

Phase Carrier approach based on Optical CDMA Systems

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Abstract

Our work proposes and analyses a technique for optical CDMA (code-division multiple access) systems using a phase shift approach. Our proposed method utilizes spectral amplitude coding (SAC) to integrate both optical CDMA systems over the same phase carrier. This approach has several advantages compared to conventional wireless CDMA systems, such as systems that are simple to design, cost-effective, and simple to maintain. A phase shift is implemented in the proposed method using phase modulation, and it is equipped with the orthogonal function based on the random diagonal. Using only one laser source allows the new system design to be cost-effective. The new concept will reduce interference for access network passive optical network applications and improve the bit-error-rate performance of the system (BER 10^{-12}).

Keywords: OCDMA; MD code; Phase Shift; phase modulation; spectral amplitude coding



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1. Introduction

The optical code-division multiple-access (CDMA) technology is a well-known and recent technology that is capable of supporting multiple concurrent several users simultaneously using shared media resource users and enhancing the received data rate capacity of optical fiber (Brandt-Pearce, & Aazhang, 1994). Due to its asynchronous full-duplex transmission capability and low latency, optical CDMA provides unique properties such as capacity-based triple-play services and cost-effective network access (Zhang et al., 1999; Maric et al., 1993; Salehi, 1989). Several challenges associated with code design parameters, especially due to optical hardware restrictions and the orthogonality requirement for low interference on multiple-access channels, must be addressed by SAC solutions. With the help of SAC-optical CDMA, incoherent optical coding and decoding can be accomplished at a relatively low cost. However, this network has many limitations, such as low bandwidth efficiency and a non-coherent LED source.

A solution is developed in such a way that the entire frequency domain of the received bits is splatted into different spectral sub-widths, which is named a "chip." Moreover, determining the total duration of the received code is filtered to reduce the number of overlapped chips. The phase shift occurs in each chip by referring to frequency domain spectrum-based phase code. The code length determines the code set size, and the phase shift occurs in each chip. Also, the code set size is determined by the code length. Besides, the phase is altered in each chip according to the phase code. The code set size depends on the code length (Jau & Lee, 2004; Wei & Ghafouri-Shiraz, 2002). It is important to design an optical code for Optical CDMA to transmit a large number of active users with very low error bit rates for a given code length. A superb set of limitations should obtain the maximum number of codes with the best possible orthogonality properties; cross-correlation and autocorrelation. Based on the previously published articles, the RD code has been implemented among all SAC codes because it exhibits the properties of cross-correlation and orthogonality (Fadhil et al., 2010; Fadhil et al., 2008; Wei et al., 2001). This manuscript is divided into four sub-sections. Section II presents the orthogonal function based on the RD code and the developed code about the phase angle. The proposed system diagram is described in Section III, while in Section IV, the conclusion is presented.

2. Design and Construction

In The orthogonality function with zero cross-correlation is derived from the diagonal matrix of the RD code (Djordjevic & Vasic, 2004; Fadhil et al., 2008; Goodman J., 2015). To change a unipolar set of (1,0) signals into a

bipolar signal (-1, +1), a diagonal matrix can be used in the proposed system as an orthogonal basis for preprocessing by changing 0 by -1. The RD diagonal matrix is presented in (Fadhil et al., 2010). For example, the [Y] matrix is a bipolar random diagonal combination of $[4 \times 4]$ elements, shown in Table 1, the sum for each symbol position is -2. When four users send signals (+1, -1, -1, -1), the sum becomes -2 for time slot 1. The code sequence (+1, -1) summation of the RD code can be changed into a code set with bits of (0, 1) summation by adding the sum of each slot, as shown in Table 1. The code construction of the unipolar is mainly based on the diagonal matrix shown in (1). The phase shift of the RD code is designed by replacing the zero's bit with -1, as presented in (2).

$$[Y] = \begin{bmatrix} +1 & 0 & 0 & 0 \\ 0 & +1 & 0 & 0 \\ 0 & 0 & +1 & 0 \\ 0 & 0 & 0 & +1 \end{bmatrix} \quad (1)$$

$$[Y] = \begin{bmatrix} +1 & -1 & -1 & -1 \\ -1 & +1 & -1 & -1 \\ -1 & -1 & +1 & -1 \\ -1 & -1 & -1 & +1 \end{bmatrix} \quad (2)$$

