Improving of Scm-Sac-OcDMA System by Using Optical Amplifier Based on Md Code

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Abstract: Free space optic (FSO) is one of the most effective solution technique to transmit the information due to its advantage such as cost and speed, but it suffers from various disadvantage that affects on the signal performance like weather condition that results loss in optical signal power over the communication path. So, in this paper we study the effect of the rain weather in Iraqi cities [ Baghdad , Basra , Mosul ] during 2017 on the FSO signal with system of hybrid Sub-carrier multiplexing _Spectral amplitude coding _ optical code division multiple access (SCM-SAC-OCDMA) with multi diagonal (MD) code and intermediate stage called ‘optical amplifier’. OCDMA allows multiple users to access the medium without any contention; it provides privacy and security with reducing the interference that may occur due to multiple users. MD code has been use to provide simplicity in design and high data rate. The optical amplifier with controlled gain leads to amplify the power of the signal. Results from simulation analysis for the proposed system can transmit data rate with (1Gbps) for (1Km) distance and transmit power of (5dB) with bit error rate (BER) $10^{-12}$ in Mosul, $3 \times 10^{-56}$ in Baghdad, $1 \times 10^{-62}$ in Basra.

1. Introduction
Free space optic (FSO) is one of the new common technologies where free space acts as medium between transmission and reception and they should be in line of sight (LOS) for successful transmission of optical signal. One advantage of the FSO is no need to use fiber optic cable, this reduces the cost of the system and permits large number of users to get it own. OCDMA has become a popular choice for supporting multiple accesses and can operate asynchronously. This result increasing capability of the system, implement high speed, secure the transmission of information [1]. OCDMA system suffers from different noises like shot noise, thermal noise, and multi-access interference (MAI), so that, it is important to design code to reduce MAI such as spectral amplitude coding is a good solution to reduce the effect of MAI by using code to help suppressing the effect of the MAI [2], and using of Multi Diagonal (MD) code in the system helps to increase the simplicity and support large number of user with high data rate. Sub-Carrier Multiplexing (SCM) is used in this project because instead of modulating the optical carrier directly, we can have data first modulate on electrical carrier. The upper carrier frequency is determined by the bandwidth available from the transmitter.

This modulating carrier modulates with the optical transmission laser and transmits it in free space [3]. The main reason of using SCM is to multiplex multiple data stream onto single optical signal. In this modern paper, we study the effect of rain in Iraqi cities using SCM-SAC-OCDMA with intermediate stage (optical amplifier) to see the enhancement on the system by using ‘opt systems’ software Ver.7.
2. System Design and Component
Figure 1 shows the design of SCM-SAC-OCDMA system with optical amplifier based on MD code. In the transmission side the laser is used to transmit through free space because of its high power and bandwidth. An external optical modulator (EOM) calls Mach-Zehnder modulator is used for direct modulation of laser and generates optical signal [4]. The optical amplifier is used as intermediate stage during signal transmitting. This amplifier receives input optical signal and generate an optical signal with high power [5]. In the receiver side, the multi-diagonal (MD) code sequence are filtered by using type of filter called fiber Bragg grating (FBG) filter, then pass it to the photo detector which receives the laser light and convert it to electrical signal. The SCM signal and laser light are combined with each MD code and they filtered by using band pass filter (BPF) to reject the unwanted signals.

3. Rain Weather Attenuation
FSO system communication has been found to be effected by atmospheric attenuations like rain and lead to attenuate the signal power [6]. The attenuation of rain in Iraq cause scattering and absorption in laser light and result reduction in laser power. The rain attenuation can be calculated by the following expression as[7]:

\[ \alpha_{rain} = 1.076 \times R^{0.67} \]  \hspace{1cm} (1)

where \( R \) is rain intensity rate in (mm/hr), and the rainfall rate of Iraqi cities in the three different regains [BAGHDAD, BASRAH, MOSUL] that can be shown in the table below [8]:

| Region   | R at heavy rain (mm/hr) | R at Mid rain (mm/hr) | R at Light rain (mm/hr) |
|----------|-------------------------|-----------------------|-------------------------|
| Baghdad  | 30.3                    | 11.7                  | 3.8                     |
| Mosul    | 78.0                    | 45.7                  | 2.1                     |
| Basrah   | 26.1                    | 13.0                  | 1.4                     |

The rain attenuation for FSO link can be reasonably well approximated by using the equation below [7]:

\[ \alpha_{rain} = \frac{2.8}{V} \]  \hspace{1cm} (2)

Where \( V \) is the visibility range in (Km).

