Comparison of Different Detection Techniques Based on Enhanced Double Weight Code in Optical Code Division Multiple Access System

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NAND Subtraction Detection Technique,
Fiber Bragg Grating,
Multiple User Interference,
Signal to Noise Ratio

Abstract

OCDMA is a scheme in which the Radio Frequency Code Division Multiple Access concepts are used for the communication through optical fiber and hence the large bandwidth of optical fiber channel can be exploited along with other advantages of optical fiber communication. OCDMA is a technique which allows many users to access the optical network simultaneously and asynchronously on the same frequency band by allocating the unique code to each user. And hence Optical code-division multiple-access (OCDMA) has been recently proposed as an alternative to frequency and time based multiple, and multiplexing methods for next generation high speed optical fiber networks. With the use of spectral coding the multi user interference (MUI) can be completely removed. Here Enhance Double Weight (EDW) coding is used as a signature address in designing the system because this code can accommodate more number of simultaneous users under considerable standard Bit-Error-Rate (e.g. ≤ 10-9). By using EDW codes for OCDMA system in subtraction techniques multi users interference can be suppressed and bit-error-rate performance is increased with optimum transmit power. EDW (Enhanced Double Weight) code based OCDMA is analyzed here. Four detection techniques, such as direct detection, complimentary detection, AND detection and NAND detection are compared. The simulations are carried out using Optisystem. The analysis has revealed that NAND subtraction detection technique exhibits better results.

1. Introduction

From the last decades OCDMA is gaining much research attention as novel multiplexing technique for multiple access networks taking the advantage of the spread spectrum techniques with its two main types frequency hopping spread spectrum (FHSS) system and direct sequence spread spectrum (DSSS) which used with (OCDMA) systems. CDM allows signals from a series of independent sources to be transmitted at the same time over the same frequency band. In CDMA systems, the narrowband message signal is multiplied by a very large bandwidth signal called spreading signal (spreading signal) to spread each signal over a large, common frequency band. Each user has its own pseudo-random codeword which is approximately orthogonal to others. The receiver performs a time correlation operation to detect only the desired codeword. All other codeword appear to be noise. OCDMA is a scheme in which CDMA concepts is used for the communication through optical communication. OCDMA can increase the transmission capacity of an optical fiber [1] and support both wide and narrow bandwidth applications on the same network [2]. OCDMA is required to meet the demand for high-speed, scalability, flexibility, convenient network management, large-capacity communications in optical networks, large number of asynchronous users with low latency and robust signal security.

Detection plays an important role to design the system transmitter and receivers. In general there are two well known basic techniques, namely coherent and incoherent [5]. When coherent detection send detection signal the phase information knowledge is important while in incoherent detection it is not required. Complexity of hardware is less in incoherent detection compared to coherent detection. With the coding operation, coherent is performed in bipolar behavior and the incoherent OCDMA is performed in a unipolar approach. The application of the coherent technique will be more difficult than incoherent technique. Therefore, we have chosen the incoherent detection technique for this research. However, the cross correlation function is always generated in the incoherent code words which give rise to the multiple access interference (MAI) in the system. So to reduce MAI suitable detection technique can be used in OCDMA systems. Many kinds of detection techniques are available and already proposed by many researchers [3, 6, 7 and 8]. The well known detection techniques are the complimentary subtraction technique [6 and 7], the AND subtraction technique [7], the spectral direct detection technique (SDD) [8] and the NAND subtraction technique [4].So here we will observe the comparison among these subtraction detection technique in reducing MAI.

The remainder of this paper is organized as follows. In Sec II, we review EDW code construction. We discuss about detection technique and the system architecture in Sec III. Network simulation setup is shown in Sec IV. Graphical analysis are shown in sec V. Results and discussions are

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shown in Sec VI, and finally some conclusions are drawn in Sec VII.

2. EDW Code Construction

Enhanced double weight (EDW) code is derived from modifying double weight (DW) code. Enhanced double weight (EDW) code possesses ideal cross-correlation properties and weight can be any odd number which is greater than one. The code weight has a direct effect on the performance of an OCDMA system, as increased weight results in better SNR. This is because by increasing the code weight the signal power of the user increases, hence signal-to-noise ratio increases.

