Security enhancement of 2-D DIM codes using $4 \times 1$ NOR logic based on FISO

Simarpreet Kaur$^1$ · Simranjit Singh$^2$

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Abstract
Security enhancement and bandwidth increase are requirements of ultrafast future optical code division networks that also minimise the latency at nodes without distressing the traffic performance. In OCDMA systems, eavesdropper tries to breach the optical code, and encoded/encrypted data in order to get correct code word of legitimate user. For security enhancement, an ultra high speed $4 \times 100$ Gbps two dimensional Diagonal identity matrix (2D-DIM) code and four input single output (FISO) all optical logic gate with private key encryption is proposed and its performance in terms of security is analyzed. Expressions for synchronous and asynchronous transmissions are derived for proposed work and it is perceived that asynchronous transmission has better security. Further performance/security analysis is carried out for different scenarios such as with/without FISO, with 1D-DIM/2D-DIM codes, using $4 \times 1$ AND gate/NOR gate in terms of correct code detection rate (CCDR), max. eye amplitude, Received Q factor, Signal to noise ratio at different launched power levels for legitimate user and eavesdropper. Eavesdropper attacked the proposed system but due to FISO layering, private key encryption, and 2D-DIM codes, cannot get acceptable level of CCDR. To the best of author’s knowledge, proposed system is ultra high speed with enhanced security and no reported studies have investigated security enhancement at this much ultra high speed.

Keywords CCDR · MEA · OCDMA · SNR · 2D-DIM · 1D-DIM · AND gate · NOR gate · S-OCDMA · A-OCDMA
1 Introduction

OCDMA systems have been deployed in military and commercial communication systems for data transmission (Sahraoui et al. 2021a; Filatov 2021). Network security is a prime requirement in these systems due to highly sensitive information (Sahraoui et al. 2021b). Three different security schemes are prominent to boost the security of networks, such as (i) algorithmic cryptography (ii) quantum key distribution (QKD) (iii) physical layer cryptography (Alléaume, et al. 2014). Algorithm cryptography is used in upper layers or layer 3 and is constantly prone to security breaching. QKD provides high security but with a trade off between distance and data rate. Nowadays, physical layer cryptography has received attention because of enhanced security at intermediate data rates and performances. Further, different strategies which eavesdropper may use to get the signal are energy detection, code interception and differential detection. Eavesdropper can easily detect the "1" and "0" in case of non return to zero modulated transmission with simple photo-detector (Dai et al. 2010). Multicode keying is also demonstrated in Chen (2019), Kaur and Singh (2016) and differential detection is used in Wang et al. (2009a). Multicode keying is the most widely used technique for chipertexting to randomize data in OCDMA for security purposes. Multicode keying allows multiple binary bits for each one and zero of authentic user bits but it wastes the bandwidth of the medium. Cryptanalysis is a method to decrypt signals when a key is not known to eavesdropper (Liu et al. 2015) and different attacks are known-plaintext attack, chosen-plaintext attack and cipherext-only attack. In the case of a known-plaintext attack, plaintext and ciphertext are known but the key is not available. Chosen plaintext attack is freedom to select plaintext attack in which ciphertext and key are not known. In cipherext-only attack, plaintext is not available. For security enhancement, many techniques are incorporated into the OCDMA systems, such as AOLG (Sharma and Maddila 2020; Sharma et al. 2019), multi-code keying (Lin et al. 2016), steganography (Yen et al. 2018), virtual user scheme (Jyoti and Kaler 2011), and etc. Logic gates are prominently deployed in OCDMA systems due to simple encryption and decryption. Semiconductor optical amplifier (SOA) based XOR logic proposed at 120 Gbps (Agarwal et al. 2019), code swapping using XOR gate (Wang 2019), quantum Logic Gate Code with NAND gate (Sharma et al. 2019) and with multi diagonal coded NAND gate (Ahmed et al. 2013) etc. Optical logic gates with SOA deployment are studied in literature but SOA’s data rate capability is perceived to be limited (Wang et al. 2009b). Fiber nonlinearities are a popular technique for generating high speed optical logic gates, according to the picoseconds operation (Bogis et al. 2007). As researchers studied and engineered optical logic gates with highly nonlinear fibres, they came across the issue of long HNLFs that may decrease system compactness. Logic gates in OCDMA system for security enhancement have two input ports and a single output port (2×1 logic). Minimal power losses are desired for long reach systems, but multiple 2×1 logic gates introduce power degradation. As a result, more than two inputs based on all AOLG are required to reduce power losses.

