Performance Analysis of SAC OCDMA Systems based on New Coding Scheme

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Abstract---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. This is because OCDMA allows many users to access the same optical fiber channel asynchronously through the assignment of unique code words sequences. Furthermore, OCDMA offers strong security in the physical layer. Due to these reasons, OCDMA has been recognized as one of the most important technologies for supporting many users in shared media at the same time. In conventional multiple access techniques such as time division multiple access (TDMA) and wavelength division multiple access (WDMA), the maximum transmission capacity is determined by the total number of the slots while for optical CDMA the transmission capacity depends on the number of active users. Spectral amplitude coding optical code division multiple access (SAC-OCDMA) systems attract more attentions since the multi user interference (MUI) can be completely eliminated by spectral coding existing in conventional systems. MUI can be reduced by using subtraction technique. 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 version12. The analysis has revealed that NAND subtraction detection technique exhibits better results.

Keywords: Spectral Amplitude Coding Optical Code Division Multiple Access (SAC-OCDMA), Enhanced Double Weight (EDW) code, Direct detection, Complimentary Subtraction Detection Technique, AND subtraction detection technique, NAND subtraction detection technique, Fiber Bragg Grating (FBG), Multiple user Interference (MUI).

I. INTRODUCTION

Consumer bandwidth demands are growing at an enormously high rate, and are projected to grow for years to come. This growth rate applies not only to the entire Internet, but to a large range of individual institutions. 59% to 64% of the downstream traffic is web media-related which is mainly because of photo and video communication and real-time streaming. Peer- to-peer (P2P) traffic covers over one fifth of downstream and over 60% of upstream traffic. Services alternative to P2P like file hosting and remote storage are gaining more interest. Also the growing interest in voice, video and data delivery on the same infrastructure (triple-play) has changed the common way of network usage; a necessity of running many applications on several devices connected simultaneously to a single access point has arisen. Thus the bandwidth hunger is increasing day by day. These forces the efforts towards developing new generation networks that can offer enough bandwidth to satisfy the increasing needs of the users. This bandwidth-hungry scenario created by both content providers and consumers stimulates the development of novel components and network architectures which should not only be capable of transmitting data at high bit-rates but should also be cost efficient

Frequency Division Multiple Access (FDMA) is the most widespread technique in current communications systems. In FDMA, the available frequency band is sub-divided into disjoint intervals, each of which is dedicated to a particular user, even when it is not active. The number of users sharing the channel is equal to the number of frequency intervals. As an alternative to the frequency domain partitioning strategy, there is TDMA: Time Division Multiple Access. In TDMA, the time is divided into equal and successive periods, each of which is divided into an integer number of time-intervals. Each interval is allocated to a user to transmit its frame of bits. Once its dedicated time-interval has run out, a user should wait during the other time-intervals intended for other users. It resumes transmission when its interval in the following period starts. The allocation of time intervals is made in a permanent way to the users, although the user will not always need the time allocated. The number of users sharing the channel is equal to the number of time-intervals in a period. In fiber optic transmission, the bit rate per wavelength channel is also rapidly growing.

The allocation of frequency bands in FDMA, or time-intervals in TDMA, is made in a deterministic (or static) way, *i.e.*, the resource is allocated to users whether they are active or not. This effectively leads to undesirable situations, where certain intervals of frequency (resp. intervals of time) in FDMA (resp. TDMA) are not exploited whereas others are overloaded. This is always the case in typical access networks, where traffic is naturally bursty. This problem has historically led the researchers to think about dynamic allocation of the resource, *i.e.*, the channel is given to the sub-set of users at the convenient time for them. The first proposals required a centralized administration of the resource. This solution improved channel throughput at the price of additional complexity in the communications system. Indeed, this requires a complex supervisory system to arrange the user's requests, manage the queues lengths, and control the priority.

