Three-Fold Increase in Number of Active Users in an O-CDMA System Using Novel Code-Cycle Modulation

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Abstract: A novel, spectrally-efficient modulation scheme, code-cycle modulation (CCM), that permits a threefold increase in the number of active users is presented along with a supporting receiver architecture.

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1. Introduction

There has been renewed interest in optical code-division-multiple-access (O-CDMA) systems due to their potential for enhanced data privacy as well as "plug-and-play" operation [1]. However, a key drawback for O-CDMA has been that for the kinds of data rates demanded by current practical applications, and the number of users desired to be supported, conventional O-CDMA systems require an excessively high chip rate.

One approach towards partially alleviating the high chip rate requirement has been the introduction of two dimensional (2-D) O-CDMA architectures, in which the quasi-orthogonal spreading codes of the different users are spread over both time and wavelength. [2]. However, even under the time/wavelength approach using a reasonable number of wavelengths and practical chipping rates, O-CDMA systems are still unable to accommodate an abundance of active users [3].

We present here, a novel O-CDMA modulation scheme, termed CCM for Code-Cycle Modulation. CCM can be used in conjunction with either 1-D or 2-D O-CDMA systems. While O-CDMA permits the different users to operate asynchronously, in order for a particular transmitter and receiver to exchange information, a synchronous link needs to be created, usually accomplished through code acquisition at the receiver. CCM takes advantage of the synchronous link that has so been created to send $log_2(T)$ bits of information across the link in the time that it takes an OOK scheme to communicate a single bit, where T denotes the length of the spreading code along the time axis. More specifically, under CCM, the transmitter selects and transmits a particular cyclic (or wrap-around) shift of the spreading code assigned to that transmitter. The relative spectral efficiency of CCM permits a vastly increased number of users to be supported. For instance, with *16* wavelengths, $T=64$ chips per message symbol, CCM will permit the number of users supported to be increased more than threefold in comparison with traditional OOK

2. Code-Cycle Modulation

While CCM can be employed in conjunction with either a 1-D or 2-D O-CDMA systems, the discussion here will focus on the 2-D case. The spreading code of each user in a 2-D OCDMA system with Λ wavelengths and T time slots, can be visualized as a 2-D ($\Lambda\times T$) {0, 1} array [4]. Let T_c denote the chip time, corresponding to the duration of a time slot and a chip rate of $1/T_c$ chips per second. The duration T_b of a message symbol is then given by $T_b=TT_c$.

Each user in an O-CDAM system operates asynchronously. Under On-Off Keying (OOK) modulation, the presence or absence of the signal marks a 1 or a 0 respectively (Fig. 1).

Prior to demodulating data, each receiver in an O-CDMA systems uses the relative orthogonality between a spreading code and time-shifted versions of the code to align the phase of the locally generated replica of the *k*th-user spreading code to that of the incoming signal. Once the code has been acquired, the receiver then proceeds to demodulate data. Thus in the post-acquisition phase, a synchronous link exists between transmitter and receiver. The CCM transmitter takes advantage of this synchronous link and transmits one of T distinct cyclic or wrap around phase shifts of the user's spreading code. Thus the size of the message alphabet under CCM is T and to send the ith symbol in the modulation alphabet, the transmitter sends the ith cyclic shift along the time-axis of the 2-D spreading code allocated to it. The right portion of Fig. 1 shows the *8* cyclic shifts of an example 2-D code corresponding to Λ=*4* wavelengths and *T*=*8* time slots.

