ISSN (Print) : 0974-6846
Indian Journal of Science and Technology, *Vol 10(31), DOI: 10.17485/ijst/2017/v10i31/113899, August 2017* ISSN (Online) : 0974-5645

OCDMA and its Applications in Fiber Optics Communication Networks

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Abstract

As multiple accessing techniques that can be used to provide access to multiple users to transmit data to same channel simultaneously without any scheduling or delay in transmission, Optical Code Division Multiple Access (OCDMA) has been an alluring for the past few decades. All users share all bandwidth simultaneously and access the network asynchronously. To provide access to multiple users simultaneously, many coding techniques to increase possible users and improve performance has been analyzed for OCDMA systems. In this paper, many different proposed methods of coding are reviewed. Performance, cardinality and capacity of these codes are discussed. Significance of introducing dimensions in optical code is also being discussed. **General Terms:** Auto Correlation, Cross Correlation.

Keywords: Multiple Access Interference (MAI), Optical Fiber Communication, Optical Code Division Multiplexing (OCDMA)

1. Introduction

Optical Transmission has been topic of tremendous interest for past few decades. A fiber is used as a waveguide to transmit the information from one place to another and optical wave is used as information carrier. As optical signal has advantage of large bandwidth that is available for use because optical signals operates in the frequency range of THz. In optical transmission, higher data-rate and data security demands can be met which has been a global challenge. By using OCDMA we can take advantage of its large bandwidth available due to optical fiber and properties of CDMA like that of asynchronous communication, anti-jamming and anti-eavesdropping[1,2].

In optical CDMA, different users who share a common communication channel transmit signals which could be overlapped both in time and frequency to provide better cardinality. Different code sequences that show minimum interference with each other are assigned to different users, which afterwards can be detected by other users who know the assigned code sequence in this system. These codes help minimize multiple access interference. In OCDMA, time is divided into 'n' equal parts to transmit each bit. These equal interval time parts are called time chips or time slots. We transmit the optical code sequence in the form of short optical pulses in some time chips and transmit nothing for remaining time chips. Pulse that is transmitted can be in any domain like time, frequency or space or in the combination of these domains. Each user has a unique code assigned to them. The encoder of each transmitter is programmed such that each '1' is represented by transmitting the unique codeword assigned to each user and each '0' is represented by transmitting an all zero sequence[3].

In this paper many different codes are discussed and analyzed to justify the significance of introducing the dimension in the optical codes OCDMA communication system. The two dimensional and three dimensional codes can be constructed using already available one dimensional codes such as prime sequence codes, Optical orthogonal codes, gold codes, Walash Hadamard codes etc. Auto correlation and cross correlation properties of these codes are also given. This paper also includes the discussion to reduce Multiple Access Interference and increase number of users that can be active in chorus.

The rest of the paper is organized as follows: Section 2 Deals with the Literature Review of the optical coding techniques which gives the insight for the optical codes

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used in OCDMA. Section 3 includes the discussion along with the future directions on 1D, 2D and 3D optical codes introduced in the literature review. Section 4 concludes the review of OCDMA and its application using different optical codes.

2. Literature Review

Author in[3] described the prime sequence codes. The minimum hamming distance of the prime code family is P −1 when we take P as the prime number. The construction of a PC is carried out in two steps as follows. First, consider P as a prime number and based on Galois field GF (P) and create a prime sequence according to described eq. Second, each prime sequence is mapped into the binary Sequence. It can be seen that the codeset with code length P^2 and code weight P can have P distinct prime sequences. Thus we can conclude the number of available code in the code set is again equal to the generating prime number 'P', while the number of active users for a given Bit Error Rate (BER) depends upon the correlation properties of these codes. No. of simultaneous users increases as value of P is increased. Auto correlation is poor (≤ P) and max cross correlation is two.

They also described the extended prime sequence codes. The code length of the sequence is increased as compared to the original prime sequence. It can be seen that the code set with code length P (2P −1) and code weight P can have P distinct prime sequences. Thus we can say that the number of available code in the code set is again equal to the generating prime number 'P', while the cross-correlation value is equal to 1, thus minimizing the amount of mutual interference. Auto correlation properties of this code is same as original's.