In this research article, for the first time, we demonstrate a 4×100 Gbps OCDMA system using diagonal identity matrix codes (Kaur and Singh 2018) with cipherexting using private key and four input single output (FISO) all optical DCF-MZI based NOR/AND gates. In order to breach network security, eavesdroppers have to break not only logic gates operations but also private key cipher texting.

Introduction of OCDMA systems and security enhancement are given in Sect. 1, code construction of 2 D DIM codes is given in Sect. 2. The concept of all optical gating is mentioned in Sect. 3. System setup and system parameters are written in Sect. 4 and this is followed
by results and discussion. Graphical representation for different parameters is incorporated in Sect. 5. Conclusion/outcomes of the proposed work are given in Sect. 6.

2 Code construction of 2 dimensional DIM codes

For the OCDMA system implementation, DIM codes are used which are presented by us in Wang et al. (2009b) and these are upgraded to 2 dimensional DIM codes. K is users, W is weight of code and L is length of the code, \( \lambda_c \) cross correlation, and \( \lambda_a \) auto correlation. For the code sequence \( x = (x_1, x_2, x_3, \ldots, x_N) \) and \( y = (y_1, y_2, y_3, \ldots, y_N) \), auto correlation and cross correlation is given as (1) and (2) respectively

Auto correlation: \( Ax, x = \sum_{n=0}^{N-1} C[x]C[x] \) where \( 0 < m < N - 1 \) 

Cross correlation: \( Cx, y = \sum_{n=0}^{N-1} C[x]C[y] \) where \( 0 < m < N - 1 \)

\( \lambda_c = 0 \) and \( \lambda_a = 2 \) in DIM codes. Final code matrix size is \( K \times L \) and length of code is \( K \times W \). There is freedom to select any weight \( \geq 2 \). Size of base matrix \( (IB) \) is \( 2 \times W \) Balance and basic matrix of size \( Y \times Z \) is given as

\[
I_B = \begin{bmatrix}
UE & \cdots & LE \\
LE & \cdots & UE \\
\vdots & \ddots & \vdots \\
LE & \cdots & LEUE
\end{bmatrix}_{Y \times Z}
\]

where UE and LE are upper and lower elements respectively. Where \( Y = 2 \) and \( Z \) is equal to \( W \).

For \( K \) users, a final matrix of size \( K \times L \) is represented by matrix \( M \) which illustrates the final code of each user. Construction of \( M \) comprises three steps such as \( M_1, M_2 \) and final \( M \) can be obtained. First and foremost, in a sub matrix \( M_1, I_B \) is repeated \( K - 1 \) times as depicted in Eq. (4)

\[
M_1 = \begin{bmatrix}
UE & \cdots & \cdots & LE \\
LE & \cdots & \cdots & UE \\
\vdots & \ddots & \ddots & \vdots \\
LE & \cdots & \cdots & LEUE
\end{bmatrix}
\]

In matrix \( M_2 \), placement of identity matrix is repeated for \( K \times L \) times as shown in Eq. (5)

\[
M_2 = \begin{bmatrix}
UE & \cdots & \cdots & LE \\
LE & \cdots & \cdots & UE \\
\vdots & \ddots & \ddots & \vdots \\
LE & \cdots & \cdots & LEUE
\end{bmatrix}_{K \times L}
\]
Final user codes are illustrated in matrix $M$ and it can be obtained by inserting zeros in the vacant positions of matrix $M_2$ as expressed in Eq. (6)

$$M = \begin{bmatrix}
UE00000000000000LE \\
LEUE000000000000LF \\
00LEUE000000000000 \\
000000LEUE000000 \\
0000000000LEUE00 \\
00000000000000LE \\
\end{bmatrix}_{K \times L}$$

(6)

2 D wavelength time spreading code obtained from 1 D DIM code and advantages are
(i) Increase in users using same weight (ii) Increase the security of code (iii) Show zero cross correlation (iv) code length unchanged.

