Review on Optical Code Division Multiple Access Systems

Gurjeet Kaur[1,a], Simranjit Singh[1,b]

[1]Department of Electronics and Communication Engineering, Punjabi University, Patiala
E-mail: [a]ergurjeetkaur92@gmail.com,[b]simranjit@live.com

Abstract. With the emergence of network driven applications and high speed requirements in communication along with security and large bandwidth, there is a need for a network technique which is capable of providing all the above with a reduced cost. A multiple access technique called Optical Code Division Multiple Access (OCDMA) seems to be fulfilling the above criteria. OCDMA combines the large bandwidth of the optical fiber communication and CDMA technique to achieve the high speed connectivity. The performance of the OCDMA system is reduced due to Multiple Access Interference (MAI). To enhance the performance various detection techniques are used. The software used for simulation is OptiSystem from Optiwave. It has been shown that the bit error rate (BER) is equal to less than 10^{-9}.

Keywords: Bit Error Rate (BER), Multiple Access Interference (MAI), Optical Code Division Multiple Access (OCDMA), Optical Orthogonal Codes (OOCs), Passive Optical Network (PON), Spectral Amplitude Coding (SAC), Zero Cross Correlation Code (ZCC).

1. Introduction

The Optical fiber communication is being used at a rapid rate in many fields of communication because the optical fibers provide large bandwidth through which we can transmit large amounts of data which makes the system efficient in every way possible [16]. In optical communication the signal is sent in form of light to the other end instead of using the electrical signal. It depends upon optical fibers to carry the signal to the destination.

In CDMA the data signal is spread by the unique spreading code which is a pseudo noise code sequence having high chip rate before being given to the channel [17]. Each transmitter has different pseudo random codeword and these codewords are orthogonal to each other. Time correlation is done by the receiver to detect the desired codeword and the remaining codewords appear as noise to the desired receiver.

Combining the above two technologies leads to new technology called Optical CDMA. OCDMA allows several transmitters to transmit the data simultaneously over an optical fiber communication channel by simultaneously allocating the available bandwidth to each transmitter. Each transmitter is allocated unique chip sequence generated by the pseudo random binary sequence generator. This chip sequence is used in spreading the data signal. The encoded signals from various transmitters are multiplexed and sent over an optical fiber to the receiver. The decoder is used to decode the desired data signal by using the same chip sequence as used by the desired transmitter.Despite of the potential advantages of the OCDMA system, it has some limitations too. It suffers from Multiple Access Interference (MAI) where the desired receiver is tuned only to detect its data signal while considering the other signals as noise. MAI increases the BER as the number of users increase.These limitations of the OCDMA system can be resolved by increasing the code weights and code lengths, and by using the codes having least cross correlation. This paper focuses on the implementation of the OCDMA system. This paper is organized as follows: Section 2 presents the literature review of the OCDMA systems and the conclusion is determined in Section 3.

2. Literature Review

The implementation of the SAC-OCDMA system was done with the help of codes and there were many code families available like OOC, Prime Codes, Modified Double Weight (MDW) code, Hadamard code and Modified Frequency Hopping (MFH) code [1]. Comparison of all these codes was done for number of users being 30. The results reveal that the MDW codes are better than the Hadamard and MFH codes because MDW codes have code lengths larger although the code weight was less. Moreover, the MDW codes had cross correlation value 1, high signal to noise ratio (SNR) and gave BER up to 10^{-12} for 10 Gbps communication system. The OOCs were used in the implementation of the OCDMA system for communicating over the atmosphere [2]. Upon transmission through the atmosphere, many factors were taken into account such as the atmospheric turbulence, ambient light, thermal noise, weather conditions and most importantly MAI. For the atmospheric communication to take place among buildings a line of sight (LOS) path was essential. Space diversity and coding were utilized for the reducing the effects of fading. The OCDMA system was implemented for Pulse Position Modulation (PPM) and On- Off Keying (OOK), and OOK gave better results as it required less bandwidth.To reduce MAI themost simplest technique used was the direct detection technique for ZCC code in an OCDMA system [3]. The main reason for the occurance of the MAI was the increase in the number of users. For the ZCC code, the direct detection technique performed better compared to other techniques such as AND subtraction because the number of filters used at the receiver were reduced due to which further the power losses reduced. The performance of the OCDMA system using the direct detection totally eliminated the MAI and PIIN.

