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DESIGN AND IMPLEMENTATION OF IMPROVED SUPERIMPOSED CYCLIC OPTICAL ORTHOGONAL CODES (SCOOC) BASED OPTICAL ENCODER/DECODER STRUCTURE FOR 1GBPS OPTICAL CDMA SYSTEM

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Abstract

In this paper, an improved form of two dimensional optical orthogonal codes is introduced for optical CDMA system by using just six lasers. This new technique not only reduces the length of the code but also improves the bit error rate (BER) performance of the system. The uniqueness of this coding architecture is that the two adjacent codes are not only different by their time slots but have different wavelength combination as well. The encoder and decoder structure has been designed with the help of filters and optical delay lines. An OCDMA system at 1 Gbps bit rate is designed for above codes and performance is evaluated and compared for various parameters i.e. number of simultaneous users, bit error rate, quality factor. The OCDMA system can accommodate 25 users for permissible BER of 10^{-9}, with -15db received power at 1 Gbps bit rate respectively. If received power is kept low i.e. -22db, the OCDMA system can support 16 users with extremely low BER of $1.58e^{-41}$ for 1G bps bit rate.

Keywords: Optical code division multiple access, Bit error rate, Encoder, Decoder.

1. Introduction

In the optical orthogonal code family several researcher works on the 2D codes by using different construction techniques [1-3]. Hernandez et al. [4] have developed an optical code division multiple access (OCDMA) technology demonstrator (TD) based on two dimensional (2D) codes derived from folded optimum Golomb rulers which can support six asynchronous users at less than 10-11 bit error rate (BER) and up to eight users at 10-8 BER. Hernandez et al. [5] designed a technology demonstrator for an incoherent optical code-division multiple-access

Nomenclatures

L	Length of the code
N	Number of time slots
W	Number of wavelengths

Abbreviations

BER	Bit error rate
OCDMA	Optical code division multiple access
SCOOC	Superimposed cyclic optical orthogonal codes

scheme based on wavelength/time codes which can support 16 users operating at 1.25 Gsymbols/s/user while maintaining BER < 10^{-11} for the correctly decoded signal.

2. Coding Architecture

In this research an improved two dimensional optical orthogonal codes have been introduced successfully by designing an encoder/decoder section of OCDMA system based on rigorous analysis. These codes have been designed by remodelling and improving the existing concept of Optical Orthogonal Codes. The new code set is designed with the help optimum goloumb ruler. In this research, two sequences from optimal goloumb ruler are used with Length, L= 18, Weight, W=6, i.e. {1, 1, 0, 0, 1, 0, 0, 0, 0, 0, 1, 0, 1, 0, 0, 0, 0, 1} and {1, 0, 0, 1, 0, 1, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 1, 1} respectively. These sequences are used as a baseline to design SCOOC codes. These two sequences are taken as one dimensional superimposed cyclic code which is then converted to two dimensional superimposed codes using ruler to matrix transformation. The dimension of the matrix has been decided for the conditions i.e. $(W\times T) \geq L$ where W is the number of wavelengths and T is the number of time slots. In this code design two cases are possible:

(a) In the first case, if $(W\times T > L)$, then N number of filler zero's where $N = (W\times T) - L$ has to be added at the end of the code word to form a proper matrix set. With W= 4 and T = 5, i.e. (5×4 > 18), 2 filler zero's are needed to make a proper matrix. But in this architecture four lasers are required for one code which will further increase the cost.

(b) In the second case, with W = 3, T = 6, a (3×6) physical matrix can be formed without any need of filler zero's. This is a compact and optimum size because it satisfies $(W\times T) \geq L)$ i.e. as $W\times T$ = 18 which is equal to L, i.e. 18 and requires less, i.e. 3 lasers for one codeword. So this is more optimum situation because it saves the cost of the laser by increasing one more optical delay line.

So in this coding technique total six mode locked lasers of wavelengths (W1, W2, W3, W4, W5, and W6) are used to design thirty six codes. The uniqueness of this code is that the two adjacent codes use different wavelength combinations. Code 1 is designed by using wavelengths {W1, W2 and W3} whereas the Code 2 is designed by using {W4, W5 and W6} wavelengths which further reduces the

MAI very intelligently. This design improves the security because two adjacent codes are not different by time slots but with wavelengths also. Table 1 represents the code design for code C1 and C2.