A multiple access protocol that can dynamically allocate resource without complex control overhead is extremely interesting. This explains the success of CDMA. In CDMA, each user is identified by a different code, which represents, at the same time, its address. The CDMA user inserts its code (or address) in each data bit before transmission. Only the intended receivers, having the code used in transmission, are able to decode the message. Users other than the desired code are unable to pick up the data. CDMA makes it possible for simultaneous active users to take advantage of all the available time and frequency resources, thus enormously improving the quality of their data transmission. CDMA users can embark or exit without supervision. When an additional user embarks, it slightly degrades the performance of all active users. Due to these significant properties, CDMA had much success in wireless and satellite communications. Moreover, CDMA is now classified among the most promising technologies for the next generation of fiber optic LANs (Local Area Networks) [3], [4].

Although in the Code Division Multiple Access (CDMA) system soft capacity is obtained, the system faces interference in case of two users simultaneously access the communication channel which, in turn, degrades the performance of the CDMA system. Consequently, the main shortcoming of the CDMA system is multiple users' access of the communication channel. For this reason, scientists and researchers are looking at systems that enable transmission without interference when considering multiple users. That's why scientists turned their attention on the Optical CDMA, a system that tries to improve the shortcoming of the classic CDMA system**.**

Nevertheless, there are several differences between the electrical and the optical CDMA. The optical CDMA is very important and becoming increasingly popular due to its high available bandwidth and elimination of cross talks. In the OCDMA system, multiple users can access the same channel with help of various coding techniques. These codes help maintaining low correlation between users and also help maintain low interference for each user. Even though there exist some limiting factors in OCDMA like MAI, PIIN etc. To eliminate the influence of MAI by using codes with fixed in phase cross-correlation SAC– OCDMA was proposed. This project mainly deals with these techniques.

II. EDW CODE CONSTRUCTION [1]

The EDW code is used as SAC code of each user group in the proposed scheme. EDW code is the enhanced version of Modified Double Weight (MDW) code. The MDW code weight can be any even number that is greater than two while the enhanced double weight EDW code weight can be any odd number greater than one. EDW code can be represented by using a K x N matrix. In EDW codes structures, the matrix K rows and N columns represent the number of users and the minimum code length respectively. The basic EDW code denoted by (6, 3, 1) is shown below [1], [9].

$$H_1 = \begin{bmatrix} 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \end{bmatrix}$$

From the basic matrix, a larger value of K can be achieved by using a mapping technique as shown below.

$$H_2 = \begin{bmatrix} 0 & H1 \\ H1 & 0 \end{bmatrix}$$

EDW codes have the subsequent properties like ideal maximum cross-correlation λ_{max} =1, code weight can be any odd number greater than one, the weight pair structure maintained, the chip combination is Maintained 1, 2, 1 for every consecutive pairs of codes.

III. DETECTION TECHNIQUES

In optical CDMA systems, the detection process affects the design of receiver and transmitter. Basically, there are two types of detection technique; coherent and incoherent. The coherent detection technique refers to detection signal with knowledge of phase information of the carrier, while incoherent detection technique is reversely from coherent detection technique. By referring to incoherent detection technique, this technique does not need phase synchronization. Therefore, it will reduce the hardware's complexity of the systems. Due to this advantage, it is better to choose incoherent detection technique rather than coherent detection technique. Some of the detection techniques used in OCDMA are discussed below [6],[10],[11],[12],[13].

A. Direct detection technique

In this technique only those component of the optical spectrum are retained which are desired. Other undesirable components are removed by filtering. In direct detection technique MAI does not exists. But, this technique is applicable only to those codes, in which the spectral chips are not overlapped with other spectral chips of the other channel, i.e. a minimum of one clean chip in every code sequence. Since the same frequency component being directly detected at the receiver side and its circuitry is very simple and less costly.

B. Complementary Subtraction Technique

Complementary detection technique is also known as balance detection technique. In complementary subtraction technique, the cross-correlation is defined as

$$\theta_{XY}(k) = \sum_{i=0}^{N-1} x\ i\ y\ i + k \qquad (2.1)$$

Where X and Y are two OCDMA code sequences, the complement of sequence (X) is given by ($\bar{X}$) whose Elements are obtained from (X) by $\bar{X}$ = 1-X. Let X = 1100 and Y = 0011 and therefore $\bar{X}$ = 0011. The periodic cross correlation sequence between ($\bar{X}$) and (Y) is similar to Equation (1) and is expressed as

