BER Analysis of Random Diagonal Code Set for Spectral Encoded Optical CDMA System

Laxman Verma, Gagandeep Singh

Abstract— **The spectral amplitude coding based optical CDMA system has been analysed for the random diagonal codes for incoherent optical communication system. An investigation of detrimental effects on OCDMA is presented, showing the effect of effective power from each user, code weight, data rate on bit error rate and signal to noise ratio of the system. The simulated performance of intensity modulation technique is presented using 80 MHz electrical bandwidth at 1550 nm. The performance evaluation has been done using MATLAB in terms of SNR and BER as a function of different code and system parameters.**

Index Terms— OCDMA, BER, SNR

I. Introduction

From past few decades, we all have observed exponential growth in data traffic. Everyday market is being flooded with electronic gadgets with highly tech savvy applications. Since, all these sophisticated technology's products are available at low price, their affordability to common man has been increased. As a matter of fact, all data hungry applications has increased the requirement of the bandwidth many folds. Therefore, the technical challenge to today's communication network systems is more information carrying capacity. The information carrying capacity of any communication system is proportional to its bandwidth, which in turns is proportional to the frequency of carrier. Fiber optic based communication networks use light as a carrier with the highest frequency among all the practical signals. This is what makes optical fiber the linchpin of today's communication networks as a transmission medium [1].

Optical CDMA has been proposed as a solution i.e. the technology that could meet the higher data rate requirement of internet data traffic. The idea of OCDMA has been derived from wireless CDMA by Salehi in 1980. The technology uses binary orthogonal codes, unique to every single user, to exploit the full potential of optical fiber. Such codes must exhibit two important characteristics namely Auto Correlation property that increases the detectability of signal under noise and Cross correlation Property that helps in minimizing interference between multiple users.

In this paper, random diagonal code's performance has been analyzed in terms of bit error rate for various code and system parameters. The rest of the paper is organized as follows. In Section II, literature review is given. Section III gives mathematical modeling for RD code. System parameters and simulation results are presented in section IV, followed by conclusion in section V.

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II. Literature Review

J. Salehi gave the basic notion that classical code division multiple access (CDMA) principles can be translated to the optical domain, resulting in all-optical derivatives of electronic systems [2]. For the practical realization of such systems, a code family (signature sequences), namely, optical orthogonal codes (OOC's) was proposed by J.A.Salehi in 1989. Subsequently, he calculated the bit error rate and demonstrated FO_CDMA CDMA system as a function various system parameters like code length, code weight, number of users, and receiver threshold etc. [3].

Since, the codes designed by Salehi were of higher value of cross correlation coefficient, they caused severe interference between users. As a result, the bit error rate was considerably higher than maximum acceptable error rate of 10^{-9} of optical communication system. He demonstrated that the performance of the FO-CDMA can be enhanced significantly by applying optical hard-limiter. In 1992, Salehi et.al , proposed another class of optical orthogonal codes as sequences of 0's and 1's with good auto- and cross-correlation properties to reduce interference among users[4]. After that, many researchers have had proposed optical code families based on Greedy Algorithm, Iterative constructions, Algebraic coding theory, Block design etc for Incoherent Optical CDMA. To realize the full potential of optical fiber, in 1993, from 1993 to 2001, many code families have been derived for OCDMA as an improvement in their auto and cross correlation properties. Since, Auto correlation decides ease in the detection of the signal in noise whereas cross correlation decides interference among users. It has been suggested that the auto correlation can be improved by designing codes with maximum number of ones in code sequence and by keeping code length high. The constraint to this was that if one keeps number of 1's high then cross correlation and hence interference among users was increasing. Moreover, due to the non availability of very high speed lasers, keeping code length higher with maximum number of 1's, was completely an impractical solution.