Table 1: Mapping unipolar to bipolar

Ch1 to Ch4	Sum of the MD function
0 0 0 0	0 0 0 0
0 0 0 1	1 -1 -1 -1
0 0 1 0	-1 1 -1 -1
1 0 0 0	-1 -1 1 -1
0 1 0 0	-1 -1 -1 1
:	0 -2 -2 0
:	-2 -2 0 0
:	:
:	:
:	:
1 1 1 1	-2 -2 -2 -2

Table 2: Bipolar to phase mapping table

Add sum of 2	Map to phase
2 2 2 2	$\Theta 2$ $\Theta 2$ $\Theta 2$ $\Theta 2$
3 1 1 1	$\Theta 3$ $\Theta 1$ $\Theta 1$ $\Theta 1$
1 3 1 1	$\Theta 1$ $\Theta 3$ $\Theta 1$ $\Theta 1$
1 1 3 1	$\Theta 1$ $\Theta 1$ $\Theta 3$ $\Theta 1$
1 1 1 3	$\Theta 1$ $\Theta 1$ $\Theta 1$ $\Theta 3$
2 0 0 2	$\Theta 2$ $\Theta 0$ $\Theta 0$ $\Theta 2$
0 2 0 2	$\Theta 0$ $\Theta 2$ $\Theta 0$ $\Theta 2$
0 0 2 2	$\Theta 0$ $\Theta 0$ $\Theta 2$ $\Theta 2$
2 2 0 0	$\Theta 2$ $\Theta 2$ $\Theta 0$ $\Theta 0$
:	:
:	:
0 0 0 0	$\Theta 0$ $\Theta 0$ $\Theta 0$ $\Theta 0$

For the bipolar signals to be converted into various (Θn) phase mapping, implementation is done by including the summation of +2 to each time slot to get the high-power amplitude at multiple levels. The procedure is depicted in Table 2.

3. Proposed Scheme

The proposed scheme provides more advantages than conventional SAC–Optical CDMA schemes. The proposed system is shown in Figure 1, which demonstrates that the downstream information is transmitted in phase without changing the amplitude of the carrier light. 1. In phase modulation (PM), a difference in phase shift means a difference in modulation amplitude at the same time. This laser light source has a wavelength of 1550 nm and a bandwidth of 5 MHz, and it has a 6-phase modulation. Each PM is connected to a binary signal generator. The receiver part is a conventional optical CDMA-based detection system (Wei et al., 2001a; Djordjevic & Vasic, 2004; Wei et al., 2001b). The suggested system's optical CDMA coding is shown in Figure 1. Table 3 shows the original bits sent from the transmitter to the receiver are 0110, 0011, etc. Table 4 depicts a mapping of a coded optical CDMA signal converted to a phase change signal, where a light phase difference transmits the symbols.

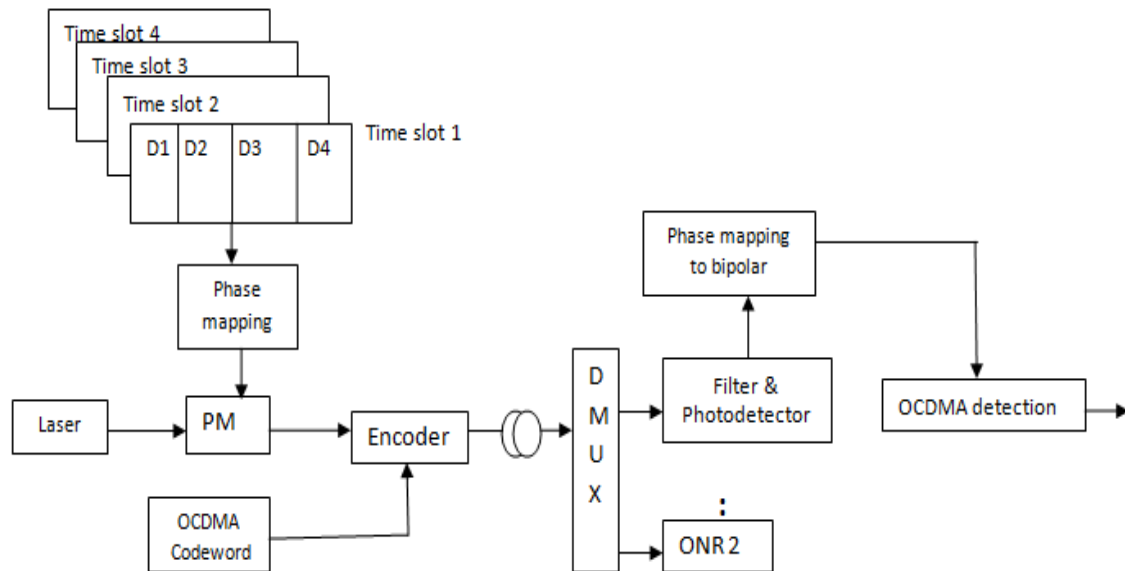


Figure 1: Proposed phase-carried OCDMA network.