For the conversion of 1 D DIM codes (6) into 2 D DIM codes, dimension of time ($t$) is added to (6) and then final matrix is $M_T$

$$M_T = \begin{bmatrix}
\lambda_1 \\
\lambda_2 \\
\lambda_3 \\
\lambda_4 \\
\lambda_5 \\
\lambda_N \\
\end{bmatrix}
\begin{bmatrix}
t_1t_2t_3t_4t_5t_6t_7t_8t_9t_N \\
UE00000000000000LE \\
LEUE000000000000 \\
00LEUE000000000000 \\
000000LEUE0000000000 \\
0000000000LEUE0000000000 \\
00000000000000LE \\
\end{bmatrix}_{K \times L}$$

(7)

Wavelengths are representing row wise and time in column. Time $t$ is selected as

$$t_N = j_N \times t_b$$

(8)

where $j$ is number of time the slot $j$ (1,2,3,4…..N) and $t_b$ bit time slot, calculated as

$$t_b = \frac{1}{\text{bitrate}}$$

(9)

Performance of comparison performed in reported work (Wang et al. 2009b) and 1D DIM codes emerged as an optimal code out of double diagonal weight, multi diagonal weight, enhanced diagonal weight, walsh hadamard code. Therefore, in this work we are upgrading 1D DIM code to 2D DIM codes.

### 3 Concept of all optical gating

Figure 1 represents the two co-propagating optical signals (Fig. 2). Four wave mixing (FWM) occurs inside nonlinear medium and represented in Fig. 3. Mixed product of $N$ number of wavelengths is given as (Mohammed et al. 2012)

$$N = \frac{N^2}{2}(N - 1)$$

(10)

Efficiency $\eta$ for equal channel spacing, same input power, for fiber is given as
where $P$ is the power of the channel, $n_2$ is nonlinear refractive index, $A_{\text{eff}}$ is fiber effective area, $\Delta \lambda$ is spacing between channels and $D$ is chromatic dispersion.

Dispersion compensation fiber (DCF) in Mach–Zehnder interferometric (MZI) configuration employed and Compensation of dispersion with DCFs is prominently observed in optical communication systems (Agrawal et al. 2013; Ajmani et al. 2019) and has negative dispersion from $-70$ to $-90$ ps/nm/km. Power of signal or probe significantly affects the FWM in DCF and higher the probe power, more is the signal quality. On contrary, high pump power, suppress the power level of ones and zeros. For the better power and shape of signal pulse, optimal power levels are needed. We present four input single output AND/NOR gate for security enhancement using DCF-MZI configuration. Output at AND will be true if all the inputs are true and for NOR gate to be true, all input bits should be false. In simple works, 4 input bits having 0 on all ports provide 1 for NOR only and having 1 on all

$$\eta = \frac{n_2 P}{A_{\text{eff}} D (\Delta \lambda)^2}$$  \hspace{1cm} (11)
ports provide 1 for AND gate only. Concept diagram of FISO is represented in Fig. 3 using DCF-MZI structure and gate logic tables are shown in Tables 1, 2.

Four signals S_A, S_B, S_C, S_D generated from optical laser source, amplified with erbium doped fiber amplifier (EDFA) and for the wavelength multiplexing, send to part (A). P_k is the private key (explained in Sect. 4) as depicted in part (B).