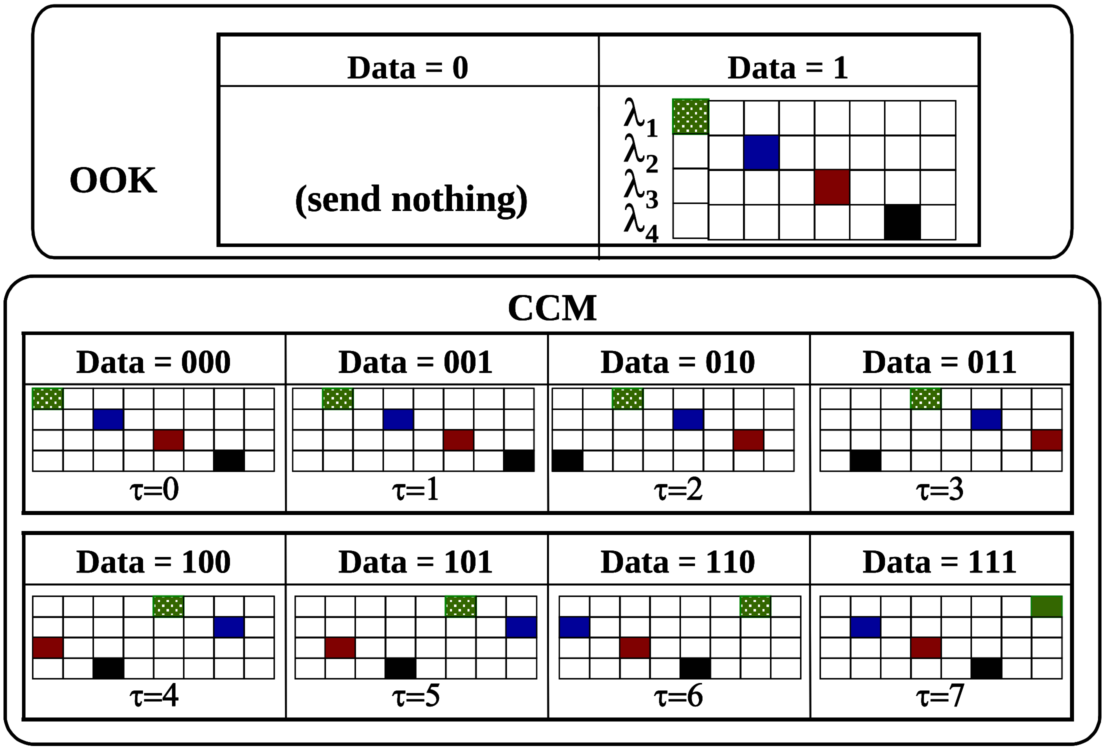

Fig. 1.Comparing OOK with the new modulation scheme, Code-Cycle Modulation (CCM) introduced here. The higher spectra efficiency of CCM arises from its larger modulation alphabet. The figure shows how CCM employs the 8 possible cyclic (wrap-around) shifts of a single 2-D spreading code with 4 wavelength and T=8 time slots to create an 8-ary modulation alphabet, thereby permitting 3 binary digits to be transmitted in place of a single bit under OOK.

3. CCM Receiver Architecture

In an OOK system, at the receiver end, the pulses along the different wavelengths are delayed by the appropriate integer multiples of chip delay T_c, needed to bring all the pulses into time alignment. If in place of the spreading code, the incoming spreading code were a cyclic shift of the spreading code, then the presence of the cyclic shift would cause some pulses to be misaligned relative to others by *T* time slots. As a result of this decoding one bit can take up to two bit-times ($2T_b$). So we need a circulating optical shift register to memorize the arriving bits within one bit time for duration of up to 2 bit times. One means of bringing the resultant two sets of pulses into alignment is to feed the pulses into a circulating optical shift register (COSR) (Fig. 2).

In practice, one would need two banks of COSR's so that while one bank of COSR's is processing the current bit, the other COSR completes decoding of the previous bit. It means that the receiver consists of two copies of COSR bank shown in fig.2. In each bit time while one of the COSR banks is connected to the input and saving the current data the other COSR is connected to the output to decode the previous bit.

3. Probabilistic Performance Analysis of CCM

We will define the spectral efficiency (SE) here by:

$$\text{Spectral Efficiency} = \frac{(\text{\# of active users}) \times (\text{Data rate of each user})}{(\text{\# of wavelengths}) \times (\text{\# of chips per message symbol})}$$

There are three aspects of CCM to be considered in determining its spectral efficiency: (a) under CCM, one is able to transmit $log_2(T)$ bits of information every T_b seconds as opposed to *1* bit every T_b seconds under OOK, (b) under OOK the transmitter of each user is silent roughly 50% of the time, whereas, under CCM however, the transmitter of each user is never silent and (c) under CCM, the receiver must test for the presence of all possible phases of the spreading code as opposed to just checking for the presence or absence of the code. A probabilistic model of signal and interference was developed taking into account these observations and used to analyze performance. Fig. 3(a) shows the distribution of interference under OOK and CCM respectively. As it can be seen