Later, in 2002, Ghafouri- Shiraz proposed a new code family with ideal in phase cross correlation for spectral amplitude-coding optical CDMA systems. This new MQC code(Modified Quadratic Congruence)could exist for a much wider number of integers, and hence, one can choose a code with the desired length more freely but, the limitation to this code was that it could only exist for a prime number seed value [5]. In 2007, Anuar, Alijunid and Abdullah proposed Double Weight code family for the optical spectrum code

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division multiple access (OSCDMA) which has unity cross correlation value. By eliminating the intersection columns of this code, the cross correlation value would be zero instead of one. This new derived code was called Zero Cross-Correlation Code (ZCC), which helped in reducing the Multiple Access Interference (MAI) among users by using electric subtraction using bragg gratings but still optical fiber bandwidth cannot be fully utilized due to the presence of phase induced Intensity Noise.[6].

To reduce PIIN noise, in 2009, H. A. Fadhil et.al has proposed a new method to construct codes using code segment and data segment. One of the important properties of this code is that the cross correlation at data segment is always zero, which means that phase intensity induced noise (PIIN) is reduced. It has many advantages like Simplicity of code construction, flexibility of choosing the number of users and weights. In addition, novel detection scheme has also been proposed. [7]. In this paper, these codes have been studied further and the impact of various code and system parameter has been investigated to exploit the full potential of FO-OCDMA system.

III. PERFORMANCE RESULTS

This section presents an investigation into methods for the spectral efficiency enhancement of optical CDMA communication system for random diagonal code. The performance evaluation has been done for these codes using MATLAB 7 in terms of SNR and BER. Each simulation plot shown in this thesis is produced using MATLAB simulation script. Standard system parameter taken into consideration for these evaluations are enlisted in Table I. Fig. 1 is showing the impact of code weight and numbers of users simultaneously accessing the optical channel. The effective power from each user is 0 dBm (Ideal case). Where, 0dBm is defining that there exist no channel impairment between transmitter and receiver. Optical power launched into the optical fiber at the transmitter side is similar to the optical power received at the receiver side. It can be observed that SNR is high for lesser number of user and decrease with an increase in number of users. Code weight doesn't influence the system performance much as long as the effective power from each user is fixed and less.

Table1. System Parameters

S.No.	Parameter	Value
1	Line width of source(Δv)	3.75 THz
2	Operating Wavelength(λ)	1550 nm
3	PD Quantum Efficiency(η)	0.6
4	Receiver Noise Temperature(Tr)	300K
5	Load resistor (RL)	1030 Ohm
6	Per user data rate (Rb)	Variable
7	Electric Bandwidth(Δf)	80 MHz

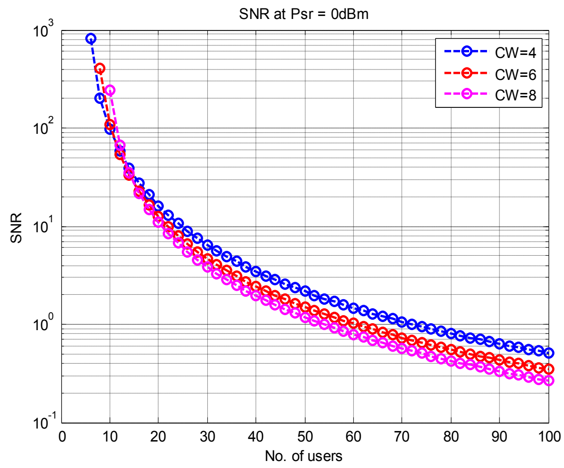

Fig.1: SNR verses user for effective power 0 dBm (Ideal Case), w=4, w=6 & w = 8

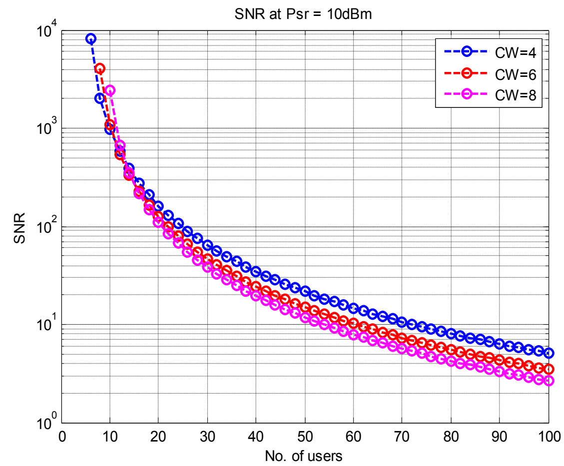

Fig.2: SNR verses user for effective power 10 dBm, w=4, w=6 & w = 8.

