, we propose a new Optical CDMA scheme that uses optical processing on the encoding and on the decoding of the baseband signal. It was based on the ideas introduced in [7] and designed to work with any bipolar spreading sequence. Another advantage of the propose scheme is that both the transmitter and receiver can be easily tuned in a different spreading sequence, which make the network more flexible and efficient.

The proposed transmitter consists of an optical splitter that separates the optical input pulses in G different paths, according to the processing gain of the system. Each of the paths has an optical switch and an optical delay line. The optical switches are programed according to the information bit value and the specific spreading sequence of the user. The delay lines are fixed and chosen in order to allow increasing numbers of chip-time delays on the parallel paths. All paths are then combined to form the output of the transmitter. With the exception of the optical switches programming, all steps are performed in the optical domain. For this reason the transmitter can be easily re-programmed (or tuned) to any bipolar sequence while the transmitter, as a whole, still works with the benefits of optical processing.

The receiver initially uses an optical splitter to separate the incoming signal into 2 paths: the first one will decode the signal using a certain spreading sequence c(j,t); the second one will decode the same signal, but using the the sequence -c(j,t). In other words, the sequence -c(j,t) is the same as c(j,t), but with all bipolar chip values inverted. Each of these 2 decoders consists of an 1:G optical splitter, G optical switches (programed according to either c(j,t) or -c(j,t)) followed by delay lines and an 1:G optical combiner which will combine the resulting signals from the delay lines. It is noteworthy that on both decoders the delay lines used have decreasing values of chip-time delay, whereas the delay lines used in the transmitter have increasing values of chip-time delays. The outputs of each the two optical combiners will reach two different photodetectors, producing the electrical values T(j,+1) for the first decoder and T(j,-1) for the second one. The value T(j,+1) will be multiplied by N(-1,c(j)), resulting in T1 and the Value T(j,-1) will be multiplied by N(+1,c(j)), producing T2. N(-1,c(j)) is the number of -1 chips contained in the spreading sequence c(j) and N(+1,c(j)) is the number of +1 chips on the same sequence c(j). At eh end of the receiver, value T1 is compared with T2. If T1 > T2, then the decision +1 is made. Otherwise, -1 is the decision. Note that, interestingly, the multiplication of T(j,-1) and T(j,+1) values by the number of 1's and -1's in the sequence performs the same role as the DC level elimination step described in [7].

The performance of the proposed architecture is analyzed and approximate analytical expressions for the Signal-to-Noise Ratio (SNR) and Bit Error Rate (BER) are derived. For this analysis, pseudo-noise spreading sequences (known as PN sequences) were used. When the Multiple Access Interference (MAI) is much higher than the thermal noise, we observed a SNR proportional to the processing gain and to the inverse of the number of users on the network. Using realistic parameters like a user data rate of 10Mbit/s, 30 users on the network and a processing gain of 1000, we would reach approximately a 10^{-9} BER. Some performance limitations of the proposed architecture are discussed as well as potential possibilities to overcome such limitations.

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