The LEDs were also used as the optical sources in the SAC-OCDMA system [4]. For the code weight 4 the number of users was made to vary from 12 to 48 for the LED power of -16.77dBm. Super Luminescent Diodes (SLDs) were preferred due to their highly focussed optical power. The results revealed that the ZCC codes performed better than other codes as they accommodated up to 100 active users while having BER 10^{-9}. Moreover, LEDs were preferred because their outputs were composed of many wavelengths compared to lasers where one laser gave only wavelength.For the multiple rate transmission and high QoS for an OCDMA system multi-length variable weight OOCs (MLVR OOC) were used [5]. Data rate for various service classes varied, thus codes with different weights were allocated to different users depending upon the type of services used by them. Multilevel signalling technique was also used where a group of users would transmit at a specified power level. The results showed that the code family used along with the multi-level signalling made an OCDMA system less prone to MAI and increased the throughput significantly which resulted in improvement in QoS.The presentation of SAC-OCDMA system was more accurately made to analysis the mean and the variance of the decision current [6]. These were used for the calculation of the BER based on the Gaussian Approximation method. Most of the researchers used the upper and the lower bound to obtain the BER. At the receiver side the balanced detection was used for the recovery of the data where upper branch detected the codewordc_1 and the lower branch detected the complement of the codewordc_1. The currents from the upper and the lower branches were subtracted to get the decision current which was further compared with the threshold current. The derived BER was evaluated numerically and compared to upper and lower bounds of the BER for two different SAC-OCDMA codes that was Modified Quadratic Congruence (MQC) code and Walsh Hadamard code.

The different data formats could be used in the OCDMA system like Non Return to Zero (NRZ) and Return Zero (RZ) data formats [7]. Both the data formats were used for the AND as well as Modified AND detection techniques and the performance was analysed. It was found that the NRZ data format yielded better results than RZ data format but the type of the detection technique used matters more in suppression of MAI and PIIN.The Prime codes were employed for the MAI cancellation for an OCDMA system [8]. This scheme was efficient in totally removing the MAI. The experimental comparison of the OCDMA system with MAI cancellation method and without using MAI cancellation was done. The system using the cancellation schemes removed the MAI in the code families i.e. Modified Prime Code (MPC), Double Padded Modified Prime Code (DPMPC) and Uniform Cross Correlation Modified Prime Code (UC-MPC). If the cancellation scheme was not used then the UC-MPC performed better.The importance of the 2-D OOCs was that they

provided large number of users than the 1-D OOCs [9]. The optical pulses were made to spread in two dimensions in order to obtain the 2-D codes i.e. wavelength and time, or wavelength and space, or time and wavelength. These codes proved to reduce the MAI, PIIN and shot noises present in the system. It depends upon the designer in which dimensions the 2-D codes were to be obtained as different applications required different parameters to be high or low. The multi-level technique along with WOPPM was used for incoherent asynchronous OCDMA system [10]. It mainly provided different QoS for different group of users. OOC codes were used as the sequence code. The designing of the system became easier by using this technique with fixed throughput when compared to one level technique. The main limiting factor in an OCDMA system was MAI. The Overlapping Pulse Position Modulation (OPPM) and ML OOC code proved helpful in the removal of MAI [11]. The ML OOC codes were applied to OCDMA system for Wrapped OPPM Unwrapped OPPM and OOK modulations and given to correlation receivers with and without hard limiters. The results revealed that the W/UOOPM OCDMA systems gave better BER when compared to conventional OOK OCDMA system.
In order to achieve good Quality of Service (QoS) in the multimedia applications and increase the multiple services for the users a code family was needed which could support it. The Multiple-Length OOC (ML OOC) arbitrary cross correlation, λ was used. Different users need different services which require different data rates [12]. By varying the cross correlation, λ different multimedia application networks were obtained. Variable length codewords were assigned to different users depending upon the type of services they were using. Thus, the analytical and simulation results revealed that the OCDMA system using the ML OOC codes were efficient for multiple services. The group delays in the dispersive medium caused time spreading of the signal with time which further resulted in the signals not being decoded and detected correctly. The FBG based dispersion compensators could control the chromatic dispersion. The Triple-Branch Signal Detection (TBSD) scheme removed the MAI in the OCDMA systems [13]. The combination of the FBG dispersion compensator with TBSD scheme not only reduced the cost but complexity also. The simulation results revealed that for 40 km long single mode fibersusing FBG compensator with quadratic dispersion of -680ps/nm and TBSD scheme was better for code recognition.For very populated areas large number of codes were needed which were obtained by cyclically shifting of the base code for SAC-OCDMA system [14]. These cyclic code shift extension (CCSE) prevented the occurance of the bursty errors by utilizing the auto-synchronization. The code weight remained same but the number of users was increased by shifting the code and increasing its code length. The system was also implemented on a prototype and gave good results when we test it for high quality digital audio data transmission. CCSE technique proved to be good in providing high data rate asynchronous OCDMA network for highly populated areas. The OCDMA system for the OOCs was implemented for underwater wireless communication system [15]. The performance of this OCDMA system was analysed for the different types of water i.e. pure sea water, ocean water and coastal water. The implementation of this system was done on an FPGA which included the Optical Base Transceiver Station (OBTS), Optical Network Controller (ONC), transmitter and receiver. The area was divided in hexagonal cells and each cell contained an OBTS which was connected to central controller ONC via the optical fibers. The experimental results revealed that cell radius could be expanded more than the 70m for the sea water and cell radius was limited to 35m for coastal and ocean waters.