Fig. 2 is showing the impact of effective user power on signal to noise ratio of the system when simulated for Psr = 10dBm. Keeping code weight and number of simultaneous users same as in Fig. 1, it is clear the signal to noise ratio of OCDMA system degrades as the user power decreases. Therefore, inference has been drawn here that by keeping number of users and code weight same, signal to noise ratio improves significantly by increasing the effective power from each user.

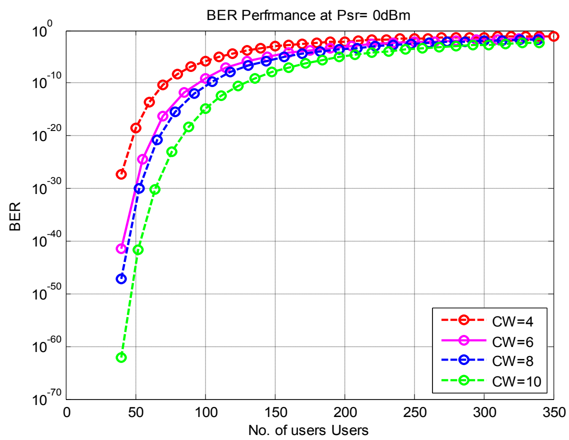

Fig. 3: BER verses user for effective power 0 dBm, w=4, w=6, w = 8 & w=10.

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For Incoherent optical code division multiple access system, bit error rate depends upon several factors like, code weight, code length, effective power from each user, number of users simultaneously accessing the optical channel and data rates from users. For a typical optical CDMA system the maximum acceptable BER is 10^{-9}. Fig. 3 to Fig. 5 is showing the effect of number of simultaneous users accessing the channel and their effective powers on bit error rate. Fig. 3 is showing the bit error rate performance of a system as a function of number of users and code weight and effective user power, when each user is launching its data with an effective power of 0 dBm. Keeping code weights and number of users same (i.e. 100 here) and by varying effective powers from 0dBm to -5dBm and -10dBm , impact on BER is seen in Fig. 4 and Fig. 5 respectively.

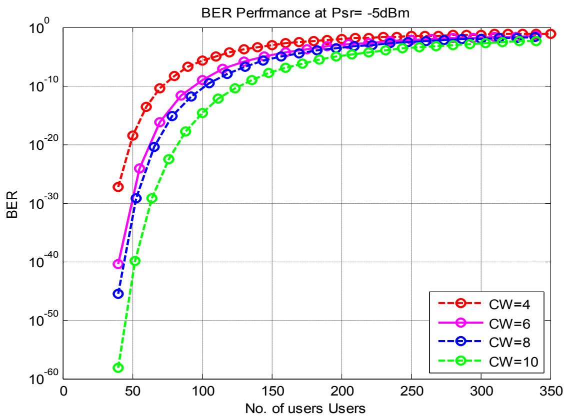

Fig. 4: BER verses user for effective power -5 dBm, w=4, w=6, w = 8 & w=10.

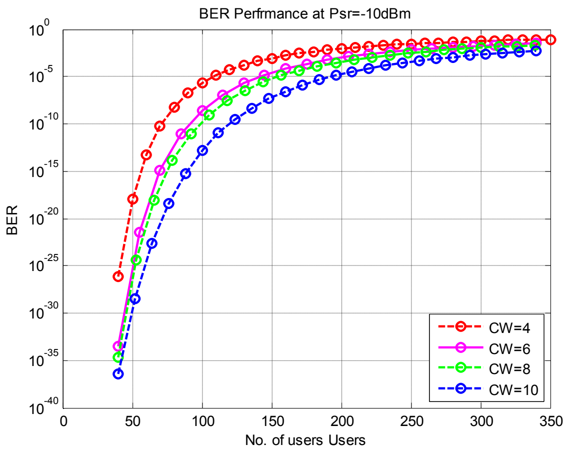

Fig.5: verses user for effective power 10 dBm, w=4, w=6 w = 8 & w=10.