It has been observed that theoretical analysis and simulation for EDW code gives much better performance compared to Hadamard and Modified Frequency Hopping (MFH) codes. It is found that EDW codes can support both 2.5 Gbps, and 10 Gbps transmission rates simultaneously with a better performance compare to other codes. While for theoretical effect, EDW code has much lower BER than the one uses Hadamard and MFH codes. EDW codes can also be represented by using the K x N matrix. The basic matrix for EDW can be developed by using the following steps:-

A. Step 1:

The basic matrix for EDW code consists of a K x N matrix which depends on the value of code weight. Figure 1 shows the general form for the basic matrix of EDW code with weight, W, where the component matrices [A1], [A2]… and [Aw] all depend on W. The basic matrix consists of a minimum number of K and N for specific number of code weight. From the basic matrix, larger number of K can be achieved by using mapping technique.

$$\left[A_1 \;\vdots\; A_2 \;\vdots\; \dots A_w \right]$$

Fig: 1. General form of the EDW code matrix

The size of each matrix consists of Ka x Na where:

Ka =W (1)

and

Na =$(\sum_{j=1}^{W} j)$/W (2)

Each matrix has combination sequence of 2, 2… 1 for the columns. The combination sequence depends on W and number times of 2 which are given by:

Times of 2 = (W-1)/2 (3)

(I.e. if W=5, so the combination sequence is 2, 2, 1)

B. Step 2:

There are two basic components in the basic matrix of EDW codes, which are:-

Basic code length,

NB = $\sum_{j=1}^{W} j$ (4)

And Basic number of user,

KB = W (5)

Where, Basic code length NB represents the basic code's column size

Basic number of user KB is the basic code's row size.

The EDW matrix is thus can be simply represented in the form of a KB x NB matrix.

Here, the EDW with the weight of 3 is used as an example. For W = 3, from Equation (4), the basic number of user or the column size is:

NB = $\sum_{j=1}^{W} j$; j=6 (6)

And from Equation (6), the basic row size is:

KB = W =3 (7)

Therefore, the basic matrix for EDW 3 consists of a 3 x 6 matrix. The component matrices are [A1], [A2], and [A3]. The size of matrix [A] will be 3 x 2 after using equation 1 and 2. The combination sequence for each matrix is 2, 1. The basic EDW code denoted by (6, 3, 1) is shown below in Fig 2

W=3	A		B		D		
Users	C1	C2	C3	C4	C5	C6	
1	1	0	1	1	0	0	3
2	1	1	0	0	1	0	3
3	0	0	1	0	1	1	3
	2	1	2	1	2	1	

Fig 2: Basic EDW Code Matrix

3. Detection Techniques

3.1. Spectral Direct Detection

Here in this technique as signal is directly detected from a clean non-overlapped chip, only one pair of decoder and detector is required in its implementation whereas in complementary subtraction technique two pairs are required. Moreover no subtraction process is needed in SDD. In this technique only those component of the optical spectrum are retained which are desired. Other undesirable components are removed by filtering. This is achievable for the simple reason that, the information is assumed to be adequately recoverable from any of the chips that do not overlap with any other chips from other code sequences. Thus the decoder will only need to filter through the clean chips (non-overlapping chips) to be directly detected by the photodiode. Since the same frequency component being directly detected at the receiver side and its circuitry is very simple and less costly. This technique has successfully eliminated the MAI because only the wanted signal spectral chips in the optical domain will be filtered. It is possible because, the code properties posses one clean signal chip for

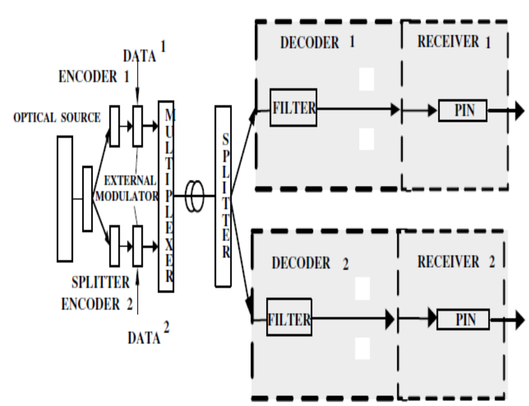

Fig: 3. OCDMA System Architecture Using Spectral Direct Detection Technique for Two Users.

each of the channels. Subsequently, the phase-induced intensity noise (PIIN) is suppressed at the receiver, thus the system performance is improved. Figure 3 shows the implementation of spectral detection technique. Codes which posses non-overlapping spectra such as MDW [9], and EDW [10] can generally be supported by this detection scheme.

