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Implementation and performance analysis of three dimensional (3D) space/wavelength/time single pulse per plane codes with direct detection

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ABSTRACT

In this paper, we present space/wavelength/time single pulse per plane (SPP) codes with direct detection (SPPDD) and implemented it as two dimensional codes by using W^2T scheme. We analyze these codes by varying the number of space channels (S) and keeping other two dimensions, wavelength (W) and time (T) constant and report that it gives better results when ($W > S$). It is found that the space channels $S = 2$ and $S = 3$ provide better BER rate than other space channels and also analyze these 3D codes by using different data modulation formats. It is found that OCDMA system with NRZ data modulation format performs better than RZ.

1. Introduction

Ever growing demand for higher data rates and data security has inspired remarkable interest in optical code division multiple access technology [1]. As the feasibility of multiple access networks increases, OCDMA network's attracts much attention. The main issue of the studies on the OCDMA network is to devise a code set of good performance [2]. In case of an OCDMA, various different types of codes have been proposed and found that one dimensional and two dimensional codes having some limitations, that is why three dimensional codes are generally preferable. In OCDMA system, the system performance is determined by the bandwidth efficiency of the optical codes which is closely related to the error probability behavior of optical codes in multiple user circumstances as well as code set size dependence on code length and also on the modulation format of the input data. Moreover, there are two possible modulation formats, nonreturn-to-zero (NRZ), in which a constant power is transmitted during the entire bit period, and return-to-zero (RZ), in which power is transmitted only for a fraction of the bit period [3], in intensity-modulated direct-detection (IM/DD) optical communication systems. The NRZ pulses have a narrow optical spectrum. The reduced spectrum width improves the dispersion tolerance but it has the effect of intersymbol interference between the pulses. The narrow spectrum of NRZ pulses yields a better realization of dense channel spacing in DWDM systems. The RZ pulse shape enables an increased strength to fiber non-linear effects and to the effects of polarization mode dispersion (PMD) [4].

Singh et al. [5] demonstrated a new family of three dimensional single-pulses per plane codes for differential detection for OCDMA systems, which achieve good code cardinality and a very high BER performance. The comparison of three dimensional SPDD with some of the best reported two dimensional/three dimensional codes.

Singh et al. [6] demonstrated a new family of three dimensional wavelength/time/space codes for asynchronous optical code-division multiple access (OCDMA) systems with off-peak auto-correlation $\lambda_a = 0$ and peak cross-correlation $\lambda_c = 1$. With wavelengths and time-slots, codes are generated. Antipodal signaling/differential detection is employed in the system. The performance is compared to the two dimensional/three dimensional codes. Arrayed waveguide grating-based reconfigurable two dimensional implementation for encoder/decoder was presented.

Kim et al. [7] demonstrated a new family of space/wavelength/time spread three-dimensional (3D) optical codes for optical code-division multiple-access (OCDMA). Two types of dimensional codes have been constructed: three dimensional codes with single pulse per plane and three dimensional codes with multiple pulses per plane. Both codes are based on the prime sequence algorithm. In order to eliminate the requirement of fiber ribbons and multiple star couplers in space/wavelength/time spread 3-D code based optical networks, a wavelength^2/time scheme has been suggested. It has been shown that the system performance can be maximized for given resources with a proper choice of the wavelength^2/time scheme.

Design of one dimensional code is proposed in Ref. [8]. The limitation of one dimensional (1D) optical codes is that the out of phase autocorrelation cannot be zero because there are multiple optical pulses within one period. The lower limit of out of phase

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auto correlation in the one dimensional code is 1, and to achieve as in OOC, code length increases rapidly as the number of user's increases. In order to overcome the limit of 1dimensional optical codes, two dimensional approaches are proposed [9]. These two dimensional codes suffer from the impact of timing skew as the time dimension of the code is large. The impact of fiber dispersion on the code performance of the two dimensional codes have been extensively investigated [10,11] and it has been shown that these are prone to the problem of timing skew arising in the fiber, if large time dimensions are used for better BER performance. In order to overcome the limit of two dimensional codes, three dimensional codes have been proposed.

Up till now, the three dimensional SPP codes were implemented using differential detection, In this differential detection [5] each user is assigned two codes: one for the transmission of bit '1' and other for the transmission of bit '0' for antipodal signaling but now in this paper we are implementing SPP 3D codes by using direct detection instead of differential detection. The direct detection, which we use in this paper is ON-OFF keying which means that each user assigned a single code and that code is used for the transmission of bit '1' and this system said to be in 'ON' state, and for the transmission of the bit '0' there is no such code is assigned and this system is said to be in 'OFF' state. In this detection technique only wanted chip in the optical domain is filtered. This detection scheme does not need subtraction detection technique at electric side. Therefore, MAI will not exist in this detection scheme. However this scheme is only applicable to codes, where the time chips are not overlapped with other time chips of other channels [12].

