IJE TRANSACTIONS A: Basics Vol. 30, No. 7, (July 2017) 988-994

International Journal of Engineering

Journal Homepage: www.ije.ir

Quadrature Amplitude Modulation All Optical Orthogonal Frequency Division Multiplexing-dense Wavelength Division Multiplexing-optical Wireless Communication System under Different Weather Conditions

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P A P E R I N F O

Paper history:
Received 25 January 2017
Received in revised form 08 March 2017
Accepted 21 April 2017

Keywords:
Dense Wavelength Division Multiplexing
All Optical Orthogonal Frequency Division
Quadrature Amplitude Modulation
Optical Wireless Channel Optical Wireless Channel

A B S T R A C T

This paper proposes an analytical model for evaluating the performance of dense wavelength division multiplexing (DWDM) for all optical orthogonal frequency division multiplexing (AO-OFDM) optical wireless channel. The investigated performance for proposed system is evaluated for the parameters bit error rate (BER) and Q factor .The constellation diagrams, and bit error rate (BER) of the received signals are specified. The effect of atmospheric attenuation of the outdoor wireless optical communication system was induced (channel impairments) such as medium rain , light rain , and dust to find their effects on system performance carrier wavelength. The results show the BER and constellation diagram under different weather conditions for different transmission distance using Quadrature Amplitude Modulation (QAM) AO-OFDM-optical wireless channel (OWC).

***doi**: 10.5829/ije.2017.30.07a.08*

NOMENCLATURE

c_k	is the ith information symbol	c	concentration of the scattering coefficient
S_k	is the waveform	q	The size of the particles dispersed
T_s	is the symbol period	**Greek Symbols**	
Δf	the frequency spacing	α	atmospheric attenuation
$d_n(t)$	data sequence of nth channel	α_d	attenuation due to dust
M	is the number of possible sequence	β	scattered coefficient
d_R	received diameter aperture	η	is viscosity of air
d_T	transmitted diameter aperture	ρ_w	water density
Za	rain fall rate	λ	wavelength
a	droplet radius	**Subscripts**	
Q_{Scat}	scatter efficiency	R	distance in Km
g	is gravitational constant	g	Gas

1. INTRODUCTION

For the past ten years many efforts have been done to increase broadband communications. This led to the development of new methods and enabling technologies to support the conventional methods such as the coaxial cable, twisted pair, microwave and radio frequency (RF) systems [1]. Optical Wireless Communications (OWC) has benefited from the developments in optoelectronics and can be a key technology for achieving cost-effective high-speed optical links. The Optical Wireless Communications (OWC) is the technology in which modulated optical signal is propagated over free space without using optical fiber medium [2]. There have been a large number of publications dealing with OFDM and

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Please cite this article as: I. A. Murdas, Quadrature Amplitude Modulation All Optical Orthogonal Frequency Division Multiplexing-dense Wavelength Division Multiplexing-optical Wireless Communication System under Different Weather Conditions, TRANSACTIONS A: Basics Vol. 30, No. 7, (July 2017) 988-994

due to the rapid growth of modern wireless communication technologies, there has been an increasing and intensive demand for its development [3]. OFDM is an efficient technology that is currently being used in many wireless standards like LTE, DVB, WiMax and WiFi. Due to its ability to counter multipath channels and combat inter-symbol interference, OFDM is able to deliver high data rates in multipath fading channels [4]. Orthogonal Frequency Division Multiplexing (OFDM) has been widely studied as a technology to compensate dispersion effects in the optical wireless communication. In optical wireless communication, intensity modulation with direct detection (IM/DD) technique is commonly used for data transmission. However, IM/DD communication is noncoherent (i.e. phase of the optical carrier cannot be used to transmit information) and the transmit signal must be real and positive. These additional constraints require some special care, if OFDM is to be used in optical wireless communications, since the equivalent baseband time-domain OFDM signal is usually complex [5]. Orthogonal Frequency Division Multiplexing is a multi-carrier transmission technique, which divides the available spectrum into many carriers. Each part is modulated by a low rate data stream. The following describes different parts of the OFDM modulator component. The input data can be in different modulation formats, for example: BPSK, QPSK, QAM. This input serial symbol stream is shifted into a parallel format. Then the data is transmitted in parallel by assigning each symbol to a carrier in the transmission. After mapping the spectrum, an inverse Fourier transform is used to find the corresponding time waveform. The cyclic prefix (guard period) can then be added to start each symbol. The component allows the introduction of a cyclic extension for transmitted symbols or a guard time with zero transmission. The parameter number of prefix points will define how many points will be used in the guard period. Different interpolation techniques (Step, Linear, and Cubic) can be used as digital-to-analog converter. After the DAC, the parallel data is shifted back into the serial symbol stream. An internal smoothing filter is applied depending on whether the parameter “Smoothing filter” is enabled or disabled [6].