FWM nonlinear medium in part (C) consists of two DCFs in MZI configurations for destructive and constructive interference. Upper port of the FISO unit shows the carriers at the OSA while lower port show only noises. Therefore constructive interference is on upper port and further in order to analyze the output data behaviour, signal is divided into two parts and each part consists of optical Bessel filers of variable frequencies. Varied frequencies are used to check the wavelengths which will provide data according to some logic gates. It is observed that data after filter 1 act as NOR logic data and after filter 2 is acting as output data of AND gate. Part (D) shows that NOR gate is high when all the inputs are low and in case of part (E) which is acting as AND gate, will provide high output when inputs are also high. Proposed FISO system is used for security enhancement of OCDMA system and legitimate user security system is depicted in

![Fig. 3 Proposed FISO AND/NOR gate using DCF-MZI](image)

**Table 1** NOR logic for 2 inputs (Truth table)

| A | B | Output |
|---|---|--------|
| 0 | 0 | 1      |
| 0 | 1 | 0      |
| 1 | 0 | 0      |
| 1 | 1 | 0      |

**Table 2** AND logic for 2 inputs (Truth table)

| A | B | Output |
|---|---|--------|
| 0 | 0 | 0      |
| 0 | 1 | 0      |
| 1 | 0 | 0      |
| 1 | 1 | 1      |
Fig. 3. Four user 2D DIM data passed through FISO system and in order to baffle eavesdropper, a private key (P_k) in place of pump signal is multiplexed with DIM data and passed through DCF-MZI. AND gate output from FISO system is neglected to increase the number of cases to get legitimate data and keep eavesdropper in illusion. NOR gate output communicated through optical fiber and then passed through DCF-MZI. Pumps equal to DIM user wavelengths are combined to DCF-MZI then again NORing with P_k is performed to get legitimate user data.

4 System model

Figure 3 represents the 2D DIM code with optical layering and private key based OCDMA system. Legitimate data can be attacked in OCDMA networks and eavesdropper can use known plaintext attack to get the authentic information. In security enhanced OCDMA systems, first and foremost data layer security is performed and optical encoder then performs physical layer security. Optical decoding implemented at receiver to retrieve legitimate data and in this work, wavelength-time spreading codes are implemented. Security enhancement of 2D DIM based OCDMA system is proposed and investigated in Optiwave Optisystem™. Four users are selected from DIM code matrix having weight (W) 2, code length (L) 8 and cross correlation 0. Code matrix for 2D DIM code is given as

\[
\text{DIM} = \begin{bmatrix}
    t_1 & t_2 & t_3 & t_4 & t_5 & t_6 & t_7 & t_8 \\
    10000001 \\
    01100000 \\
    00011000 \\
    00000110
\end{bmatrix}
\]  

(12)

Laser array with eight frequencies (193.1–193.8 THz) each at 100 Gbps provide continuous pulse train and spacing between channels is 100 GHz. From the power optimization, 10.877 dBm input power is selected and pseudo random bit sequence generator data is modulated with NRZ and further electrical to optical conversion is performed by Mach-zehndar modulation (MZM). In order to realize 2D DIM users, time delays (t) are added to each wavelength as shown in Fig. 4a and t is calculated as Eq. (8 and 9). Time delays are \( t_1 = 0.1 \) ns, \( t_2 = 0.2 \) ns, \( t_3 = 0.3 \) ns, \( t_4 = 0.4 \) ns, \( t_5 = 0.5 \) ns, \( t_6 = 0.6 \) ns, \( t_7 = 0.7 \) ns, and \( t_8 = 0.8 \) ns. After that data multiplexed and joined with private key P_k. Simulation parameters are given in Tables 3, 4. P_k has input power of -0.96 dBm and all the signals fed to FISO unit which consist of two DCFs and a MZI switch. DCFs of lengths 0.09 km are placed in two arms of MZI i.e. lower arm and upper arm. FWM occurs in both the arms and at the output of MZI, there are two ports and it is observed that lower port provide constructive interference. Constructive port output has different FWM wavelengths and outputs of these wavelengths are checked with optical filters so as to get the specific logic operation. At frequency 193.93 THz, system act as NOR gate because provide output “1” when all the input bit are “0” and act as AND when all the input bits are “1”. AND gate realized through optical filter having frequency 194.18 THz. NOR gate has high output power as compared to AND gate and therefore we have used NOR gate for further transmission and left AND gate output to baffle eavesdropper.
In Shake (2005), code interception by eavesdropper for single user is given and probability to comprehend legitimate user data at eavesdropper is denoted as $P_C$ and it is expressed as

$$P_C = (1 - P_M)^W (1 - P_F)^{(Lx\lambda - W)}$$

(13)

where $P_M$ is miss detection of transmitted pulse, $P_F$ is false detection when no pulse transmitted, code length is $L$, code weight $W$ and no. of wavelengths are $\lambda$.