Table 1. Representation of Codes C1 and C2.

C1	T0	T1	T2	T3	T4	T5	**C2**	T0	T1	T2	T3	T4	T5
W1	1	0	0	0	1	0	W4	1	0	0	0	0	0
W2	1	1	0	1	0	0	W5	1	0	0	0	1	0
W3	0	0	0	0	0	1	W6	1	1	0	1	0	0

The above mentioned code design have then been used for implementing the OCDMA system by way of simulation for a fiber length of 60 km for Metropolitan Area Network. The performance evaluation of these code sets have been done by realistic simulation which has proximate relationship with the practical parameters and scenario.

3. System Design

The system is designed by using six mode locked lasers of different wavelengths ranging from 1550e^{-9} m to 1.554e^{-6} m with 0.7 e^{-9} m wavelength spacing which generates the pulses of width e^{-11} which is equal to the data rate of the system i.e. 1e^{9} for 1 Gbps system. Figure 1 describes the architecture of the OCDMA system using new encoder structure.

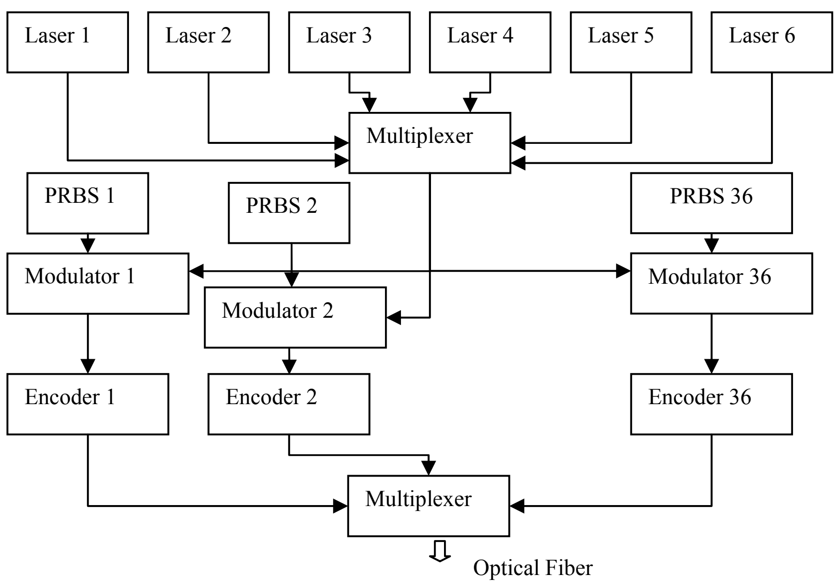

Fig. 1. Optical CDMA System Design.

The pseudo random sequences are used as a data source of 2^6 -1 pattern length. The Machzender modulator LiNbO3 modulator modulates this data signal with the carrier which is then fed to the encoder. The encoder of Code 1 is designed by using optical filter and time delay circuits of three wavelengths and 6 time slots as represented in Fig. 2.

In this system, 36 codes have been designed for different wavelength and time delay combinations. The bit period of 1 Gbps is $1.0e^{-9}$s and $1.67e^{-10}$s respectively. Table 2 represents the chip period and time delay of the various time slots.

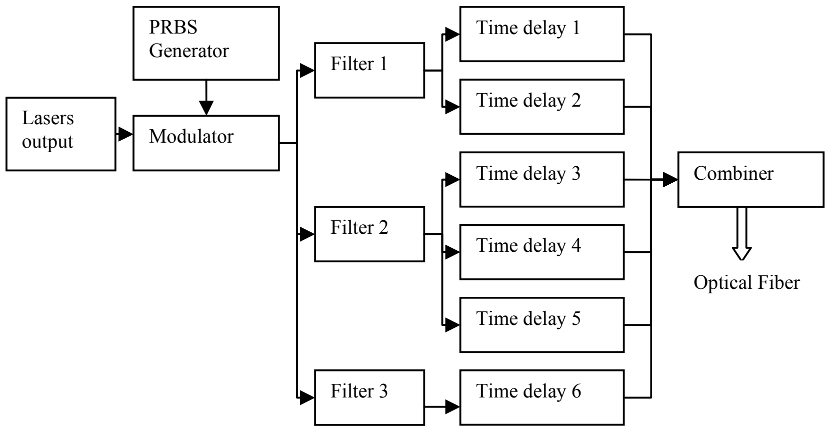

Fig. 2. Encoder Design of Optical CDMA System.