4. Md Matrix Design
The MD code is characterized by following parameters (N, W, and \( \xi_c \)), where N is code length (number of total chips), W is code weight (number of chips having value ‘1’), \( \xi_c \) is in-phase cross correlation [9].
The matrix of MD code consist of $K \times N$ matrix functionally depending upon the number of user that share the system $(K)$ and code weight $W$. Value of weight for MD code should be more than 1. MD code has zero cross correlation among the code words. Due to the zero cross correlations, there is no overlapping in spectral of different user and for this reason the effect of incoherent intensity noise has been ignored. The MD code for 5 users with $W=2$ are given:

$$\begin{pmatrix}
1000000001 \\
010000010 \\
001000100 \\
000100100 \\
0000110000
\end{pmatrix}$$

So, the codeword for different users according to above example is:

- User1 => £1, £10
- User2 => £2, £9
- User3 => £3, £8
- User4 => £4, £7
- User5 => £5, £6

MD code provide flexibility in choosing the value of number of user and the weight $W$. moreover there is no overlapping chips of different user since each user has its own spectral to transmit the data. Due to the reason of no overlapping, only one pair of detector is required comparing with other techniques. The MD code presents more flexibility in choosing $(W, K)$ parameter and simply the design of the system project and thus lead to supply large number of user compared with other code like MQC and RD codes. Furthermore, there are no overlapping chips for different users.

5. MATHEMATICAL MODEL OF SCM-SAC-OCDMA SYSTEM WITH OPTICAL AMPLIFIER BASED ON FSO

The action of SCM-SAC-OCDMA system is affected by the weather phenomena like rain and this atmospheric turbulence interacts with laser light. Due to the composition of the atmospheric, this turbulence causes decreasing in SNR that lead to growing BER value and decrease the performance of the system. The Gaussian approximation is applied to calculate BER. We have to take into account the effect of noise because the noise in laser has an important factor effect on signal in optical communication [10].

Thermal noise $(I^2\text{th})$, shot noise $(I^2\text{sh})$ and inter-modulation distortion $(I^2\text{IMD})$ noise happen in the photo detector due to the spontaneous emission of the uncontrolled photons emission. The SNR of an electrical signal is defined as average signal power $(I^2)$ to the average noise power $(\delta^2)$ [11]

$$\text{SNR} = \frac{\rho}{\delta^2} \quad (3)$$

Where $\delta^2 = P\text{th} + P\text{sh} + P\text{IMD} + \alpha$ space (4)
\[ I^2 = \left[ \frac{R_{psr} W}{N} u_{n,k} m_{n,k} \right]^2 \]  

Where \( R \) is responsively of photo-detector, \( P_{sr} \) is broadband power, \( N \) is MD code length, \( u_{n,k} \) is the normalized digital signal at the \( n^{th} \) subcarrier channel of the \( K^{th} \) codeword, \( m_{n,k} \) is the modulation index of the \( n^{th} \) subcarrier of the \( K^{th} \) users.

\[ P_{sh} = \frac{eB R_{psr} w}{N} \]  

Where \( e \) is electric charge, \( B \) is electric bandwidth.

\[ P_{th} = \frac{4k_b T_n B}{R_l} \]  

Where \( k_b \) is boltzman constant, \( T_n \) is receiver noise temperature, \( R_l \) is receiver load resistor.

\[ P_{IMD} = p_{str}^2 R^2 m_{n,k} \left[ \frac{D_{1,1,1}}{32} + \frac{D_{2,1}}{64} \right] \]  

\[ D_{1,1,1} = \frac{N_c}{2} (N_c - N_s + 1) + \frac{1}{4} \left( (N_c - 3)2^{-\frac{1}{2}} \left[ 1 - (-1)N_c \right] (-1)N_c + N_s \right) \]  