3.2. Complementary Subtraction Detection Technique

Complementary subtraction detection scheme is also called as balanced detection scheme. At receiver, the received signal is divided into two complementary branches of spectral chips as shown in Figure 4. These two branches of spectral signals are sent to a balanced detector that computes the correlation difference. In complementary subtraction technique, first proposed by M. Kavehrad, the cross-correlation is defined as:-

$\theta_{xy}\ (k) = \sum_{i=0}^{N-1} x_i y_{i+k}$

Where X and Y are the two OCDMA code sequences. The complementary of sequence (X) is given by ($\bar{X}$) whose elements are obtained from (X) by $\bar{X}$ = 1− xi. Let X = 1100 and Y = 0110 and therefore $\bar{X}$ = 0011. The periodic cross correlation sequence between ($\bar{X}$) and (Y) is similar to above Equation and is expressed as:

$\theta_{\bar{x}y}\ (k) = \sum_{i=0}^{N-1} \bar{x}_i y_{i+k}$

We look for sequences for which

$\theta_{xy}\ (k) = \theta_{\bar{x}y}\ (k)$

At the receiver, the photodetectors will detect the two complementary input which will be fed to the subtractor whose cross-correlation output, Z can be expressed as:

$Z_{Complementary} = \theta_{xy}(k) - \theta_{\overline{xy}}(k) = 0$

By the end the answer is 0, which means that, at the output of the subtractor, there will be no more cross-correlation terms indicating that there is no more signal from other users in the intended channel.

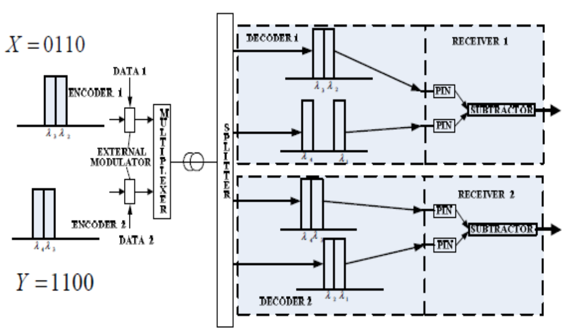

Fig: 4. Implementation of the Complementary Subtraction Technique.

3.3. AND Subtraction Detection Technique

In figure 5, at the receiver side of the system, the incoming signal splits into two parts, one to the decoder that has an identical filter structure with the encoder and the other to the decoder that has the AND filter structures. A subtractor is then used to subtract the overlapping data from the intended code. In AND subtraction technique, the cross-correlation $\theta_{\overline{xy}}(k)$ is substituted by $\theta_{(x\&y)y}$ where $\theta_{(x\&y)}$ represents the AND operation between sequences X and Y. For example, let X =0011 and Y = 0110 and therefore (X AND Y) = 0010. Example of an AND receiver is shown in Figure 2.

At the receiver,

$$Z_{AND} = \theta_{xy}\ (k) - \theta_{(x\&y)y}(k) = 0$$

Above equation shows that, with AND subtraction technique, the multiple access interference or the interference from other channels can also be cancelled out. This subtraction technique can be implemented with any OCDMA codes, but for comparison purposes, the Double Weight (DW) code is used as an example.

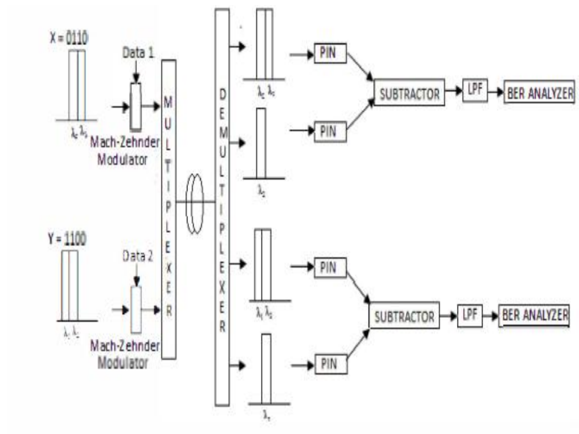

Fig: 5. Implementation of AND subtraction

3.4. NAND Detection Subtraction Technique

NAND gate is having advantage over AND/NOR gate that mobility of the digital electrons in NAND gate is three times higher than AND/NOR gates [11]. This statement refers to the digital logic gates (AND, OR, NAND). However, in our proposed system the idea of NAND is used as an operation, not as a digital gate. In the NAND subtraction detection technique, the cross-correlation $\theta_{\bar{x}y}$(K) is substituted by $\theta_{\widetilde{xy}}$, where $\theta_{\widetilde{xy}}$ represents the NAND operation between X and Y sequences. For example, let X=1100 and Y=0110 and therefore the NAND is ($\widetilde{XY}$) =1011 .Table 1 shows the comparisons between complementary, AND and NAND subtraction detection technique using EDW codes.