Table 3: Construction of OCDMA coding

Original Signal	Orthogonal Basis	OCDMA code			
0 1 1 0	1 -1 -1 -1	0 1 1 0	0 -1 -1 0	0 -1 -1 0	0 0 0 0
0 0 1 1	-1 1 -1 -1	0 0 0 0	0 0 0 0	-1 1 -1 -1	-1 1 -1 -1
0 1 0 1	-1 -1 1 -1	0 0 0 0	0 -1 0 -1	0 0 0 0	0 -1 0 -1
1 1 1 0	-1 -1 -1 1	-1 -1 -1 1	-1 -1 -1 1	-1 -1 -1 1	0 0 0 0

The signals generated for the BSGs are given as follows:

BSG0(Θ_0) 0 0 0 0 0 1 0 0 0 0 1 0 0 1 0 0,

BSG1(Θ_1) 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1,

BSG2(Θ_2) : 1 0 0 0 1 0 0 0 0 1 0 0 1 0 1 0

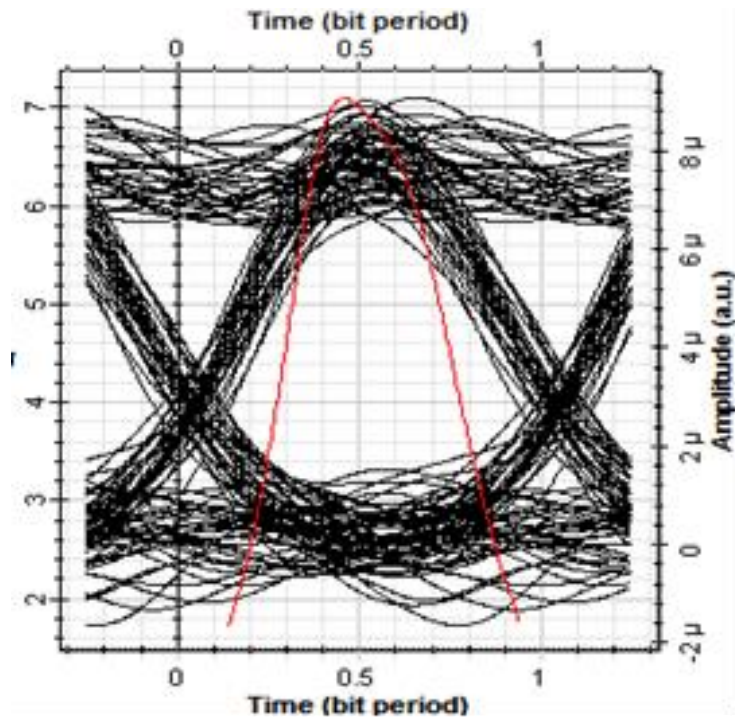
BSG3(Θ_3) : 0 1 1 0 0 0 0 1 0 0 0 1 0 1 0 0