Table 2. Time Delay for 1Gbps System for Various Time Slots.

Time Slots	Chip period for 1 Gbps System (s)	Time delay for 1 Gbps System (s)
0	$1.67e^{-10}$	0
1	$1.67e^{-10}$	$1.67e^{-10}$
2	$1.67e^{-10}$	$3.34e^{-10}$
3	$1.67e^{-10}$	$5.01e^{-10}$
4	$1.67e^{-10}$	$6.68e^{-10}$
5	$1.67e^{-10}$	$8.35e^{-10}$

In the encoder the corresponding wavelength according to the codes are filtered out and time delays places the pulses in their appropriate time slots which are further combined with the help of combiner. These encoded codes from all the users are then multiplexed and passes through the 60 km span of the single mode fiber followed by a loss compensating EDFA amplifier. Figures 3 and 4 represent the signal diagram and eye diagram of the encoded signal.

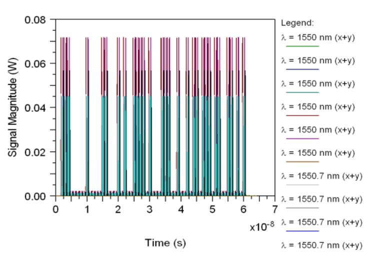

Fig. 3. Signal Output at Encoder.

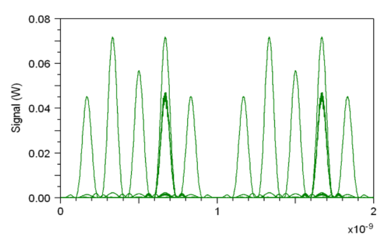

Fig. 4. Eye Diagram Output at Encoder.

Each code is designed using three wavelengths as depicted in Fig. 5. The decoder, tuned to user 1, has the same structure as the corresponding encoder, but it has inverse delays which realign the pulses. The filters used in the decoder section filter out the corresponding wavelengths according to the encoder wavelengths.

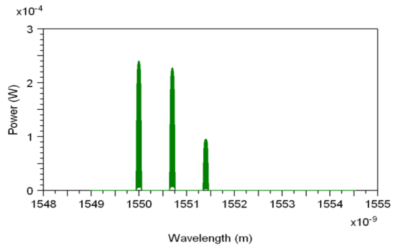

Fig. 5. Spectrum Analyzer Output at Encoder.

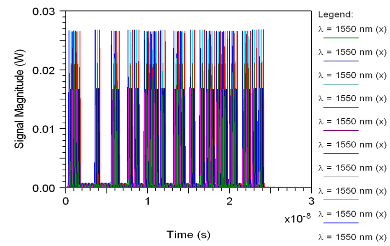

Fig. 6. Signal Diagram at Decoder.

The optical power normalizer adjusts the received power of the signal. Avalanche photo diode has been used at the receiver section. Figures 6 and 7 represent the signal outputs at the decoder and receiver section respectively. The bit error eyelids in Fig. 8 represent the decision level offset voltage for one user.

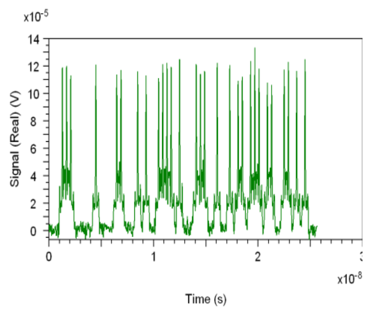

Fig. 7. Signal Diagram at Receiver.