Note that λ_i (where i is 1, 2…..) is the column number of the codes which also represents the spectral position of the chips. Therefore, MAI can be cancelled using these

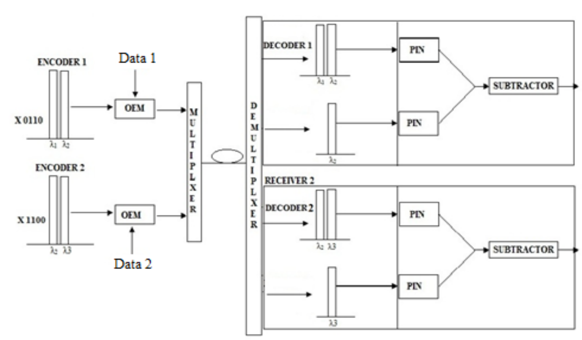

Fig: 6. Implementation of NAND Subtraction Technique

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techniques. However, NAND subtraction detection technique can generate extra weight as shown in Table I. This is due to the fact that when the code weight is increased, the signal power also increases hence, signal-to-noise ratio increases. Therefore, the OCDMA performance is improved significantly using the NAND subtraction detection technique compared to other techniques. Figure.6. shows the implementation of NAND subtraction technique.

TABLE I. COMPARISON OF COMPLEMENTARY AND NAND SUBTRACTION DETECTION TECHNIQUE

	Complementary Subtraction				NAND Subtraction				AND Subtraction			
	λ_1	λ_2	λ_3	λ_4	λ_1	λ_2	λ_3	λ_4	λ_1	λ_2	λ_3	λ_4
X	1	1	0	0	1	1	0	0	0	0	1	1
Y	0	1	1	0	0	1	1	0	0	1	1	0
	$\theta_{XY} = 1$				$\theta_{XY} = 1$				$\theta_{XY} = 1$			
	$\theta_{X\overline{Y}} = 0011$				$\theta_{\tilde{X}\tilde{Y}} = 1011$				$X\&Y = 0010$			
	$\theta_{\overline{XY}} = 1$				$\theta_{(\tilde{X}\tilde{Y})Y} = 1$				$\theta_{(X\&Y)} = 1$			
Z	$Z = \theta_{XY} - \theta_{X\overline{Y}} = 0$				$Z_{NAND} = \theta_{XY} - \theta_{(\tilde{X}\tilde{Y})Y} = 0$				$Z_{AND} = \theta_{XY} - \theta_{(X\&Y)Y} = 0$			