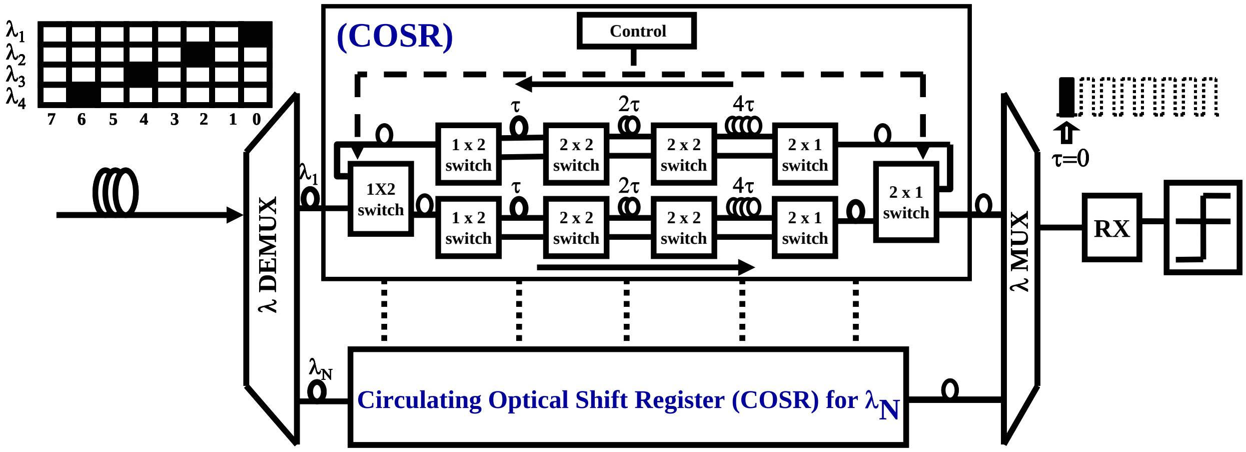

Fig. 2. Receiver architecture for CCM including the time-aligning circulating optical shift registers

by using CCM the probability of interference grows. Fig. 3(b) shows the increase in number of users that can be supported for two different wavelengths 16, and 64. It should be noted that in this graph the interference model of the CCM is incorporated. So it shows that although the interference of the CCM is higher than regular OOK, the number of active users in the CCM still increases up to 4 times while using CCM. Fig. 3(c) shows the increase in the spectral efficiency using CCM. As can be seen, the SE of CCM is between twice and three times that of comparable systems employing OOK. This allows CCM to support a threefold or greater number of active users. Note that the number of wavelengths does not affect much in Fig 3. b, and c.

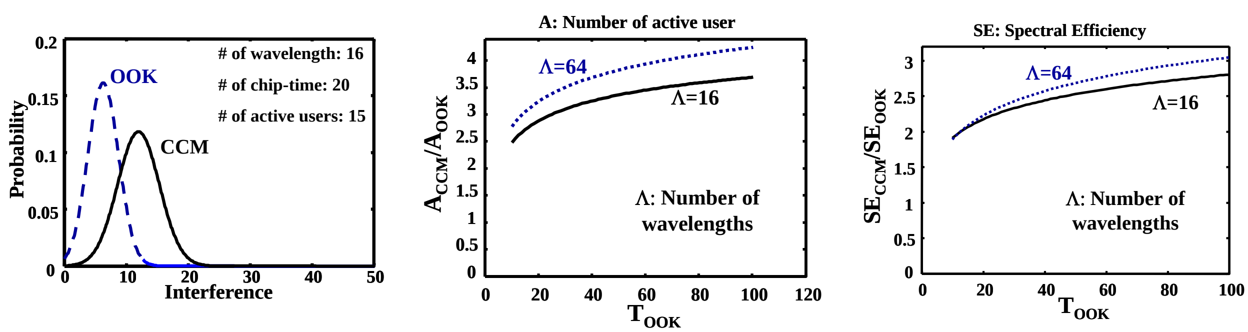

Fig. 3. Performance Gains Under CCM: (a) comparison of the pdf of a CCM and OOK(b) The first curves plot the ratio of number of users that can be supported under CCM to that supported under OOK as a function of the length along the time axis of the spreading code used in the OOK scheme. (b) the ratio of spectral efficiencies of CCM and OOK as a function once again of the time length of a spreading code

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