Where \( N_c \) is number of carrier, \( N_s \) is number of subcarrier.

\[ D_{2,1} = \frac{1}{2} - 2 - \frac{1}{2} \left[ 1 - (-1)N_c \right] (-1)N_s \]  

The previous SNR equations show the average signal power to the average noise power that generated in the photo detector. In this SCM-SAC-OCDMA system with the optical amplifier used, the noises that generated due to the spontaneous emission of photon in optical amplifier must be take into consideration as shown in the proposed system design of figure 2.

The amplifier spontaneous emission (ASE) noise is the main noise source of optical amplifier. The ASE effects on the accuracy of optical gain [12, 13] and product by spontaneous emission photons travelling along the amplifier region [14].
The spectral density of optical noise is given by:

\[ S_{sp} = (G - 1)f_{no} \frac{h \nu}{2} \]  

(11)

Where \( G \) is the optical amplifier gain that used in the system, \( h \nu \) is the photon energy (constant value).

The optical amplifier noise figure \( f_{no} \) is related to the spontaneous emission factor \( n_{sp} \):

\[ F_{no} = 2n_{sp}(1 - \frac{1}{G}) \cong 2n_{sp} \]  

(12)

In the most of particle case, the noise figure value is between 3 and 7dB, the effective noise figure of the cascade of \( K \) amplifier with corresponding gains \( G_i \) and noise figure \( f_{no,i} \) can be expressed by:

\[ F_{no} = f_{no,1} + \frac{f_{no,2}}{G_1} + \frac{f_{no,3}}{G_1G_2} + \ldots + \frac{f_{no,K}}{G_1G_2\ldots G_{K-1}} \]  

(13)

According to (11) (12) (13) equations, the total power of spontaneous emission noise for an optical amplifier followed by an optical bandwidth \( B_{op} \) is determined by [14][15]:

\[ p_{sp} = 2S_{sp}(G - 1)B_{op} \]  

(14)

\[ p_{sp} = (G - 1)f_{no} h \nu B_{op} \]  

(15)

The total SNR equation will be:

\[ \text{SNR} = \frac{I^2 + \text{Optical power o.p.}}{I^\text{th} + I^\text{sh} + I^\text{IMD} + R_{\text{rain}} + P_{sp}} \]  

(16)

\[ \text{SNR} = \frac{eBP_{p}W}{N} + \frac{P^2_{SPR}R^2_{m,n,k}}{N} + \frac{R_{m,n,k}}{R^2_{11}} + \frac{R_{21,11}}{32} + 1.076R^0.67 + (G - 1)f_{no} h \nu B_{op} \]  

(17)

Using Gaussian approximation equation, the Bit Error Rate can be expressed as [11]:

\[ \text{BER} = \frac{1}{2} \text{erfc} \sqrt{\frac{\text{SNR}}{8}} \]  

(18)

erfc defines as error function.

Parameter used to numeric calculates the SNR and BER are obtained in table 2.
Table 2. parameter used in the numerical calculation

| symbol | value |
|--------|-------|
| Psr    | 5 dB  |
| $\alpha$ | Depend on result of equation 1 |
| B      | 311MHz |
| $T_n$  | 295 Kelvin (K) |
| e      | $1.6 \times 10^{-19}$ coulomb (C) |
| $k_b$  | $1.38 \times 10^{-23} j/k$ |
| $N_c$  | 3-10 |
| $N_s$  | 2-20 |
| G      | 20 dB |
| $f_{no}$ | 1.9 dB |
| $h\nu$ | $1.28 \times 10^{-19}$ |
| $B_{op}$ | 20 GHz |
| R      | 0.95 A/W |
| Optical power o/p | $3.2 \times 10^{-3}$ Watt |
| $R_l$  | 1030 $\Omega$ |