4. Simulation Setup of Detection Techniques

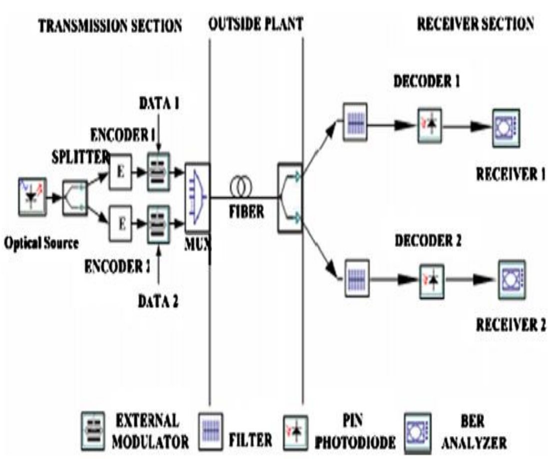

Fig: 7. Simulation Setup for the OCDMA System with Direct Technique

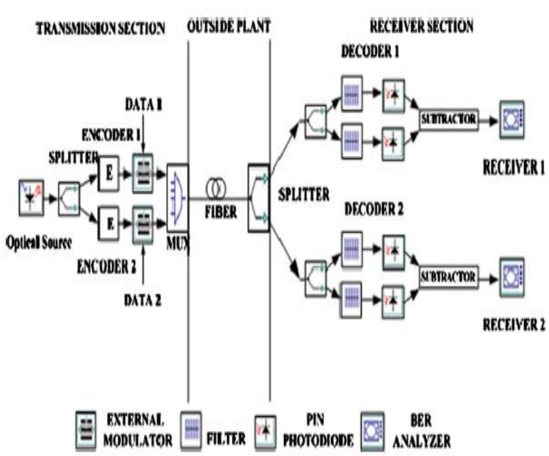

Fig: 8. Simulation Setup for the OCDMA System with Complementary Technique

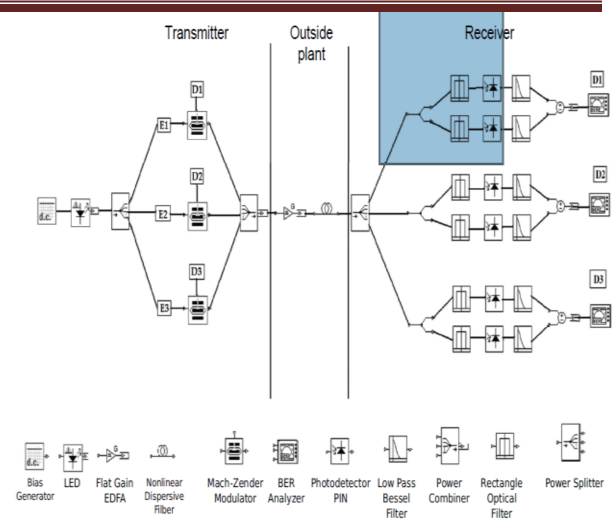

Fig: 9. Simulation Setup for the OCDMA System with AND Detection Technique.

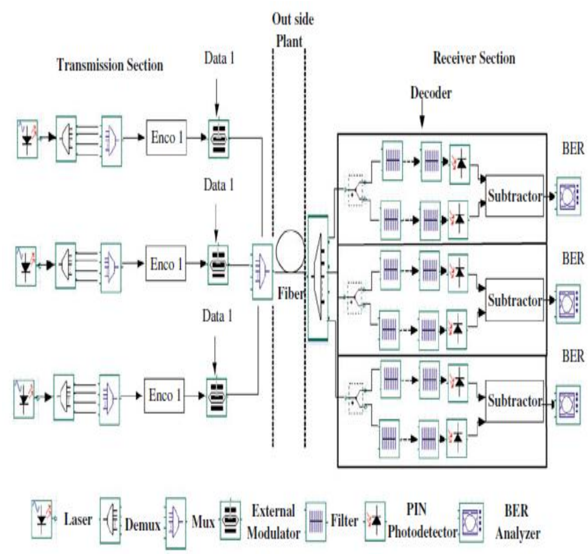

Fig: 10. Simulation Setup for the OCDMA System with NAND Subtraction Detection Technique

5. Graphical Analysis

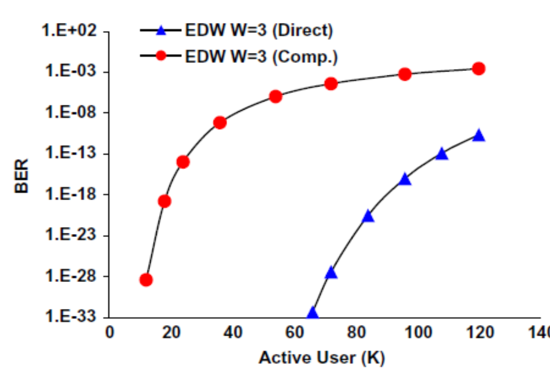

Fig: 11. BER Versus Number of Simultaneous User When psr = -10 dBm for Direct and Complementary Techniques

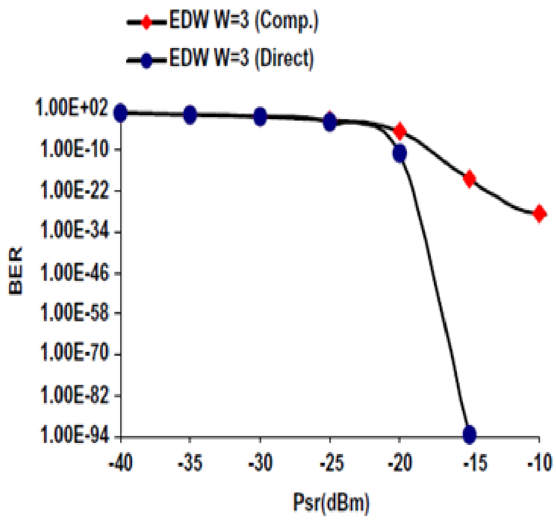

Fig: 12. BER versus Psr When Number of Simultaneous Users is 12 for Complementary and Direct Techniques