$$\theta\bar{X}\ Y\ (k) = \sum_{i=0}^{N-1} \bar{x}\,i\ \ y\,i + k \qquad (2.2)$$

We want the sequence to be $\theta\ XY\ (\ k\ ) = \theta\bar{X}\ Y\ (k)$ Now at the receiver, the photodetectors will detect the two complementary inputs which will be fed to the subtractor whose cross-correlation output, Z can be expressed as:

$$Z_{Complement\ ary} = \theta XY\ (k) - \bar{X}\ Y(\text{k}) \qquad (2.3)$$

Transmitter of Complementary model is similar to that of direct detection. In receiver, the received signal is divided into two complementary branches of spectral chips. These two branches of spectral signals are sent to a balanced detector that computes the correlation difference.

C. AND Subtraction Technique

AND subtraction technique, have the cross-correlation θ $\bar{X}_{(k)}$ is substituted by $\theta X\&(k)$ where the θ $(X\&Y)$ represents the AND operation between sequences X and Y. Here at the receiver:

$$Z_{AND} = \theta\ (XY)\ (k) - \theta\ (X\&Y)(k) \qquad (2.4)$$

Equation (2.4) shows that, with AND subtraction technique, the MAI or the interference from other channels can also be cancelled out. In this technique, the received signal is divided into two AND branches of spectral chips.

D. NAND Subtraction Detection Technique

In the NAND subtraction detection technique, the cross-correlation $\overline{XY}(k)$ is substituted by $\theta(\overline{XY})$ y, $\overline{XY}$(k) where represents the NAND operation between X and Y sequences. For example, let X = 0110 and Y = 1100 therefore the NAND is ($\overline{XY}$) Y = 1000.

IV. IMPLEMENTATION OF THE CODE

The particular system setup of OCDMA using EDW code is simulated by Optisystem 12. The Transmitter sections for all the detection techniques are same. Encoder and decoder design are two important parameter in OCDMA network. This coding scheme is designed in a way to decrease the number of FBGs used in the encoder and decoder modules to maintain the cross-correlation parameter ($\lambda_{c)}$ as one. EDW allows the code weight (number of ones in a row) to be in any odd number which is greater than one. The basic EDW code denoted by (6, 3, 1) is shown below. This can be used to encode 3 users.

$$H_1 = \begin{bmatrix} 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \end{bmatrix}$$

In EDW code, one pair of ones (higher bits) is present in every code word (Row). Thus number of FBG used for encoder or decoder can be reduced by half since a pair of chips can be covered by a single FBG with a broader line width. In order to implement the EDW code in OCDMA network a specific wavelength is assigned to each column of bits in the basic EDW code matrix. A range of wavelength starting from 1548nm to 1552nm with a chip width of 0.8 nm is assumed here. The wavelength assignment corresponding to the column of bits is shown in Table 1. In a 3 user network FBG will encode wavelengths which are represented by the wavelength values of 1550nm ($\lambda_{3,\,4}$), 1552nm (λ_6) for the first code word (row) ,1548.8nm ($\lambda_{\,2}$), 1551.6nm ($\lambda_{5,\ 6}$) for the second code word and 1548.4nm ($\lambda_{2,\,3}$), 1550.4nm (λ_4) for the third code word as shown.[14],[15].

λ_1	λ_2	λ_3	λ_4	λ_5	λ_6
1548 nm	1548.8 nm	1549.6 nm	1550.4 nm	1551.2 nm	1552 nm
0	0	1	1	0	1
			1550		**1552**
0	1	0	0	1	1
	1548.8			**1551.6**	
1	1	0	1	0	0
1548.4			**1550.4**		

Table. 1: Wavelength assignment for EDW codes

A. Encoder Design

A two user network is analysed here. The wavelength assignment for FBG is shown in Table 2.