$$P_M = 1 - Q\sqrt{\frac{2E}{N}} \sqrt{\frac{2\gamma}{N}}$$

(14)
Marcum Q function is expressed in Eq. (16), detection threshold is \( \nu \), and Peak pulse energy to the noise power spectral density is \( E/N \).

\[
P_F = \exp \left( -\frac{\nu}{N} \right) \quad (15)
\]

In linear cryptanalysis in which output ciphertexts are utilized, is termed as known plain-text attack (Ji et al. 2019). Time required obtaining output cipher texts by eavesdropper using linear cryptanalysis is given as:

\[
T = \sum_{n=1}^{\infty} n(T_{en} + T_{in})C_{dn} \quad (17)
\]

SMF of 50 km is deployed and output is given to logic gate decoder such as DCF-MZI unit having same DCFs lengths with eight laser wavelengths same as DIM transmitter wavelengths/frequencies. The FWM again emerges and data from 193.93 THz spread on other laser wavelengths and specific legitimate output wavelength selected with demultiplexer. Negative time delays corresponding to specific user are given to wavelengths such as \( t_1 = -0.1 \) ns, \( t_2 = 0.2 \) ns, \( t_3 = 0.3 \) ns, \( t_4 = 0.4 \) ns, \( t_5 = 0.5 \) ns, \( t_6 = 0.6 \) ns, \( t_7 = 0.7 \) ns, \( t_8 = 0.8 \) ns and general receiver is shown in Fig. 4b. PIN photodetector, low pass filter, 3-R regenerator, BER analyzer are together make receiver.
5 Results and discussions

Equation (17) reveals the increase and decrease in the time complexity to detect the legitimate user data at eavesdropper at different parameters i.e. for instance, signal to noise ratio (SNR) level increase at eavesdropper reduce the time complexity. At lower levels of SNR, for eavesdropper, security increase and therefore complex codes preferred. For multiple users, there are two transmission schemes such as synchronous and asynchronous transmission.

5.1 Synchronous OCDMA systems (S-OCDMA)

OCDMA encoded total N users with NRZ data linecoding travel inside fiber simultaneously operating at B bits per second. Probability of transmitting logic ‘1’ by special user is ½ at given bit period and for same bit period, ‘0’ is transmitted by N-1 users is $1/2^{N-1}$. Probability of transmission of ‘1’ when other user transmits ‘0’ assuming that there are independent data bits from each other is given as $N/2^N$. Time for which eavesdropper wait to get bit of single user is $2^N/(B \times N)$.

5.1.1 Time required for breaching S-OCDMA security

Code interception is used to detect the single legitimate user code by eavesdropper and ciphertext information can be taken. Once eavesdropper gets the ciphertext, encryption key will decipher.

Time required for breaching S-OCDMA security is given as

$$T_R = \sum_{n=1}^{\infty} n \left( T_{ea} + T_{ei} + \frac{2}{B \times N} \right) P_{en}$$  \hspace{1cm} (19)

where $T_{ea}$ is eavesdropper time to attack encryption algorithm, $T_{ei}$ is eavesdropper time to get address code after interception. $P_{en}$ is eavesdropper probability till nth interception to get correct user’s code.

$$P_{en} = \frac{(1 - PC/N)^{n-1} PC}{N}$$  \hspace{1cm} (20)

If total users are not known by eavesdropper which are simultaneously travel, eavesdropper perform code interception on each bit period and thus probability is given as

$$P_{ens} = \frac{(1 - PC/2^N)^{n-1} PC}{2^N}$$  \hspace{1cm} (21)

5.2 Asynchronous OCDMA systems (A-OCDMA)

In A-OCDMA, no synchronization is needed and in this case, for the duration of transmitting ‘1’ by one user, fraction of 2 adjacent bits is transmitted for the same duration by all other users (N-1). For eavesdropper to differentiate one user, when it transmit ‘1’ for fixed duration and all other users (N-1) for same time duration must transmit 2 adjacent ‘0’.
Probability of transmit ‘1’ by one user is ½ at given time period and for N-1 users, which transmit ‘0’ on two overlapped bits, probability is \(1/2^{2N-2}\). Eavesdropper time to wait one user transmission is \(2^{2N-2}/(D \times N)\).