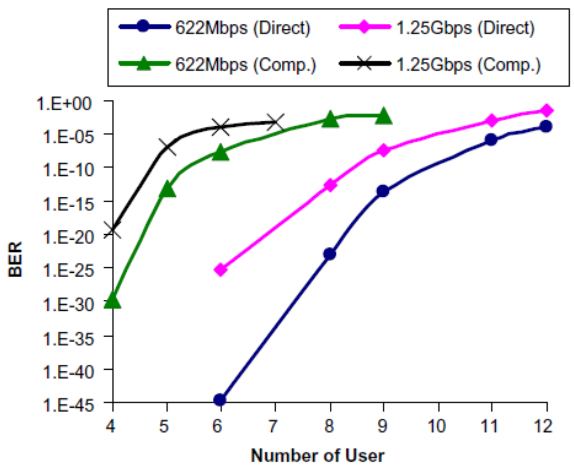

Fig: 13. BER versus Number of user for OCDMA System using Direct and Complementary Technique at Different Transmission Rates at 10 km

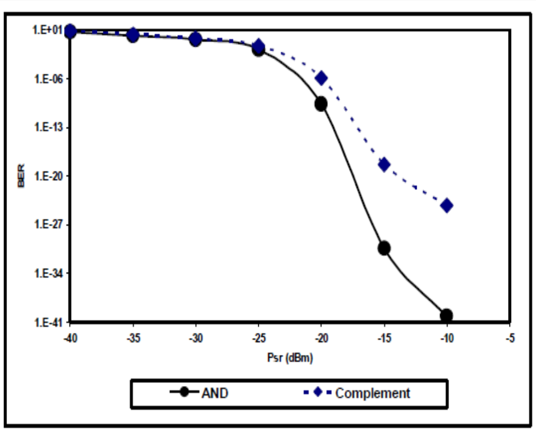

Fig: 14. BER versus Psr When Number of Simultaneous Users is 15 for AND and Complementary Techniques

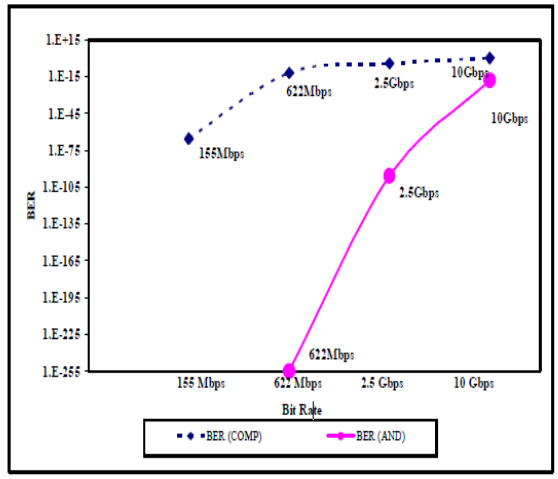

Fig: 15. BER versus Bit Rate for AND and Complementary Subtraction Technique.

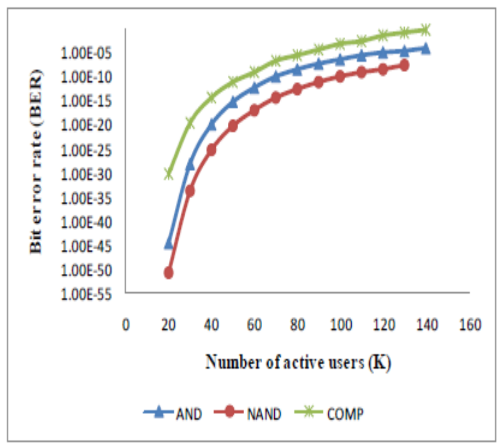

Fig: 16. BER versus Number of Simultaneous User When psr = 10dbm for NAND, AND and Complementary Techniques

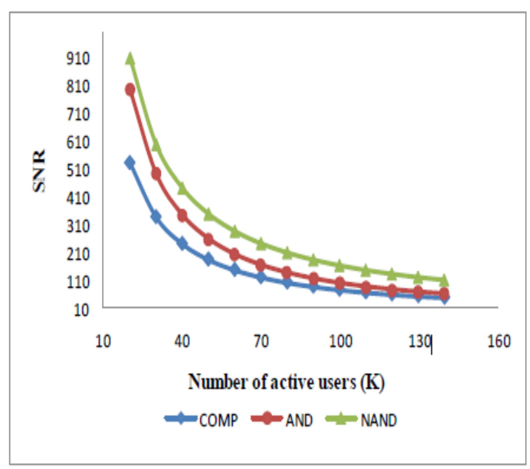

Fig: 17. SNR versus Number of Simultaneous User When psr = -10dbm for NAND, AND and Complementary Techniques