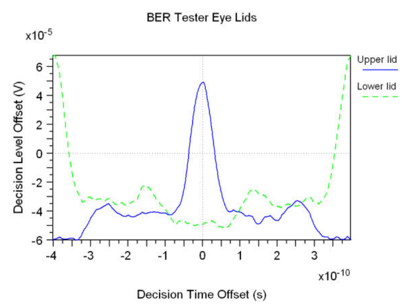

Fig. 8. BER Eyelids at Receiver.

4. Results and Discussions

From the signal diagrams in the Figs. 9 to 11 it can be analyzed that as the number of users increases from 1 to 5 the multiple access interference increases but it is in acceptable limits.

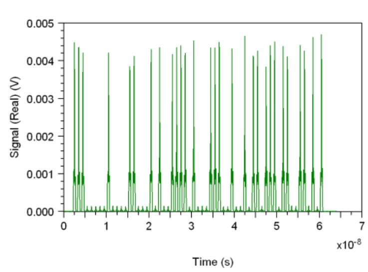

Fig. 9. Signal Diagram for 1 User.

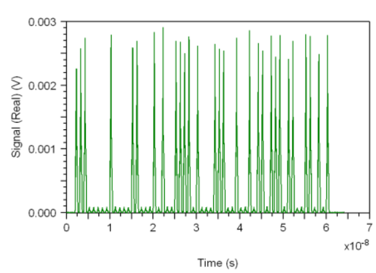

Fig. 10. Signal Diagram for 2 Users.

It is further concluded that as the number of users increases from 8 to 16 the signal amplitudes starts diminishing as shown in Figs. 12 and 13. The amplitude of the signal decreases with increase in number of simultaneous users. For 8 users the maximum amplitude of the signal is 0.003 V which degrades to 0.0017 V for 27 users as shown in Figs. 12 and 13. It is evident from the signal diagram of Fig. 14 that multiple access interference exists along with the original signal which restricts to increase the number of users.

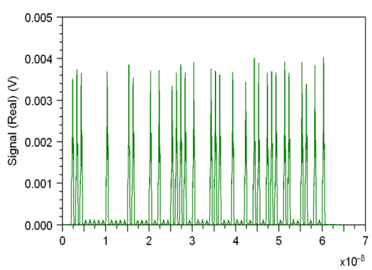

Fig. 11. Signal Diagram for 5 Users.

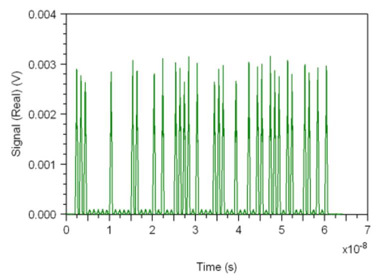

Fig. 12. Signal Diagram for 8 Users.

The performance of 1 Gbps SCOOC based OCDMA system has been evaluated in terms of number of users and bit error rate and quality factor as represented in Figs. 15 to 18. The permissible bit error rate e^{-9} and quality factor = 15 is baseline for concluding the results. This system performs outstanding for -15db received power and can accommodate 25 simultaneous users for bit error rate of e^{-9}.

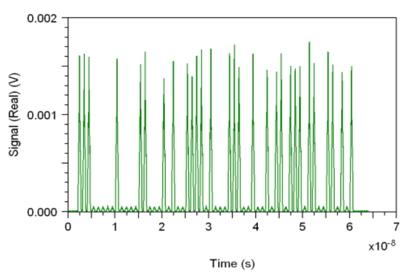

Fig. 13. Signal Diagram for 16 Users.

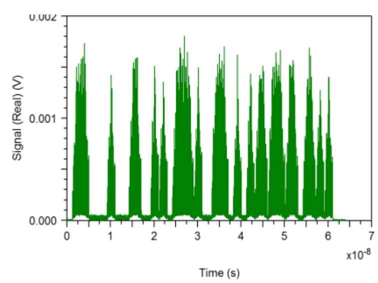

Fig. 14. Signal Diagram for 27 Users.

Results show that the system performance is better when received power is higher. As the received power decreases from -15db to -30db the bit error rate also decreases from $1.06e^{-77}$ to $1.69e^{-34}$ for 8 users. Similarly as the number of users increases from 1 to 25 the bit error rate performance degrades as represented in Figs. 15 and 16.