User	FBG	Centre Wavelength (nm)	Bandwidth (nm)
User1	FBG1 FBG2	1550 1552	1.6 0.8
User2	FBG3	1548.8	0.8
	FBG4	1551.6	1.6

Table 2: Centre Wavelength assignment for FBGs at the encoder side

The setup model for encoder module in this design is shown in Figure 1. A serial arrangement of FBGs is used to encode the wavelengths. The reflected branches are combined to construct the code. In Channel 1 the transmitted branch of the first FBG ($\lambda_{3,\,4}$) is connected to the second FBG (λ_6) and in channel 2 the transmitted branch of the first FBG (λ_2) is connected to the second FBG ($\lambda_{5,6}$) where all FBGs are linked directly to the broadband source.

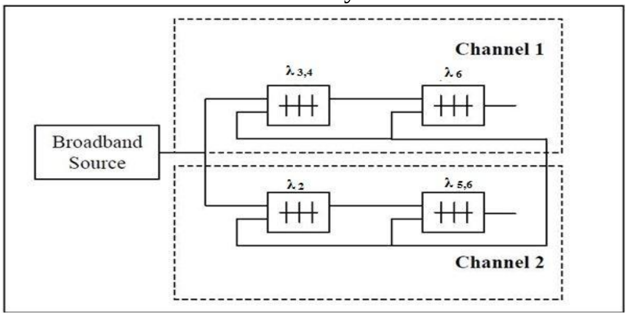

Fig. 1: Encoder Module for 2 user network

B. Decoder Design

Four detection techniques like Direct, Complimentary subtraction, AND subtraction, and NAND subtractions are analysed here. Either one of these can be used for the decoding purpose. The centre wavelength assignment for FBG in decoding section is shown in Table 3. The reversed order of FBGs from the encoder section is used to decode the code sequence.

User	FBG	Centre Wavelength (nm)	Bandwidth (nm)
User 1	FBG1 FBG2	1552 1550	0.8 1.6
User 2	FBG3 FBG4	1551.6 1548.8	1.6 0.8

Table. 3: Centre Wavelength assignment for FBGs at the decoder side

The decoder section using direct detection technique resembles the corresponding encoder section but reversed order of FBGs is used ie, in Channel 1 the first FBG (λ_6) of decoder1 is connected to the second FBG ($\lambda_{3,\,4}$) and in channel 2 the first FBG ($\lambda_{5,6}$) of decoder 2 is connected to the second FBG (λ_2) which is shown in Figure 2.

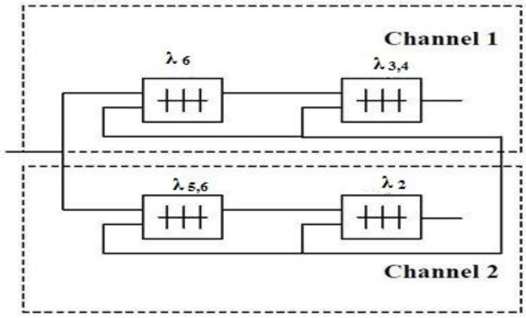

Fig. 2: Decoder Module using direct detection techniques

V. SIMULATION SETUP

The particular system setup of OCDMA using EDW code is simulated by OptiSystem 12. In the transmitter part, each of transmitters consists of six components; a dc bias generator, a LED or LASER, Uniform Fiber Bragg Gratings (FBGs), a pseudo random bit sequence (PRBS) generator, a Non-Return to Zero (NRZ) pulse generator and a Mach Zehnder Modulator. The Single Mode Fiber cable (20km) acted as the interface to connect from transmitter side to receiver side. 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 and specified according to the typical industrial values to simulate the real environment as close as possible.

From the transmitter section the signal passes through the optical fiber. Now the output of the optical fiber, which is a single mode fiber, is fed to the input of the optical splitter which splits the input into the 1:2 outputs. Now the 2 outputs of the filter are fed to the corresponding receiver of users. Receiver section includes decoders, photodetectors, and filters and simulation block of direct detection technique is shown in Figure 3.