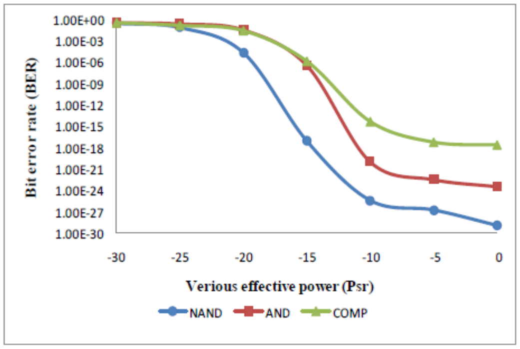

Fig: 18. BER versus Psr when number of simultaneous users is 40 for NAND, AND and complementary techniques

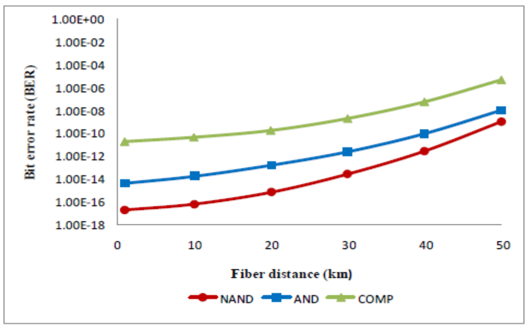

Fig: 19. BER Against Distance of OCDMA System Using NAND Subtraction at Transmission Rates at 50 km for NAND, AND and Complementary Techniques

6. Simulation Results

A simple schematic block diagram consisting of 2 users is illustrated in Figs. 7 and 8 as an illustrative example (the study was carried out from 4 to 12 users). Each chip has a spectral width of 0.8 nm. Fig. 11 shows the bit error rate (BER) versus number of users for SDD and complementary subtraction techniques. Fig. 12 shows the performance of the system using SDD and Complementary techniques at various values of received power Psr. The number of active users in the system is fixed at 12.The tests were carried out using OptiSystem version 9.0 from Optiwave, established commercial software at the rates of 622 Mbps and 1.25 Gbps for 10 km. The fiber used had the values of parameters taken from the data which are based on the G.652 Non Dispersion Shifted Fiber (NDSF) standard. This included the attenuation, group delay, group velocity dispersion, dispersion slope and effective index of refraction, which were all wavelength dependent. The non-linear effects such as the Four Wave Mixing and Self Phase Modulation (SPM) were also activated. At 1550 nm wavelength, the attenuation co-efficient was 0.25 dB/km, and the chromatic dispersion co-efficient was 18 ps/nm-km and the polarization mode dispersion (PMD) co-efficient was 5 ps/pkm. The transmit power used was 0 dBm out of the broadband source. The noises generated at the receivers were set to be random and totally uncorrelated. The dark current value was 5 nA for each of the photodetectors. The performance of the system was evaluated by referring to the bit error rate. Fig. 13 shows the BER increases as the number of user becomes bigger for the different techniques. The number of users is varied from 4 to 12 at 622 Mbps and 1.25 Gbps bit rates. The effect of varying the number of user is related to the power level of the received power. A larger number of users have higher insertion loss, thus smaller output power. In this particular system, direct technique can support higher number users than the conventional technique because of the number of filters at the receiver is reduced, thus a smaller power loss. Note that the very low BER values are just a measure of the quality of the received signals as calculated by the simulator, although they may not be very meaningful, practically speaking.

Fig. 9.shows the Simulation setup for the OCDMA system with AND detection technique and Fig. 16 shows the BER versus number of simultaneous user for NAND-subtraction, AND-subtraction and Complementary technique. It is seen from Fig. 16 that the NAND subtraction detection technique in SAC-OCDMA system using EDW codes suppressed MAI completely and the received power (detected 1'st user) is higher than Complementary and AND-subtraction technique. It also shows very clearly that the NAND subtraction technique supports more number of users (users 140 at 10-28) compared to Complimentary and AND subtraction technique. The reason of the better performance of NAND subtraction detection is that the MAI is completely suppressed in the receiver side. Fig. 17 shows the signal to noise ratio (SNR) against the number of simultaneous user. It is seen that the EDW codes give a much higher SNR value using NAND subtraction technique compared to Complimentary and AND detection techniques when the effective power is high (when Psr<-25dbm). Fig. 18 shows the performance of the system using AND, NAND and Complementary subtraction technique at various values of received power. The numbers of active users in the system are fixed at 40. The performance of the system using NAND subtraction technique is better than other two techniques. Although the BER is go down but the value is very negligible.