This paper is divided into six subsections: Section 1 gives the introduction of OCDMA and their codes, Section 2 provides the analytical model of three dimensional codes, and Section 3 gives implementation of this 3D SPPDD code, Section 4 gives results and discussions and Section 5 provides conclusions.

2. Analytical model

3D codes are the simply extension of the two dimensional codes. These three dimensional codes have been obtained from two dimensional codes by adding a third dimension, in which optical pulses are spread in all the three directions. Various three dimensional codes are available, some of them are

- Space/wavelength/time codes [13].
- Time/wavelength/polarization codes [14].

The most commonly used 3D code is space/wavelength/time because the time/wavelength/polarization codes requires polarization maintaining fiber for the fiber links, the polarization sensitive components are used throughout the link starting from encoder to decoder [5]. This complex polarization control at all stages in the network, making it very complicated and a costly affair. This space/wavelength/time codes are classified as

- SPP codes
- MPP codes

SPP codes: These codes having single pulse in each dimension or in plane.

MPP codes: These codes having multiple pulses in all or some dimensions.

By comparing both these codes in Ref. [7], found that three dimensional SPP codes offer greater system scalability than the three dimensional MPP codes. By addition of more wavelengths, increases the generated codes in the case of SPP codes only, while MPP codes are upper bounded to the number of time slots. We can say that, for a small number of simultaneous users the three dimensional MPP showed better performance due to dominant effect of increased threshold. The three dimensional SPP code showed lower error probability for large number of the simultaneous users, since the effect of reduced cross correlation probability become dominant. For that reason three dimensional SPP codes are commonly used, these three dimensional SPP codes combines with direct detection technique and that forms SPPDD codes.

Now, we define 3D code mathematically, $A\ (S \times W \times T,\ C_w,\ \lambda_a,\ \lambda_c)$ represents 3D code, C is a set of binary (0,1) here $(S \times W \times T)$ is a three dimensional matrices, C_w is a code weight and λ_a, λ_c represents the auto-correlation and cross correlation of the code respectively.

The code auto-correlation and cross-correlation constraints for a general 3-D SPP code family are defined below [7]:

Auto-correlation constraint: For a 3D SPP code $Y\,(W, T, S)$ [7]

Auto-correlation:

$$RY, Y = \sum_{l=0}^{W-1}\sum_{m=0}^{T-1}\sum_{n=0}^{S-1} yl, m, nyl, m(n \oplus t)$$

such that $RY, Y = \text{Code weight} \quad \text{for} \quad t = 0$

$\leq \lambda_a \quad \text{for} \quad 1 \leq t \leq S-1$

Cross-correlation constraint: For any two 3D SPP codes Y & Z (W, T, S) [7]

Cross-correlation:

$$RY, Y = \sum_{l=0}^{W-1}\sum_{m=0}^{T-1}\sum_{n=0}^{S-1} Zl, m, nZl, m(n \oplus t)$$

such that $RY, Z \leq \lambda_c \quad \text{for} \quad 1 \leq t \leq S-1$

In the above equations, non-negative integer's λ_a and λ_c are the peak out-of-phase auto correlation and the peak cross-correlation values; $\oplus$ denotes modulo-n addition.

Hence use of direct detection with 3D optical SPP codes improving the bit error rate performance and provides larger code set.

3. Implementation of three dimensional SPPDD codes

In order to implement this 3D codes, multiple star couplers and associated hardware was required, this makes the system complicated.

In order to overcome that W^2T scheme (using AWG based encoder/decoder and tunable filters) i.e. 2D can be used for the implementation of the three dimensional codes [6], which removes the requirement of star couplers and associated hardware. AWG based [15] 2D implementation is shown in [16]. For this purpose code can be written as $(W \times S) \times T$, where the number of wavelengths are $(W \times S)$. In this, we can construct W^2T code only if $(W > S)$ and during this condition it provides lower bit error probability. As the $(W \leq S)$, the bit error probability increases [9], this is proved by implementing W^2T scheme. Block Diagram for the implementation of three dimensional codes is shown above in Fig. 1. The values of space, Wavelength and time are taken from the construction of the SPPDD codes. In this paper we are presenting the setup by taking $S = 2$, $W = 4$ and $T = 4$ at bit rate 2.5 Gbps. Here the total number of the available wavelengths is given by $(W \times S)$. Now, here in this case the total number of wavelengths becomes 8 and we are having two space channels and each space channel is having four wavelengths. Four wavelengths of one space channel are multiplexed to form broadband source, the next four wavelengths of the second channel is delayed by some value this delay works as a function of AWG because we are having only 4 time slots or delay units. The output of the multiplexer is given to the optical input of the modulator; another input to the modulator is the data. A PN sequence