Figure 3. Attenuations of FSO signal against rain intensity

6. Simulation Result and Discussion
The proposed system are simulate and the data has been building using 'opt system' software to built the FSO system in order to evaluate, compare the performance of the proposed FSO system with employing MD code to see the effect of rain attenuation in the three different regions of Iraq on the free space optic signal when travel through the air, see figure 2. The rain can effect on system performance and increase its intensity will increase in signal attenuation, see figure 3. The eye diagram used to realize how the atmospheric attenuation influence on the user data. BER rate used to compare the effect of intensity of rain on the signal performance. Table 3 shows the BER value for the three different regions of Iraqi cities.
According to figure 4, it can be seen that maximum weather occur in Mosul because of its high rain fall rate and hence lead to unstable state in eye diagram figure. The BER rate in Mosul is $10^{-12}$, in Baghdad is $10^{-56}$, in Basra is $10^{-62}$. Figure 5 depicts the BER performance evaluate with respect to rain rate at different value for both using optical amplifier in FSO system and without using it. It can be observed that the performance of the system is better when using the optical amplifier because the BER is reducing when using the amplifier and leads to enhance the signal parameter.

Table 3. BER of The state of rain in the three regions.

| region | $BER_{max\text{rain}}$ | $BER_{mid\text{rain}}$ | $BER_{light\text{rain}}$ |
|--------|-----------------|-----------------|-----------------|
| Baghdad| $3 \times 10^{-56}$ | $2 \times 10^{-85}$ | $1 \times 10^{-97}$ |
| Basra  | $1 \times 10^{-62}$ | $2 \times 10^{-83}$ | $2 \times 10^{-101}$ |
| Mosul  | $8 \times 10^{-12}$ | $2 \times 10^{-37}$ | $2 \times 10^{-101}$ |

Table 4: the technical specification of FSO system

| Parameters                        | Specifications |
|-----------------------------------|----------------|
| Transmission Distance             | 1 Km           |
| Wavelength                        | 1550 nm        |
| Transmission power                | 5 dB           |
| Photo-detector                    | APD            |
| Gain                              | 20             |
| Modulation type                   | Mach-Zehnder   |
| Transmission aperture diameter    | 0.1 cm – 2 cm  |
| Transmission aperture diameter    | 5 cm – 20 cm   |
| Laser type                        | CW             |
| Bandwidth                         | 500 GHz        |
| User data rate                    | 1 Gbps         |

Figure 4. eye diagram of(A mosul, B Baghdad, C basrah)
Because the rain have the highest attenuation effect in environment, so it increase the BER and the using of optical amplifier to decrease the loses in laser beam. The distance can reach to 1Km as a transmission distance between the sender and the recipient. Figure 6 shows how the transmission distance can effect on the signal impairment. The usage of SCM-SAC-OCDMA with MD code cannot lead to add enhancement on the BER value only, but it can enable us to increase the data rate of the transmission signal to reach in the system to 1 Gbps of transmission data.

Figure 7 shows the performance of the system is better when the transmission power is large with using optical amplifier. This improved performance was obtained because of rising in laser intensity, higher transmitted power, higher in SNR, hence lead to lower in BER value.

Figure 8 shows the visibility can affect on the attenuation result and degrade the FSO system. And also shows the reason of use the wavelength 1550 nm in the SCM-SAC-OCDMA system because like what we notice it give less effect in atmospheric attenuation that the signal exposed to it.
Fig 7: BER against transmission power

Fig 8. Signal attenuation against visibility

7. Conclusions
Nowadays, the development in the communication system is very substantial and the enhancement of many system are increase day by day to keep contribute communication field. In this paper, the performance of SCM-SAC-OCDMA communication system with MD code and optical amplifier has been introduced. The result of weather effect can say that rain factor give significant effect on the signal of the FSO system and produced higher weather attenuation. Max rain falling register BER with value $8 \times 10^{-12}$ in Mosul, $3 \times 10^{-56}$ in Baghdad, $1 \times 10^{-62}$ in Basra. The optical amplifier with gain of 20 dB can help the system of FSO to increase the link distance up to 1Km for communication system with data rate 1Gbps and decrease BER value.

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