Table 1. Comparison of various OCDMA Systems.

Sr. No.	Title	Author Names	Name of the Publication	Work Done
1)	A New Family of Optical Code Sequences for Spectral Amplitude Coding Optical	S. A. Aljunid, M. Ismail, A. R. Ramli, Borhanuddin M. Ali and MohamadKhazani Abdullah	IEEE Photonics Technology Letters, vol.16, no.10, pp.2383-2385, Oct. 2004.	Comparison of OOCs, Prime Codes, MDW codes, Walsh Hadamard codes and MFH codes

	CDMA Systems [1]			was done for SAC-OCDMA network. MDW codes outperformed from all the codes.
2)	Atmospheric Optical CDMA Communication Systems via Optical Orthogonal Codes [2]	Mahmoud Jazayerifar and Jawad A. Salehi	IEEE Transactions on Communication, vol.54, no.9, pp.1614-1623, Sept. 2006.	The OOCs were used in the implementation of the OCDMA system for communicating over the atmosphere for PPM and OOK. OOK proved better as they required less bandwidth.
3)	Study of Direct Detection Technique for Zero Cross Correlation Code in OCDMA [3]	C.B.M.Rashidi, M.S Anuar and S.A. Aljunid	Computer and Communication Engineering (ICCCE), 2010 International Conference on , vol., no., pp.1-5, 11-12 May 2010.	OCDMA system for ZCC code was implemented using direct detection and it totally eliminated MAI and PIIN.
4)	LED Spectrum Slicing for ZCC SAC-OCDMA Coding System [4]	M.S Anuar, S.A Aljunid, A.R Arief and N.M Saad	High-Capacity Optical Networks and Enabling Technologies (HONET), 2010 , vol., no., pp.128-132, 19-21 Dec. 2010.	The SAC-OCDMA system for ZCC code was implemented using LEDs as light source because their output was composed of many wavelengths.
5)	Multirate and Multi-Quality-of-Service Passive Optical Network Based on Hybrid WDM/OCDM System [5]	HamzehBeyranvand and Jawad A. Salehi	IEEE Communications Magazine, vol.49, no.2, pp.s39-s44, February 2011.	The MLVR OOCs were used for an OCDMA system for differentiated services and multi-level signalling made system less prone to MAI and improved QoS.
6)	Closed-Form Expression for the Bit-Error Rate of Spectral-Amplitude-Coding Optical CDMA Systems [6]	Hossam M. H. Shalaby	IEEE Photonics Technology Letters, vol.24, no.15, pp.1285-1287, Aug.1, 2012.	The MQC code and Walsh code were presented for SAC-OCDMA system and used balanced detection at receiver. MQC codes performed better than Walsh codes.