In order to study the performance comparison between AND and Complementary subtraction techniques, the mathematical and simulation results are used. The performance is characterized by BER, looking at the effects of the received power. Figure 14 shows the performance of the system using AND and Complementary techniques at various values of received power Psr. The number of active users in the system under study fixed at 15. It has been shown that AND subtraction technique gives much better performance when the effective received power Psr is large (when Psr > -25 dBm). At the lower values of Psr (when Psr < -25 dBm), the performance of the system for both techniques is nearly the same. In this analysis, we do not consider any fiber optic nonlinear effect such as Four Wave Mixing (FWM), Cross Phase Modulation (XPM) and also dispersions such as Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD). This however will not affect the comparative analysis between the two techniques as both of them are subjected to the same transmission conditions. In the simulation, the transmission bit rate varied from 155 Mbps to 10 Gbps. A fiber length fixed at 30 km and the transmitted power set at 0 dBm. Increasing the bit rate will decrease the pulse width, making the signal to be more sensitive to fiber dispersion and receiver circuitry noise. Figure 15 shows that the AND subtraction system gives better performance compared with Complementary subtraction system. It is clear that AND subtraction system can support higher bit rate than complementary systems due to the higher SNR and less power loss.

Fig.10 shows the Simulation setup for the OCDMA system with NAND subtraction detection technique. The system is designed and simulated at 622 Mb/s bit rates. Each chip has a spectral width of 0.8-nm. The insertion loss of multiplexer/demultiplexer is taken in the account of 0.25 dBm and 2 dBm respectively. The ITU-T G.652 standard single-mode optical fiber (SMF) is used for transmitting signal. The used fiber parameters values are taken from the data which are based on the G.652 Non Dispersion Shifted Fiber (NDSF) standard. This include all fiber parameter such as group delay, group velocity, attenuation α (i.e., 0.25 dB/km), polarization mode dispersion (PMD, i.e.,18 ps/nm km), non linear effects such as four wave mixing (FWM) and self phase modulation (SPM), which were all wavelength dependent. All these parameters were activated during simulation. The dark current values were 5 nA for each of the photo detectors. The generated noises at the receivers were set to be random and totally uncorrelated. The system performance is carried out by referring to the bit error rate. The whole simulation is specified according to the typical industrial values to simulate the real environment as close as possible. The data are plotted in Fig. 19 where the simulated fiber distance is taken account for maximum 50 km. It is shown that as the distance are increasing the BER decreases. The simulation results are compared same like analytical method where the NAND is compared between AND and complementary technique. Significantly, the NAND technique always transmits the better signal because the MAI is fully suppressed with extra one filter in the decoder side. The error-free transmission ($BER<10^{-9}$) is always maintain until 50 km for NAND technique. Significantly, the complementary technique cannot maintain standard error free transmission at 50 km distance. Though AND can maintain the value but lower than NAND. It can point out that the very low BER values are just measure the quality of the signals.

7. Conclusion

In this paper, a detection technique known as Spectral Direct Detection (SDD) has been proposed for SAC-OCDMA systems. The performance was evaluated based on EDW code. The theoretical and simulation results have proved that the Spectral direct detection technique provides a better performance than the conventional complementary subtraction technique. This is achieved by virtue of the elimination of MAI and PIIN by selecting only the non-overlapped spectra of the intended code sequence. The overall system cost and complexity of the system can be reduced because of the less number of filters used in the detection process.

Thereafter it has been proved that with AND subtraction detection technique, the performance of the OCDMA system can be improved significantly compared to complementary subtraction technique. The overall system cost and complexity of the system can be reduced by reducing the number of filters in AND subtraction. The performance of the OCDMA system improved significantly because of the less number of filters in the decoder, the total power loss can be reduced, and this can be seen clearly in the simulation result.

And finally, we have successfully developed a novel OCDMA detection technique referred to as the NAND subtraction technique to improve the system performance. The performance of the system was carried out by using Enhanced Double Weight (EDW) code. The Bit-Error-Rate (BER) performance of OCDMA system using NAND subtraction technique has been evaluated extensively. The evaluation results for the NAND subtraction technique were compared with AND and Complementary subtraction technique. Based on the comparison, we found that the NAND subtraction technique can support some extra active users and offer better performance as compared to other two conventional detection techniques.

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