Author in[4] proposed modified prime codes for the synchronous mode as all the prime codes described before can only be used for asynchronous communication. As the codes can be used in synchronous communication, the explained modified prime codes have better code cardinality and performance then asynchronous codes. Due to the cyclic shift in generating the codes, we can see noteworthy increase in the number of possible subscriber and coinciding users in OCDMA network. We can obtain MPCs by cyclically shifting the original prime code sequence P times. In this way, the number of code sequences can be increased by original prime code, thus resulting in increased cardinality.

Author in[5] proposed the Optical orthogonal codes. It is a family of (071) sequences with good auto- and cross-correlation properties, i.e., the autocorrelation of each sequence exhibits the "thumbtack" shape and the cross correlation between any two sequences remains low throughout. It is also called Pseudo orthogonal codes due to the non-perfect nature of the orthogonal codes. Correlation properties of optical orthogonal codes are not affected by the cyclic shifts of code sequence. The cardinality of the OOC is large due to the use of cyclic shift. There a large no. of users can be possible using this method.

Author in[6] described the Walsh Hadamard codes. A Walsh Hadamard code is of matrix form with Z number of rows and Z number of columns. The matrix have bipolar valued (1, -1) entities with $Z = 2^M$ where M should be greater than or equal to 2. The length of code is the same as the value of Z and code weight of this code is half of the code length. The numbers of User that can actively transmit are $2^M - 1$. As we increase the value of M, number of user also increases resulting in the increase in value of cross-correlation. And it also requires more number of filters for each code as the number of user increases.

Author in[7] proposed the perfect difference codes and is used for synchronous optical code-division multiple-access. There are two noticeable characteristics of Perfect difference codes. First is, any two distinct codes are cyclic-shifted version of each other and second is that any two distinct codes have cross correlation between is equal to unity. All according to these characteristics a transmitter and receiver structure to enhance system performance and reduce the Multiple Access Interference has been proposed. For a given code length, when there is increase in the code weight there is also significant increase in the codeset. So, the number of users can be increased by increasing code weight.

Author in[8] propped a family of codes called 2D Projection code with Balanced Detection and their performance is compared to the 3D codes. But the codeset of this code is small as compared to the codeset of 3D codes. It mainly utilizes Balanced Detection to eliminate the multiple access interference. Construction of this code is done by projecting 2D sub-code words onto the 1D wavelength hopping code. For a given codeset, maximum number of users can be increased by relaxing correlation conditions with a significant penalty on the BER value.

Author in[9,10] proposed a wavelength hopping/time

spreading CDMA system using prime sequences. In their other paper they proposed to use this system for massive optical network and focused on how they can increase the security against the eavesdroppers. This method is a hybrid of WDM and CDMA and the increases the capacity of the network. For prime hop sequence there is maximum autocorrelation at the zero time shift and zero at out of phase instances. The cross-correlation of this sequence is unity at maximum. Due to the low cross-correlation properties allow the system to support increased number of simultaneous users, the number of possible stations in the network being also significantly increased due to the integration of both patterns.

Author in[11] proposed a 2D Wavelength/time matrix code which is constructed using optimum Golomb ruler with wavelength on one side and time slots in other slots. With less number of time slots, number of active users is few. But with the use of Guard time and optical hard limiter, no. of active users can be increased. The matrices have both a higher cardinality and higher ISD than the rulers from which they are derived and they can be used as unipolar codes for designing OCDMA local or access networks where the transceivers use intensity modulation and direct detection.

Author in[12] proposed a family of 2D codes known as 2D Time/Space single pulse per row. The performance of this code compared with 1D optical orthogonal code which has the lowest out of phase auto correlation and cross correlation among all 1D codes. It is observed that for a given BER performance and for same cross correlation size of T/S SPR codes is smaller than 1D OOC. Also number of simultaneous users is also more in case of T/s SPR codes. Also minimum of 0 out of phase auto correlation and unity cross correlation can be obtained.

Author in[13] proposed the 2D wavelength/time multiple pulses per row. It is shown that 2D W/T MPR code have high cardinality and spectral efficiency along with the minimum cross correlation properties which make it suitable for optical CDMA network. The performance of W/T MPR, SPR and OOC codes are analyzed and compared with each other by taking only multiple access interference in account. Multiple Access interference is considered the major source of noise in the OCDMA network. Both the Auto correlation and cross correlation of the code is minimum and roughly equal to unity.