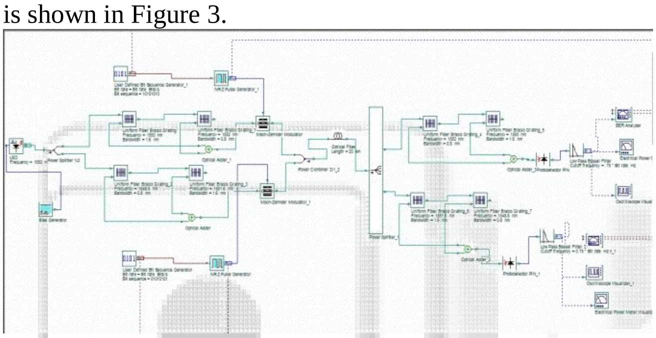

Fig. 3: Simulation block of Direct Detection technique

Simulation block of Complimentary subtraction detection technique is shown in Figure 4.

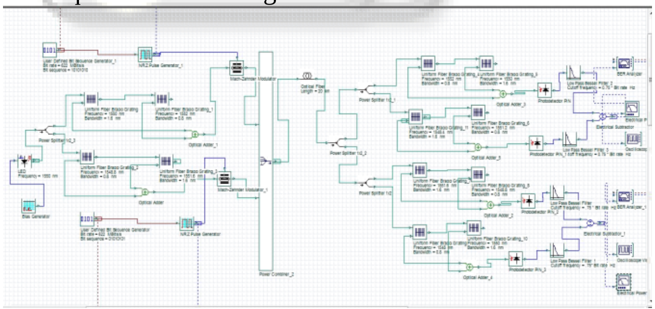

Fig. 4: Simulation block of Complimentary subtraction Detection technique

Simulation block of AND subtraction detection technique is shown in Figure 5.

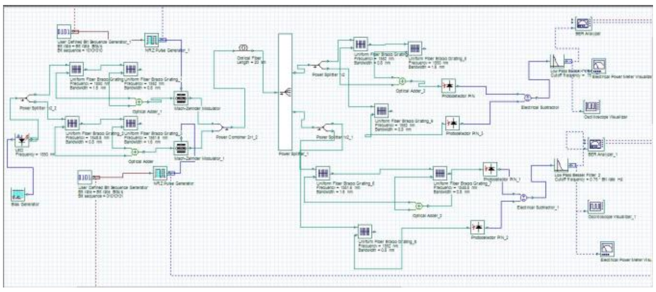

Fig. 5: Simulation block of AND subtraction Detection technique

The simulation block of NAND subtraction detection technique is shown in Figure 6.

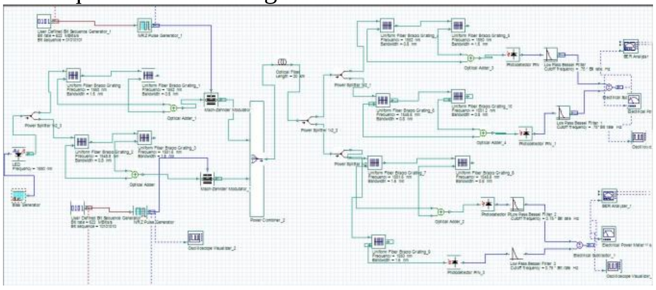

Fig. 6: Simulation block of NAND subtraction Detection technique

VI. RESULT ANALYSIS

Simulation block of OCDMA using the EDW code uses NRZ (non return to zero) PRBS signals at different bitrates like 622Mbps, 1Gbps, 1.5Gbps and 2.5Gbps. The data stream modulates a LED with a power of 5dB and central wavelength of 1550nm. Eye diagram is the methodology used to evaluate the performance of the system. The important parameters of eye diagram are Quality factor and Bit error rate. As the signals passes through the fiber, distortion may occur which affects the receiver side spectrum. The BER, Q factor obtained for each detection techniques is shown in Table 4.

Detection techniques	BER	
	Eye diagram1	Eye diagram2
Direct	$2.47433 \times 10^{(-21)}$	$5.00183 \times 10^{(-12)}$
Complimentary	$1.66040 \times 10^{(-38)}$	$3.60004 \times 10^{(-27)}$
AND	$6.63269 \times 10^{(-46)}$	$6.70081 \times 10^{(-21)}$
NAND	$1.33115 \times 10^{(-46)}$	$1.60487 \times 10^{(-40)}$

Receiver side eye diagrams for four different detection techniques like direct, complimentary, AND subtraction and NAND subtraction were analysed and is given in Figure 7, Figure 8, Figure 9 and Figure 10 respectively.