7)	Performance of Different SAC-OCDMA Detection Schemes with NRZ and RZ Data Formats [7]	M. Z. Norazimah, S. A. Aljunid, Hamza M. R. Al-Khafaji, Hilal A. Fadhil and M. S. Anuar	IEEE Symposium on Industrial Electronics and Applications (ISIEA), vol., no., pp.66-70, 22-25 Sept. 2013.	The OCDMA system was designed for NRZ and RZ data formats as well as using AND and Modified AND detection techniques.
8)	A Novel Multi User Interference Cancellation Scheme for Synchronous OCDMA Networks [8]	Mohammad HosseinZoualfaghari and HooshangGhafouri-Shiraz	Journal of Lightwave Technology, vol.31, no.11, pp.1813-1820, June1, 2013.	The MPC, DPMPC, UC-MPC were used for OCDMA system. Comparison of this system with and without MAI cancellation method was done. MAI cancellation method removed MAI in all code families.
9)	Review on Two Dimensional Code of Non-coherent OCDMA Systems [9]	RasimAzeezKadhim, Hilal Adnan Fadhil, S.A. Aljunid and MohamadShahrazelRazalli	IEEE International Conference on Control System, Computing and Engineering, vol., no., pp.90-94, 28-30 Nov. 2014.	Review of 2-D codes was presented and it was also showed that the 2-D codes perform better than 1-D codes. [9]
10)	Performance Analysis of Two-Level Asynchronous Optical CDMA Systems Utilizing Wrapped OPPM [10]	AbbasaliGhorbanSabbagh and Mohammad MolaviKakhki	IEEE Journal of Lightwave Technology, vol.32, no.1, pp.122-129, Jan.1, 2014.	Multi-level technique along with WOPPM was used for OOC codes in OCDMA system. System designing became easier with two level technique.
11)	Performance Analysis of Multirate Multiservice Optical CDMA Networks Adopting Overlapping PPM Signalling [11]	Ahmed E. Farghal, Hossam M. H. Shalaby and Zen Kawasaki	IEEE Journal of Lightwave Technology, vol.32, no.15, pp.2649-2658, Aug.1, 1 2014.	Comparison of OPPM with OOK was done and OPPM proved better in removal of MAI in OCDMA system.
12)	General Construction Method of	Xiaobin Li and Lizhi Lu	IEEE Journal of Optical Communications and Networking, vol.7, no.3, pp.156-163, March 2015.	ML OOCs with arbitrary cross correlation were used for OCDMA network and was

	Multi-length Optical Orthogonal Codes With Arbitrary Cross-Correlation Constraint for OCDMA Multimedia Network [12]			efficient for differentiated services.
13)	Modified decoding and detection scheme for spectral amplitude coding optical CDMA systems [13]	Fu-Jun Chen, Feng-GuangLuo, Bin Li and Cheng He	IEEE Electronics Letters , vol.51, no.10, pp.773-775, 5 14 2015.	FBG based dispersion compensators along with TBSD scheme was implemented which gave better code recognition.
14)	Cyclic code-shift extension keying for multi-user optical wireless communications [14]	O. González, J.A. Martín-González, M.F. Guerra-Medina, F.J. López-Hernández and F.A. Delgado-Rajó	IEEE Electronics Letters , vol.51, no.11, pp.847-849, 5 28 2015.	CCSE was used in SAC-OCDMA system and gave good results for high data rate and densely populated areas.
15)	Cellular Underwater Wireless Optical CDMA Network: Performance Analysis and Implementation Concepts [15]	FarhadAkhoundi, Jawad A. Salehi and Arvin Tashakori	IEEE Transactions on Communications, ,vol.63, no.3, pp.882-891, March 2015.	The OCDMA system using OOCs was implemented for underwater wireless communication on a prototype for pure sea water, ocean water and coastal water.

3. Conclusion

This paper presents the literature review of the different types of an OCDMA system. It shows that the OCDMA system can be implemented using different types of code families, data formats and modulation techniques. The ZCC codes and OOCs give good results as they have cross correlation values 0 and 1 respectively. The NRZ data formats are preferred over the other formats because of their simple operation and better performance. Since the SAC-OCDMA systems are widely used by SPE-OCDMA systems outperform because it can accommodate more number of users and error occurance at the receiver end decreases. Further, the OCDMA PON systems are also in demand in case of large systems such as Cable TV (CATV) systems, Fiber to the Home (FTTH), Fiber to the Building (FTTB) etc. For the transmission purposes the optical fibers are used which may be single mode or multimode, or the atmospheric transmission is also possible by using the Optical Wireless Channel (OWC) or Free Space Optical channel (FSO). On the receiver side PIN or APD photodiodes are utilized for the optical to electrical conversion of the signal. For the decoding purposes filters or FBGs can be employed depending upon the requirement of the system. Various detection techniques can be used which require less number of filters or FBGs due to which the power losses are reduced to much extent. Thus, a trade off must be maintained by designer to optimize any application so that one gets the best results possible.

References

[1] Aljunid, S.A.; Ismail, M.; Ramli, A.R.; Ali, B.M.; Abdullah, M.K., "A new family of optical code sequences for spectral-amplitude-coding optical CDMA systems," in *Photonics Technology Letters, IEEE,* vol.16, no.10, pp.2383-2385, Oct. 2004.

[2] Jazayerifar, M.; Salehi, J.A., "Atmospheric optical CDMA communication systems via optical orthogonal codes," in *Communications, IEEE Transactions on* , vol.54, no.9, pp.1614-1623, Sept. 2006.