It has been observed that code weight and effective user's power are two main key parameters on which the overall system performance depends. Results have shown that bit error rate is far lesser than 10^{-9} for 100 simultaneous users even if we increase the code weight from 4 to 8. Further, it has been observed that BER increase as the effective power from each users decreases.

Fig.6 and Fig.7 are showing the impact of effective user power on bit error rate at code weight w=4, 6, 8 and 10 for 150 and 250 users respectively. The impact of code weight is observed over a wide range of effective power. It is clear from these graphs that when more number of users is trying to access the optical channel with significant effective power received at receiver the bit error rate is reduced significantly.

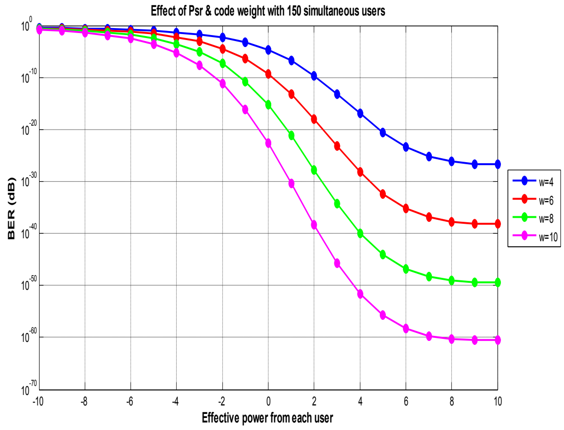

Fig. 6: BER verses Effective power for 150 users, w=4, w=6, w=8 &
w=10

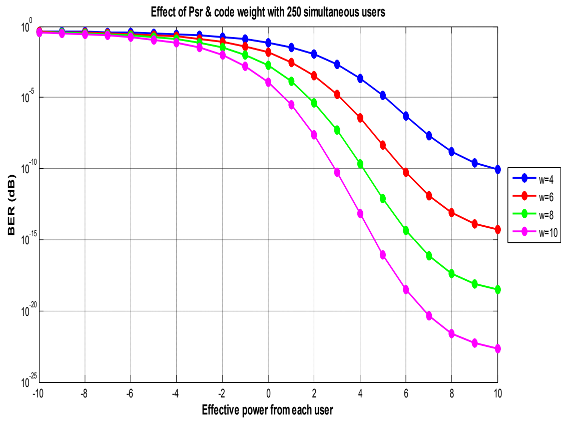

Fig. 7: BER verses Effective power for 250 users, w=4, w=6, w=8 & w=10.

The effective power and code weight are very important factors which contribute to phase induced intensity noise (PIIN). It is very clear from these graphs that when effective power is not that very good increase in code weight doesn't affect the system performance much[8-9]. It is highly wasteful situation to keep transmitter on with high code weight sequences and lesser effective power from each user. Moreover, it has also been observed that more number of users can be supported simultaneously by simply keeping user effective power high for same code weight. For example to support 150 users with BER equals to 10^{-10}, code weight equals to 10, effective user power needed is -2dBm. Whereas, to support 250 simultaneous users for same BER and code weight the effective power for each user should be 2dBm. Depending upon the code weight requirements for particular application and effective power from each other, one can opt for hard limiting if the code weight and effective power from each user is high. Whereas, for low data rate applications, code sequences with lesser code weight and effective power are recommended using soft limiting.
When more number of users is trying to access the optical channel with significant effective power received at receiver the bit error rate increases significantly. Under such situations, hard limiter should be employed, whereas, if lesser power received from each user, soft limiter should be employed to reduce the chances of false alarm. Therefore,

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conclusion can be drawn from above discussion that effective power from each user and the sequence code weight are two very important factors which contribute to phase induced intensity noise (PIIN) the trade off must be set before hand between transmitting and receiving parties for the optical CDMA to work effectively.