5.2.1 Time required for breaching A-OCDMA security

Time required for breaching S-OCDMA security is given as

\[
T_R = \sum_{n=1}^{\infty} n \left( T_{ea} + T_{el} + \frac{2}{B \times N} \right) P_{en}
\]  

(22)

Comparison of S-OCDMA and A-OCDMA in terms of time required by eavesdropper to get the correct code is clear from Eqs. (20) and (22) such that due to the presence of greater number of cases in A-OCDMA \((2^B \times 2^{N-1})\) as compared to S-OCDMA \((2^B \times N)\), the security of former system is more i.e. time required by eavesdropper to get the correct code is more. Therefore A-OCDMA is more secure than S-OCDMA systems.

If total users are not known by eavesdropper which are asynchronously travel, eavesdropper perform code interception on each bit period and thus probability is given as

\[
P_{ena} = \frac{(1 - P_C/2^{2N-1})^{n-1} P_C}{2^{2N-1}}
\]  

(23)

Number of users in the optical network is directly proportional to the security of the system and if eavesdropper do not know the users in the system, security improves and when it get to know total users, security reduces as clear from Eq. (21) and (23).

5.3 Performance and security analysis in Optisystem

2-D DIM OCDMA system having capacity \(4 \times 100\) Gbps over 50 km using FISO unit is investigated in Optisystem software.

Representation of four users multiplexed frequencies spectrum which is 2-D coded using DIM codes is depicted in Fig. 5a and carrier spectrum addition of private key is shown in Fig. 5b. As discussed in Sect. 4, four user data at the rate of 100 Gbps/user fed to FISO unit by adding \(P_k\) and FWM takes places inside FISO unit due to MZI-DCF configuration as shown in Fig. 5c. Iteration is set to select the different frequencies at filter 1 and filter 2 in order to check the behaviour of filters towards data.

It is evident that frequency 193.3 THz performs the operation of NOR gate as shown in Fig. 5d and 194.13 THz does the logic operation of AND gate as depicted in Fig. 5e. Optical data bits are checked with optical time domain visualizers at diverse points in system to check the logic operations. Input sequence of 1st, 2nd, 3rd, 4th users are shown in Fig. 6a–d and further \(P_k\) is added and it is shown in Fig. 6e. Bit sequence at NOR gate and AND gate after respective filters is represented in Fig. 6f, g. Figure 6h–k shows received bit patterns in proposed system after decoding of FISO data at legitimate users such as 1st, 2nd, 3rd, 4th users.

Launched power has significant effects on the Quality, and SNR of received signal at both legitimate and at eavesdropper. Performance of FISO-2D DIM system is affected by launched/ input power but due to presence of FWM in the FISO, there is nonlinear response in both legitimate and eavesdropper as illustrated in the Fig. 7. Power optimization is selected by observing received Q at varied power level – 20 dBm to 20
Figure 7 shows the highest Q at 10 dBm launched power for both legitimate user and eavesdropper but eavesdropper has low Q factor. SNR increase with the increase in launched power and there are approximately same values at eavesdropper for all power levels but highest SNR observed at 10 dB launched power. Investigated parameters are analyzed in terms of security and high performance also which shows that security and performance of proposed system is enhanced.