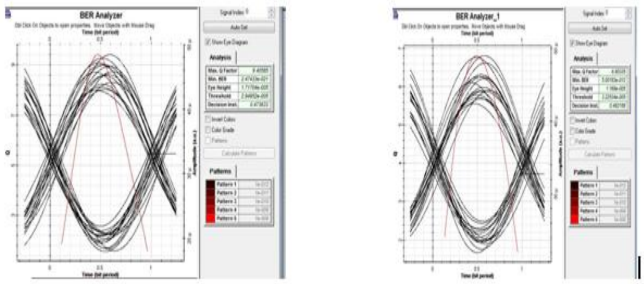

Fig. 7: Eye diagrams of direct detection technique for (a) user 1 (b) user 2

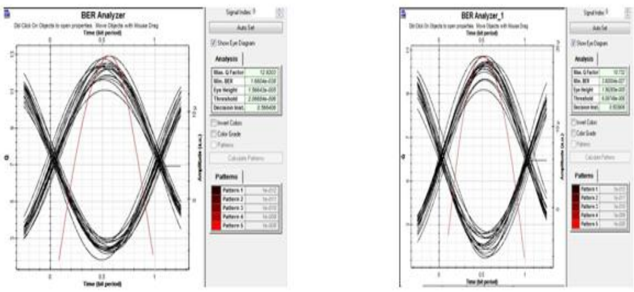

Fig. 8: Eye diagrams of complimentary subtraction detection technique for (a) user 1 (b) user 2.

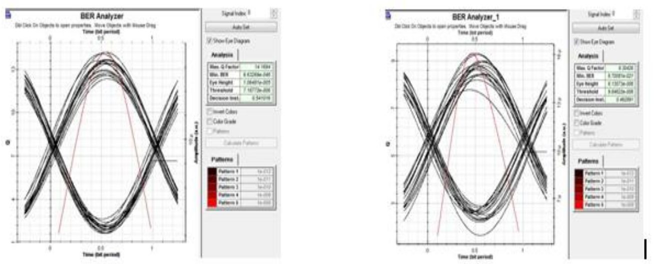

Fig. 9: Eye diagrams of AND subtraction detection technique technique for (a) user 1 (b) user 2.

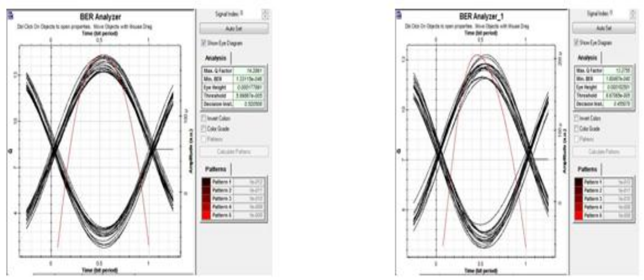

Fig. 10: Eye diagrams of NAND subtraction detection technique for (a) user 1 (b) user 2.

Performance of OCDMA using NAND subtraction detection technique for different fiber length is tabulated in Table 5.

Power (dB)	Bit Rate (Mbps)	Fiber length (Km)	BER	
			Eye diagram1	Eye diagram2
10	622	10	$3.70401\text{x}10^{(-67)}$	$6.4796\text{x}10^{(-54)}$
		20	$1.33115\text{x}10^{(-46)}$	$1.60487\text{x}10^{(-40)}$
		30	$1.85098\text{x}10^{(-28)}$	$1.06165\text{x}10^{(-22)}$
		40	$1.07796\text{x}10^{(-12)}$	$3.00019\text{x}10^{(-8)}$
		50	$4.35300\text{x}10^{(-4)}$	$1.39593\text{x}10^{(-2)}$

Table. 5: BER and Q factor of NAND detection technique for different fiber lengths.

VII. CONCLUSION

The OCDMA network using EDW code with different detection techniques was simulated and the performance of the system was analysed. Also the BER for different fiber length using NAND detection technique was studied and it is observed that the BER increase with increasing fiber length. And from the analysis based on BER and Q factor it is evident that NAND detection technique exhibits better performance compared to others.

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