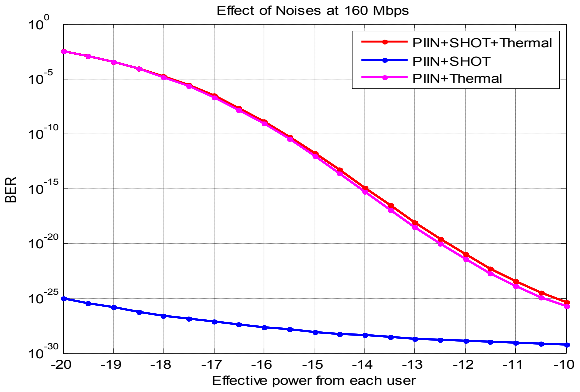

Fig. 8: Effect of Noises, w=4, Psr = -10dBm & Data Rate 160 Mbps

With higher code weight and effective power > -2dB is advantageous as it increases the value of auto correlation peak when transmitter and receiver are properly synchronized and therefore reduction in bit error rate. The next few graphs (Fig.8 to Fig. 9) are showing the noise performance of random diagonal codes. The major noises have been considered in this thesis namely shot noise, Phase Induced intensity Noise (PIIN) and Thermal noise. The dark noise impact is ignored.

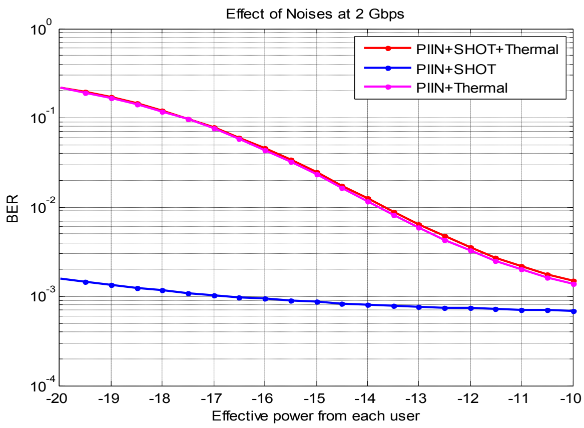

Fig. 9: Effect of Noises, w=4, Psr = -10dBm & Data Rate 2 Gbps

Fig. 8 is showing the impact of noises at data rate 160 Mbps where as Fig. 9 is showing at 2 Gbps. It has been observed that impact of shot noise is far less than thermal noise. As PIIN is common in all the curves drawn above (Refer Fig. 8 and Fig. 9), it can be observed that thermal noise is more prominent over shot noise when effective power of users is less and become comparable to shot noise as effective power increases. Major source of this Laser and its driver circuitry therefore proper cooling arrangements must be made to keep this circuitry cool. Other than noise, impact of data rate can also be observed in these figures. Comparing Fig. 8 with Fig. 9, it is clear that as the data rate increase the scale of BER shift upward. The reason of boost up in scale is PIIN. As the data rate increases, pulse duration becomes smaller and with transmission it becomes difficult to recognize pulses due to PIIN. As a result, BER increases.

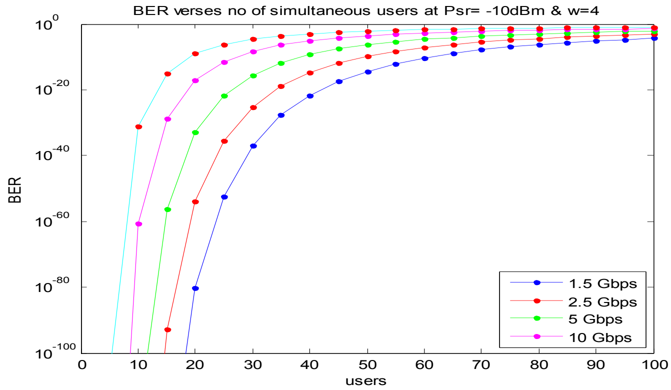

Fig. 10: BER verses user with variable data rates, Psr= -10dBm, w=4.