System security with and without FISO unit is investigated in terms of correct code-word detection rate (CCDR) at legitimate user and eavesdropper, at diverse launched powers. FISO system enhances security of the system but also introduce insertion losses as well as nonlinear effects in the system. Therefore it is evident from Fig. 8 that performance in terms of CCDR at legitimate user without FISO is enhanced followed by legitimate user with FISO. However different in both systems, is security of the communication and results revealed that eavesdropper in absence of all optical FISO system
Fig. 6 Optical bits with respect to time for (a) 1st user (b) 2nd user (c) 3rd user (d) 4th user (e) $P_k$ (f) NOR gate (g) AND gate (h) received 1st user (i) received 2nd user (j) received 3rd user (k) received 4th user
has greater success rates to receive correct code word but in other case where FISO is deployed, CCDR of eavesdropper is negligible as compared to aforementioned system.

AND gate and NOR gate are obtained from the FISO system and we have taken NOR due to high output power but in terms of security, better optical logic gate is selected after analysis. Analysis is performed on different launched power levels and system with AND gate provides lesser security to legitimate user in proposed system. AND gate encoding is common these days and become easy to decode for eavesdropper in the system. However, our FISO system is more secure than conventional system but here, NOR gate is best performing because of the logic operation of NOR. Tables 5, 6 shows the logic operation of NOR and AND gate respectively on input data bits and \( P_k \) (Fig. 9).

1-D DIM codes are ZCC codes with improved performance because of lesser multiple access interference as investigated in Kaur and Singh (2018) as compared to enhanced double weight codes (EDW), multi-diagonal codes (MD), Walsh Hadamard (WH) codes, Double diagonal weight codes (DDW) etc. In this work, 2D-DIM codes are investigated with FISO and comparison is carried out in Fig. 10 with 1D-DIM codes with FISO in terms of maximum eye amplitude (MEA). MEA is least in case of eavesdropper with 2D-DIM codes and performance in MEA of 1D-DIM is highest because 2D-DIM code has some time skews limitations but eavesdropping MEA is highest in 1D-DIM, therefore it is lesser secure than 2D-DIM. Figure 11 shows the eye diagram at 50 km SMF distance for legitimate user and eavesdropper. Eye opening at legitimate user is wide because of encryption key and FISO system. Eavesdropper attack the proposed system but get insignificant information and therefore error are more and eye opening is very less. Encrypted legitimate user data reaches to the
optical network unit with improved quality, better CCDR and high SNR. Therefore proposed 2D-DIM FISO system is suggested for the very high speed OCDMA systems in services where data protection is utmost concern.
6 Conclusion

Confidentiality enhanced ultra high speed OCDMA system is proposed in this work with all optical FISO gating and private key encryption using 2D codes. Security enhancement is performed such that eavesdropper has to breach the physical layer based optical code, FISO operation and also the encryption key in order to get correct code word of legitimate user. Large number of users in the A-OCDMA provides far better security than S-OCDMA. Optisystem simulation tool is considered for the realization of proposed work and system is analyzed at different launched powers in terms of CCDR, MEA, Received Q factor, SNR for legitimate user and eavesdropper when different scenarios are used such as system with/without FISO, with 1D-DIM/2D-DIM codes, using $4 \times 1$ AND gate/NOR gate. For the successful legitimate user data detection, eavesdropper need matched decoder/encryption at the same time. Results reveal that proposed system with FISO at 10 dBm launched power provide CCDR of $10^{-10}$ at legitimate user, CCDR of $10^{-3}$ at eavesdropper, without FISO show CCDR of $10^{-10}$ at legitimate user but system is very much prone to eavesdropper and provide CCDR $10^{-7}$. FISO system improve the security of proposed system and analysis is also performed for 1D-DIM and 2D-DIM, it is seen that eavesdropping is easier in 1D-DIM system. NOR gate due to its logic operation and high output

Fig. 10 Comparison of 1D-DIM and 2D-DIM codes in terms of MEA

![Comparison of 1D-DIM and 2D-DIM codes in terms of MEA](image)

Fig. 11 Eye diagram of proposed system for (a) legitimate user (b) eavesdropper at 50 km

![Eye diagram of proposed system for (a) legitimate user (b) eavesdropper at 50 km](image)
power from FISO offers improved security than AND gate. Therefore, proposed system is good candidate for secure transmission and in near future, effect of uni-phase, bi-phase and quad-phase modulation can be studied.

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