Table 4: Optical CDMA OVER PHASE CARRIER

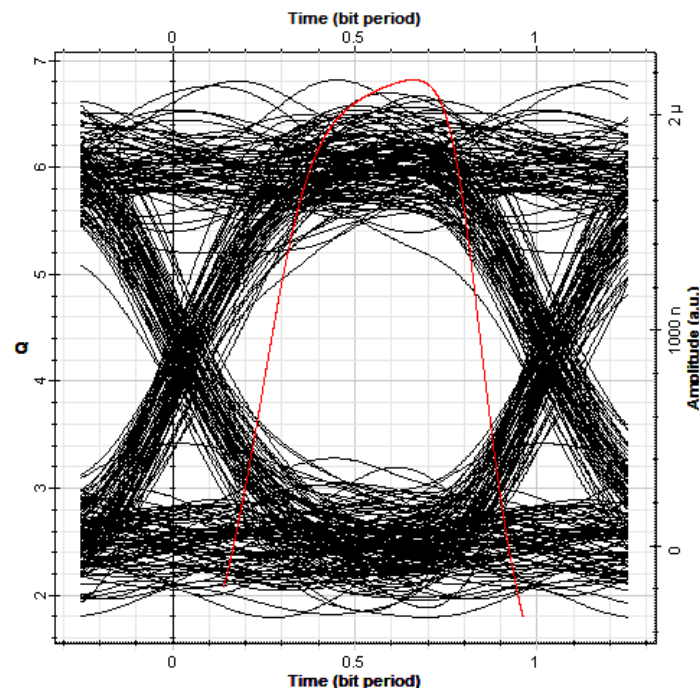
Original Signal	OCDMA code			
OCDMA code	0 1 1 0	0 -1 -1 0		
user#1	0 -1 -1 0	0 0 0 0		
OCDMA code	0 0 0 0	0 0 0 0		
user#1	-1 1 -1 -1	-1 1 -1 -1		
OCDMA code	0 0 0 0	0 -1 0 -1		
user#1	0 0 0 0	0 -1 0 -1		
OCDMA code	-1 -1 -1 1	-1 -1 -1 1		
user#1	-1 -1 -1 1	0 0 0 0		
Sum of weight code	-1 0 0 1	-1 -3 -2 0		
	-2 -1 -3 0	-1 0 -1 -2		
+3 to the sum	2 3 3 4	2 0 1 3		
	1 2 0 3	2 3 2 1		
Generated phase change	$\Theta_2 \Theta_3 \Theta_3 \Theta_4$	$\Theta_2 \Theta_0 \Theta_1 \Theta_3$		
	$\Theta_1 \Theta_2 \Theta_0 \Theta_3$	$\Theta_2 \Theta_3 \Theta_2 \Theta_1$		
Unipolar signal obtained	2 3 3 4	2 0 1 3		
	1 2 0 3	2 3 2 1		
-3	-1 0 0 1	-1 +3 -2 0		
	-2 -1 +3 0	-1 0 -1 +2		
Orthogonal basis	1 1 1 1			
Orthogonalization	0 0 0 0			

4. Results

Figure 2 shows eye pattern diagrams for phase shift RD codes that utilize spectral direct detection, which is considered cost-effective compared with conventional SAC codes. Only one filter is employed in complementary detection rather than two filter components. The eyes diagram using spectrum analyzer shows that the phase shift RD coding system performs a significant impact, with a more extensive eye-opening area. This means the information bit is received has distortion fewer effects, as shown in this diagram for RD codes systems. As the eye closes, it becomes increasingly difficult to discern between 1s and 0s. The noise margin or immunity to noise is represented by the height of the eye-opening at the selected sample period. (Zhang et al.,1999).



(a)



(b)

Figure 2: (a) BER of 10^{-12} for Phase shift MD code with transmission distance of 80 km; b) BER of 10^{-9} for conventional MD code with transmission distance of 65 km

Figure 3 shows the Performance of phase shift MD and the previous codes such as Modified Frequency Hopping (MFH), Modified quadrature code (MQC), and Hadamard codes (Abd et al., 2011; Kharazi et al., 2012). These codes are investigated as BER against the number of active users operating at a bit rate of 622 Mbps. It can be observed from the figure that the performance of the phase shift RD code is better than other codes. The maximum acceptable BER is 10^{-12} , which is obtained by the proposed code compared to the former SAC-optical CDMA codes, where it can simultaneously support up to 120 users. Table 4 shows the comparison between systems using other SAC-optical CDMA codes in terms of dynamic system parameters (BER, Distance, number of users, and Cost).

Table 4: Comparison between systems using other SAC-Optical CDMA codes, phase shift RD code design

Features	Other SAC- CDMA codes	Phase shift MD code
BER	High	Low
Distance	Short	Long
No. of users	Small	High
Cost	Expensive (CW laser)	Reasonable (LED+ CW)