The 1 Gbps OCDMA system can accommodate 25 users very elegantly with -15db received power for the bit error rate of e-9. But if the received power is limited to -30db this system can accommodate 16 simultaneous users only. So it is recommended to use this system at -22db received power up to 16 numbers of simultaneous users with very good BER of e-14. The quality factor analysis represented in Fig. 16 and 17 depicts that as the number of simultaneous users increases the quality factor decreases. For single user the quality factor ranges from $2.57e^{+01}$ to $2.46e^{+01}$ as the received power decreases from -15db to -30db.

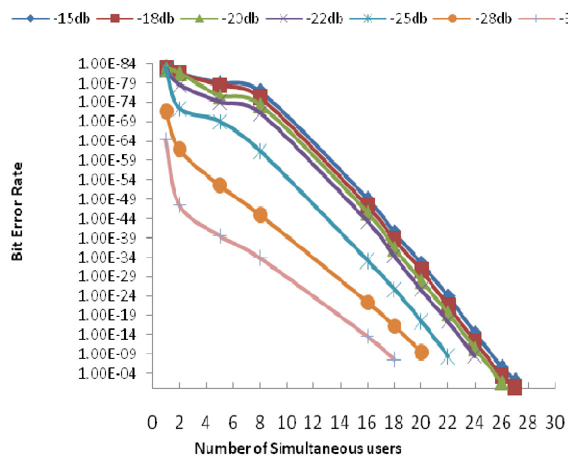

Fig. 15. Bit Error Rate versus Number of Simultaneous Users at Different Received Power for 1 Gbps SCOOC Based OCDMA System.

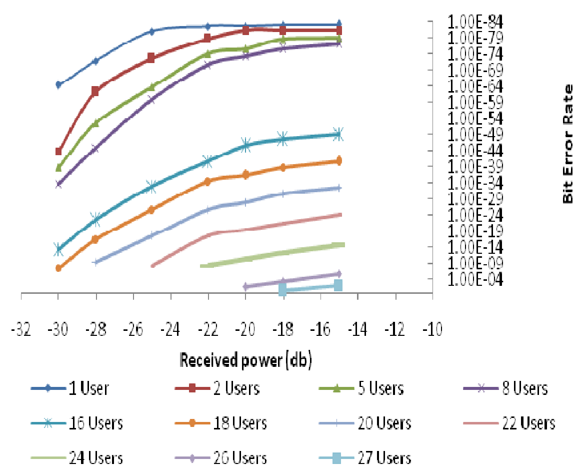

Fig. 16. Bit Error Rate versus Received Power for Different Number of Simultaneous Users for 1 Gbps SCOOC Based OCDMA System.

Therefore, there is not much variation in the quality factor for lesser number of users but as the number of users increases from 1 to 8, the quality factor degrades from $2.56e^{+01}$ to $2.17e^{+01}$ with the received power variation of -15db to -30db. For the same received power of -15db the decrease in the quality is very slight i.e. 25.7 to 25.6 as the number of users increases from 1 to 8 whereas if the number of users increases to sixteen or twenty seven the quality factor degrades at a high pace, i.e., 8.22. It is inferred from the analysis that the quality factor increases with increase in the input power. For single user system the quality factor is very good for the entire range the received power from -15db to -30db. The change in the value of quality factor is very high with change in received power i.e. -15db to -30db for the large number of user i.e. above 16. Sixteen users can be accommodated with very high quality factor of 23 provided the received power is high i.e. -15db.

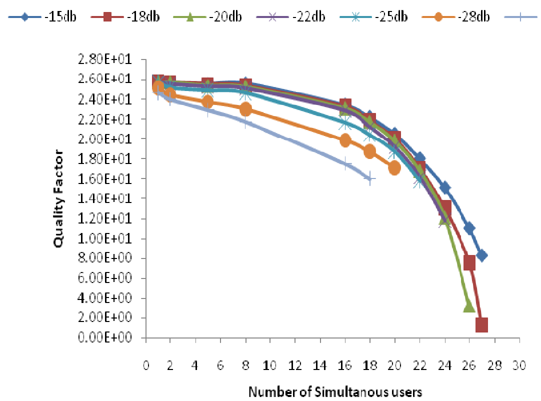

Fig. 17. Quality Factor versus Number of Simultaneous Users at Different Received Power for 1Gbps SCOOC Based OCDMA System.