Author in[14] proposed a new family of 3D wavelength/time/space codes for optical code division multiple access networks. Two types of codes are constructed i.e., 3D code with single pulse per plane and 3D code with multiple pulse per plane. A 3D wavelength/time/space code with zero out of phase auto correlation and unity cross correlation is designed. It also showed how the proposed codes can be realized. For a fixed code length, the code set size of the 3-D code w/SPP is larger than that of the 2-D prime code and the 3-D code w/MPP. 3D w/MPP codes showed better performance than SPP codes, for a small number of simultaneous users, due to dominant effect of increased threshold in the detection. The 3-D code w/SPP showed lower error probability for a large number of simultaneous users since the effect of reduced cross-correlation probability became dominant.

Author in[15] demonstrated the 3D time-wavelength-polarization encoding and decoding OCDMA system. A 3D codeset is generated where a given user has chips encoded in time, wavelength, and polarization such that each individual user's code is polarization-rotation-invariant with respect to any other user's code. This increase the number of potential users by a factor of approximately 2^K over a conventional 2D code, where "K" is the number of collisions the codeset will allow. Where collisions are the common time chips present between different codes.

Author in[16] proposed a new family of 3D single pulse per plane codes for differential detection for OCDMA systems. These codes are constructed using 1D Golomb ruler sequence as the base. Golomb ruler sequence has good cardinality and high BER performance, so the SPP codes also have larger codeset and good performance. Differential detection is used to eliminate the multiple access interference. The SPDD codes have out of phase auto correlation 'zero' and peak cross correlation equals to unity. In these codes antipodal signaling is used where each user is assigned two codes, one for transmission of bit '1' and other for transmission of bit '0'. So, total number of possible users in the system is half of the total codeset.

Author in[17] proposed a new family of 3-D wavelength/time/space (W/T/S) codes named Golomb ruler with-zero-insertions balanced codes for differential detection (GRZI-BCDD), with zero off-peak auto-correlation and unity peak cross-correlation for asynchronous OCDMA networks. These are generated using the unique inter-pulse distance property of Golomb rulers. With antipodal signaling and differential detection used in the receiver, this 3-D codes can support a larger number of

simultaneous users than the earlier reported 2-D/3-D codes for asynchronous systems. This code is similar to #D SPDD codes in construction. The procedure for generating the codes is given. The number of simultaneous users at BER of 10^{-9} is significantly large with GRZI-BCDD codes as compared to the systematic 2-D/3-D codes reported previously.

3. Discussion and Future Scope

In OCDMA, the users can send the data without any transmission delay and without any waiting. But the number of users which can active simultaneously plays a significant role in the design of OCDMA network. Different codewords are assigned to each users and these codes are required to be orthogonal to each other to reduce the interference between them. But it limits the number of codes that can be generated for finite code length. So, to increase the number of users the correlation constraints are relaxed to an acceptable level. So, the basic objective of designing a code is to achieve minimum out of phase auto correlation and cross correlation and increase in the number of users that can transmit data simultaneously.

Data can either be sent in asynchronous mode or synchronous mode. In synchronous OCDMA, the number of user's increases significantly as we can use cyclic shifted versions of the available codewords. Thus SOCDMA can be use where large number of users is present. But this method also introduces delay in the transmission. Number of users can also be increased by introducing dimensions as another degree of freedom. As we use 2D or 3D codes we can increase the cardinality of the code sequence without any increase in the code length. 3D codes have best cardinality and high BER performance as compared to the 1D/2D codes.

Efforts can be made in the data security enhancement against the eavesdroppers for the OCDMA network. 1D codes have the least data security among all other codes as optical signal can pass through cladding and protection layers of optical fiber at some point and analyzed by the eavesdroppers because 1D have the least flexibility among all other codes. Security analysis of some codes has been done and many authors have written papers to emphasize on the security against eavesdroppers and it is important because data can be analyzed without the knowledge of users. Therefore, no proper measures can be done to detect eavesdroppers.

We need three dimensional codes that are easy to implement in real-time, have data rate and performance that can be utilized to meet the demands of high speed data transfer, security and more easily accessible network. These demands can be met by doing more research that will make us utilize the high bandwidth of the optical fiber cable.

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