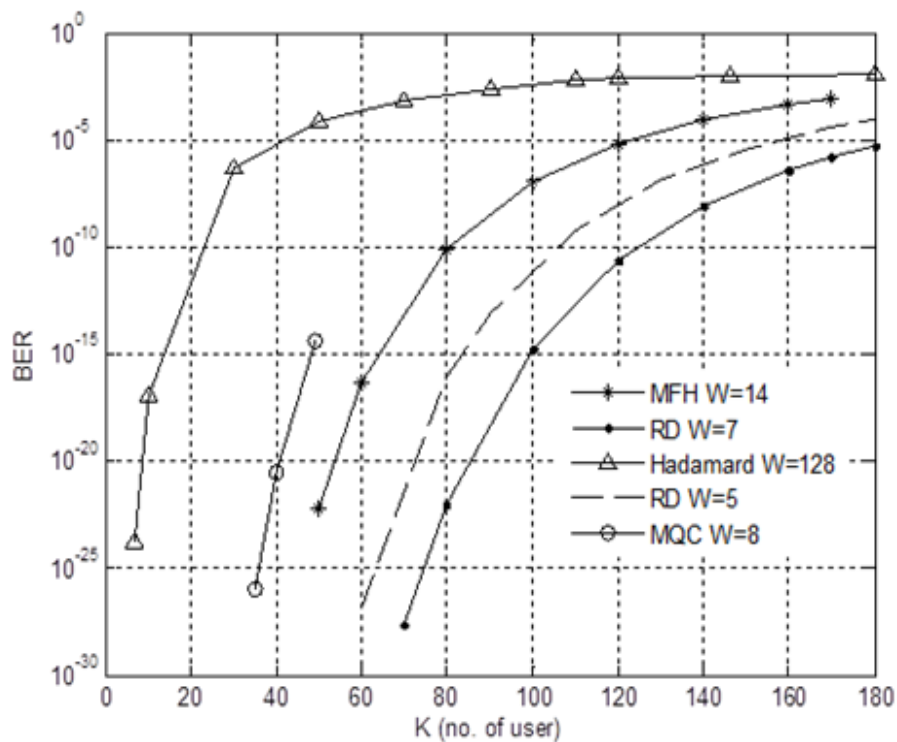


Figure 3: BER versus total number of active users for phase shift RD code included previous codes.

An optical phase modulator (PM) is used at the transmitter for encoding the optical pulses for two users according to the proposed phase shift code sequence to produce a unique codeword for each user. After modulating data with the codeword, each data from various users will be combined before being sent to the receiver via an optical channel.

At the receiver, the data is decoded using band-pass filters too, and the outputs of the filters are re-mapped to bipolar via phase mapping. The electrical signal of the photodetector is then subtracted from the signal generated to cancel the multi-Access interference (MAI). Table 4 concludes the LED sources, CW Laser sources, and MD design regarding system reliability (minimum BER, transmission Distance, and the number of supported users) and economic feasibility. It is concluded that the MD phase shift presents an affordable system from an economic point of view with significant performance.

The received optical power via the free-space link is considered the total power transmitted, including the diversity gain, loss factor, and noise factors. These parameters are related to the link margin parameters given in Eq. (3), which can be expressed as by (Goodman J.,2015).

$$P_{sr} = P_t G_t G_r \eta_t \eta_r L_s \quad (3)$$

The parameters presented in equation (3) can be expressed as follows: P_t , G_t , and η_t are the transmitted power, transmitted gain, and efficiency, respectively. The receiver gain (G_r), receiver efficiency η_r , and L is the fiber loss can be evaluated together to conclude the receiver antenna diameter given as defined in equation 4.

$$G_r = \pi(R_{AD}/\lambda)^2 \quad (4)$$

Where R_{AD} is the receiver aperture diameter, simulation results for various numbers of receivers are summarized in Table 5. It shows the function of signal-to-noise ratio (SNR) and effective received power (P_{sr}). As a result of the transmission of multi-aperture receiver signals, the SNR and P_{sr} clearly increase, which reduces the chances of severe signal fading.

Table 5: SNR requirements with different diversity branches.

No. of branches	BER=10 ⁻³		BER=10 ⁻⁶		BER=10 ⁻⁹	
	SNR (dB)	P_{sr} (dBm)	SNR(dB)	P_{sr} (dBm)	SNR(dB)	P_{sr} (dBm)
Rx=1	13.66	>-50dBm	16.41	>-50dBm	17.5	>-50 dBm
Rx=2	17.01	-45 dBm	20.42	-41.65	22.30	-39.17
Rx=3	16.30	-43.23	18.70	-40.31	21.45	-38.65
Rx=4	17.58	-40.70	28.87	-38.80	31.69	-36.75

5. Conclusion

This paper provides a method for developing an optical CDMA system based on a phase carrier. Among the benefits of the proposed technique, the proposed approach is cost-effective because only one light source is required. This methodology is considered an economical approach for multiplexing optical channels since carrier light can be reused by modulating an amplitude signal. Fiber-to-the-home installations reduce costs; as a result, this methodology is considered an economical approach to next-generation optical systems.

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