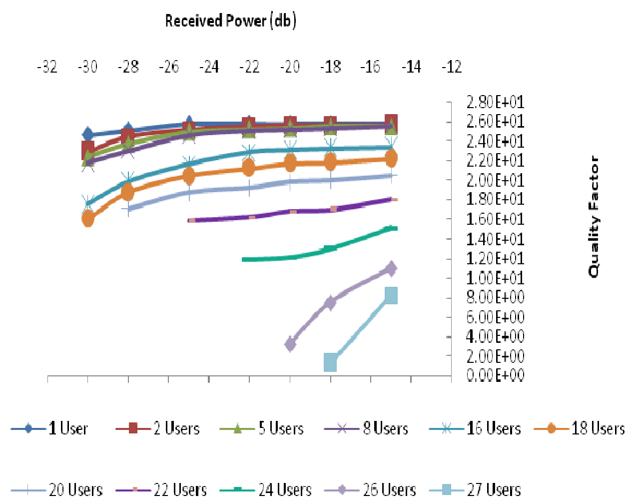

Fig. 18. Quality Factor versus Received Power for Different Number of Simultaneous Users for 1Gbps SCOOC Based OCDMA System.

This research is expected to help in determining the minimum values of transmission power requirement for various numbers of users without compromising the quality below a minimum predefined standard.

5. Conclusion

In this work an OCDMA system is designed by using a new type of code set for use in optical high bit rate transmission systems is developed and its performance is examined. The codes known up to date had the problem of long length which not only consumes more power but also increases the complexity of the encoder. Even two dimensional *W*/*T* matrix codes require more than 7 lasers to form a code family but still the number of supported users is less than 16. In this paper a new type of two dimensional encoder has been proposed which uses just six lasers and six time slots to generate two codewords. Results shows that this present system can accommodate 25, users for permissible BER of 10^{-9}, with -15db received power at 1Gbps bit rate respectively. If received power is kept low i.e.-22db, the SCOOC based OCDMA system can support 16 users with extremely low BER of $1.58e^{-41}$ for 1Gbps bit rate. This current OCDMA system is designed for Metropolitan Area Network (MAN) i.e. (sixty km) applications which can further be extended for long haul transmission by using optical amplifiers to overcome transmission losses and other similar improvements in the system design.

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References

1. Kwong, W.C.; and Yang G.C. (2004). Multiple length multiple wavelength optical orthogonal codes for optical CDMA systems supporting multirate multimedia services. *IEEE Journal of Selected Areas of Communications*, 22(9), 1640-1647.
2. Baby, V.; Glesk, I.; Runser, R.J.; Fisher, R.; Yue-kai, H.; Bres, C.S.; Kwong, W.C.; Curtis, T.H.; and Prucnal, P.R. (2005). Experimental demonstration and scalability analysis of a four node 102 Gchip fast frequency hopping time spreading optical CDMA network. *IEEE Photonics Technology Letters,* 17(1), 253-255.
3. Faucher, J.; Adams, R.; Chen, L.R.; and Plant, D.V. (2005). Multiuser OCDMA system demonstrator with full CDR using novel OCDMA receiver. *IEEE Photonics Technology Letters*, 17(5), 1115-1117.
4. Hernandez, V.J.; Mendez, A.J.; Bennett, C.V.; and Lennon, W.J. (2005). Simple robust receiver structure for gigabit Ethernet O-CDMA using matrix codes. *Journal of Lightwave Technology*, 23(10), 3105-3110.
5. Hernandez, V.J.; Mendez, A.J.; Bennett, C.V.; Gagliardi, R.M.; and Lennon, W.J. (2005). Bit error analysis of 16-user gigabit Ethernet optical CDMA technology demonstrator using wavelength/time codes. *IEEE Photonics Technology Letters*, 17(12), 2784-2786.