Fig. 10 and Fig. 11 are showing the impact of variable data rate on BER for code weight is 4, with effective user power is -10 dBm and -5 dBm respectively. It has been observed that if one may try to increase the data rate, to exploit the full potential of single mode optical fiber, of each user cause severe degradation in system performance.

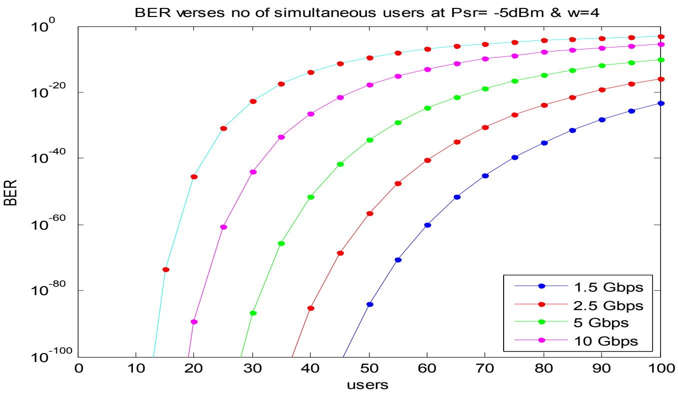

Fig. 11: BER verses user with variable data rates, Psr= -5dBm, w=4

The effect of an effective optical power Psr can also be observed here. As an effective power from each user increases, BER reduces as more power is injected into optical fiber and therefore power received at receiver side increase which further improves signal detection and therefore BER decreases. Depending upon the requirement of particular application, and type of threshold used, BER can be improved further.

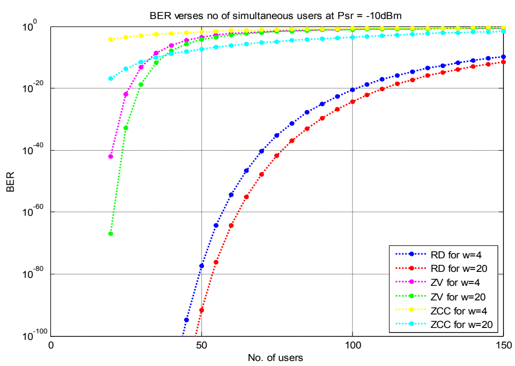

Fig.12: BER comparison of RD, ZV and ZCC codes at Psr=-10dBm, w=4 & 20

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Fig. 12 is showing the comparison of some most popular and recently proposed optical codes i.e. Random Diagonal (RD), Zero Cross Correlation (ZCC) and Zero Vector (ZV), to reduce phase induced intensity noise. Codes comparison has been done for 100 users, each with an effective power of -10dBm for code weights 4 and 20. It has been observed that bit error rate for Random Diagonal code is extremely small (almost zero) in comparison with other two codes. Careful investigation of bit error rate performance has suggested that Random Diagonal codes are the most suitable candidate for the successful implementation of spectral amplitude coded optical CDMA system.

IV. CONCLUSION

In this paper, Random Diagonal code is analysed for various system and code design parameters. Based on the simulation results, it has been concluded that for RD codes, signal to noise ratio is very high for lesser number of user and decrease drastically with an increase in number of users and code weight doesn't influence the system performance much as long as the effective power from each user is less. It can be improved significantly by increasing the effective power from each user. Therefore, the code weight and effective user's power are two main key parameters on which the overall system performance depends. The impact of three different kind of noises namely shot noise, Phase Induced intensity Noise (PIIN) and Thermal noise has also been studied and it has been observed that when effective power from each user is large, both shot noise and thermal noise become comparable and small in comparison with the phase induced intensity noise, which becomes the main limitation factor of the system performance. However, when effective power from each user is low the effect of intensity noise is minimal and thermal noise becomes the main factor that limits the system performance.

The comparison of RD code with other recently proposed code of same category suggested that bit error rate for random diagonal code is extremely small (almost zero) in comparison with other two codes. Careful investigations of bit error rate performance suggest that random diagonal codes are the most suitable candidate for the successful implementation of spectral amplitude coded optical CDMA system.

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