[3] Rashidi, C.B.M.; Anuar, M.S.; Aljunid, S.A., "Study of direct detection technique for zero cross correlation code in OCDMA," in *Computer and Communication Engineering (ICCCE),* 2010 International Conference on , vol., no., pp.1-5, 11-12 May 2010.

[4] Anuar, M.S.; Aljunid, S.A.; Arief, A.R.; Saad, N.M., "LED spectrum slicing for ZCC SAC-OCDMA coding system," in *High-Capacity Optical Networks and Enabling Technologies (HONET),* 2010 , vol., no., pp.128-132, 19-21 Dec. 2010.

[5] Beyranvand, H.; Salehi, J.A., "Multirate and multi-quality-of-service passive optical network based on hybrid WDM/OCDM system," in *Communications Magazine, IEEE* , vol.49, no.2, pp.s39-s44, February 2011.

[6] Shalaby, H.M.H., "Closed-Form Expression for the Bit-Error Rate of Spectral-Amplitude-Coding Optical CDMA Systems," in *Photonics Technology Letters, IEEE ,* vol.24, no.15, pp.1285-1287, Aug.1, 2012.

[7] Norazimah, M.Z.; Aljunid, S.A.; Al-Khafaji, H.M.R.; Fadhil, H.A.; Anuar, M.S., "Performance of different SAC-OCDMA detection schemes with NRZ and RZ data formats," in *Industrial Electronics and Applications (ISIEA), 2013 IEEE Symposium on ,* vol., no., pp.66-70, 22-25 Sept. 2013.

[8] Zoualfaghari, M.H.; Ghafouri-Shiraz, H., "A Novel Multi User Interference Cancellation Scheme for Synchronous OCDMA Networks," in *Lightwave Technology, Journal of* , vol.31, no.11, pp.1813-1820, June1, 2013.

[9] Kadhim, R.A.; Fadhil, H.A.; Aljunid, S.A.; Razalli, M.S., "Review on two dimensional code of noncoherent OCDMA systems," in Control System, Computing and Engineering (ICCSCE), 2014 IEEE International Conference on , vol., no., pp.90-94, 28-30 Nov. 2014.

[10] Sabbagh, A.G.; Kakhki, M.M., "Performance Analysis of Two-Level Asynchronous Optical CDMA Systems Utilizing Wrapped OPPM," in *Lightwave Technology, Journal of* , vol.32, no.1, pp.122-129, Jan.1, 2014.

[11] Farghal, A.E.; Shalaby, H.M.H.; Kawasaki, Z., "Performance Analysis of Multirate Multiservice Optical CDMA Networks Adopting Overlapping PPM Signaling," in *Lightwave Technology, Journal of ,* vol.32, no.15, pp.2649-2658, Aug.1, 1 2014.

[12] Xiaobin Li; Lizhi Lu, "General construction method of multilength optical orthogonal codes with arbitrary cross-correlation constraint for OCDMA multimedia network," in *Optical Communications and Networking, IEEE/OSA Journal of* , vol.7, no.3, pp.156-163, March 2015.

[13] Fu-Jun Chen; Feng-GuangLuo; Bin Li; Cheng He, "Modified decoding and detection scheme for spectral amplitude coding optical CDMA systems," in *IEEEElectronics Letters* , vol.51, no.10, pp.773-775, 5 14 2015.

[14] Gonza□ lez, O.; Marti□ n-Gonza□ lez, J.A.; Guerra-Medina, M.F.; Lo□ pez-Herna□ ndez, F.J.; Delgado-Rajo□ , F.A., "Cyclic code-shift extension keying for multi-user optical wireless communications," in *IEEEElectronics Letters ,* vol.51, no.11, pp.847-849, 5 28 2015.

[15] Akhoundi, F.; Salehi, J.A.; Tashakori, A., "Cellular Underwater Wireless Optical CDMA Network: Performance Analysis and Implementation Concepts," in *Communications, IEEE Transactions on,* vol.63, no.3, pp.882-891, March 2015.

[16] Govind P. Agarwal, "Introduction," in *Fiber Optic Communication Systems*, *3rd* ed.,New York, Wiley2007, ch.*1*, pp. *15-19*.

[17] Theodore S. Rappaport, "Wireless Systems and Standards," in *Wireless Communications: Principles and Practicesthird, 2nd* ed.,Prentice Hall, 2013, ch.*11*, pp. *469-482*.