2. DWDM-OFDM based OWC

The dense wavelength division multiplexing-orthogonal frequency division multiplexing optical wireless channel optical communication system is as shown in Figure 1. OFDM system consists of transmitter optical wireless channel and receiver. In an OFDM system, a high data rate of serial data stream is split up into a set of low data rate sub streams. The parallel data transmission offers possibility for alleviating many of the problems encountered with serial transmission systems such as ISI. The total channel bandwidth is divided into a number of orthogonal frequencies sub channels. Each low data rate sub stream is transmitted on a separate sub channel. The orthogonally is achieved by selecting a special equidistance set of discrete carrier frequencies. It can be shown that, this operation is conveniently performed by the Inverse Fast Fourier Transforms (IFFT). At the receiver, the Fast Fourier Transform (FFT) is used to demultiplex the parallel data streams [7]. The sequence of binary data is mapped to frequency domain subcarriers by employing (QAM) and processed in parallel by applying the inverse fast Fourier transform (IFFT). The multicarrier modulation MCM transmitted signal s(t) is represented as

$$S(t) = \sum_{i=-\infty}^{+\infty} \quad \sum_{k=1}^{N_{sc}} C_{ki}\, S_K(t - iT_s) \tag{1}$$

$$S(t) = \rho(t)\exp(j2\pi f_k t) \tag{2}$$

$$\rho(t) = 1 \;\; (0 < t \leq T_s) \tag{3}$$

$$\rho(t) = 0 \;\; (t \leq 0, t \leq T_s) \tag{4}$$

where, c_{ki} is the ith information symbol at the k_{th} subcarrier, S_k is the waveform for the k_{th} subcarrier, f_k is the frequency of the subcarrier, and Ts is the symbol period.

The detected information symbol C_{ik} at the output of the correlate is given by Fernando et al. [5].

$$\acute{C}_{ki} = \int_0^{T_i} r(t - iT_s) S_k^{*}\, dt = \int_0^{T_i} r(t - iT_s) \exp(-j2\pi f_k t)\, dt \tag{5}$$

3. ALL OPTICAL OFDM

This section present the all optical OFDM concept. Figure 1 shows the structure of the system. The first stage is similar to the conventional OFDM where rate serial data are converted to low bit rate parallel stream. The main difference between the all optical and convention OFDM is that the IFFT is an accomplished optically rather than electrically. Now the low frequency data parallel stream is converted to high frequency optical domain and modulated it using QAM technique. This stage is followed by IDFT which consists of variable phase shifter and couplers, where the phase shifters maintain the orthogonally between the subcarriers [8].

$$\mathrm{S(t)} = \sum_{\mathrm{n=0}}^{\mathrm{N-1}} \mathrm{d_n(t)} \mathrm{e}^{\mathrm{j2\pi(f_0+n\Delta f)t}} \tag{6}$$

where, s represents the multiplexed signal, $d_n(t)$ denotes the channel number and t= KΔt , Δt= T/N is the sampling interval , f_0 is the center frequency of the light source, Δf is the frequency spacing. The output of optically IFFT was added using different couplers, a cyclic prefix CP was added optically by optical gate like fiber delay line and optical switching in all optical OFDM to avoid ISI.

4. PROPOSED SYSTEM

The proposed system is shown in Figure 1, where the simulation parameters are given in Table 1. The QAM DWDM AO-OFDM OWC communication system consists of the following parts: AO-OFDM modulation module, DWDM multiplex module, electrical to optical conversion module and OWC channel, while the receiver side is composed of AO-OFDM demodulation , DE-DWDM optical de- multiplexer, and optical to electrical signal conversion. The parallel stream will be modulated optically into QAM signal where each stream will pick the required intensities according to its location on the QAM map. The modulated signals will be passed through an optical IDFT module. The DWDM will combine and interleave the output of the IDFT and transmitted the mixed signals over the wireless optical channel. In the receiver side after data arrival, we processed the data using different Gaussian filters. All the operations in the transmitted should reversed to restore the source data. In the proposed system the sequence is designed to approximate the characteristics of random data Pseudo Random Binary Sequence (PRBS) according to different operation modes with bit rate 12 Gb/sec. The optical carrier signal generated using the N CW lasers at different frequencies, the average output power is a parameter that you specify at -5 dBm. The modulation technique achieved by generating two parallel M-ary symbol sequences from binary signals using (QAM). With the QAM sequence generator, the bit sequence is split into two parallel subsequences, each can be transmitted in two quadrature carriers when building a QAM modulator. This is achieved by using a serial to parallel converter. Square QAM maps the transmitted information. We can vary the amplitude of a signal according to the source symbols. For each output port, the amplitude takes one of the values from the set of amplitudes

$$a_i = (2i - 1 - M) \tag{7}$$

where, i = 1 ,2,...M, M is the number of possible sequence of binary digits. The up conversion of the electrical data frequency to optical frequency was performed using Mach-Zehnder modulator MZM. The Mach-Zehnder structure consists of an input optical branch, which splits the incoming light into two arms, followed by two independent optical arms, which are subsequently recombined by the output optical branch. Appling an electrical signal to one or both of the optical arms, controls the degree of interference at the output optical branch and therefore controls the output intensity. All OFDM channels interleaved on DWDM multiplexer with 15 GHz bandwidth are sent over (OWC) with the following parameters center wavelength 1550 nm, 6 Km range, transmitter aperture diameter 15 cm, receive aperture diameter 15 cm, transmitter gain 0 dBm and receiver gain 0 dBm.

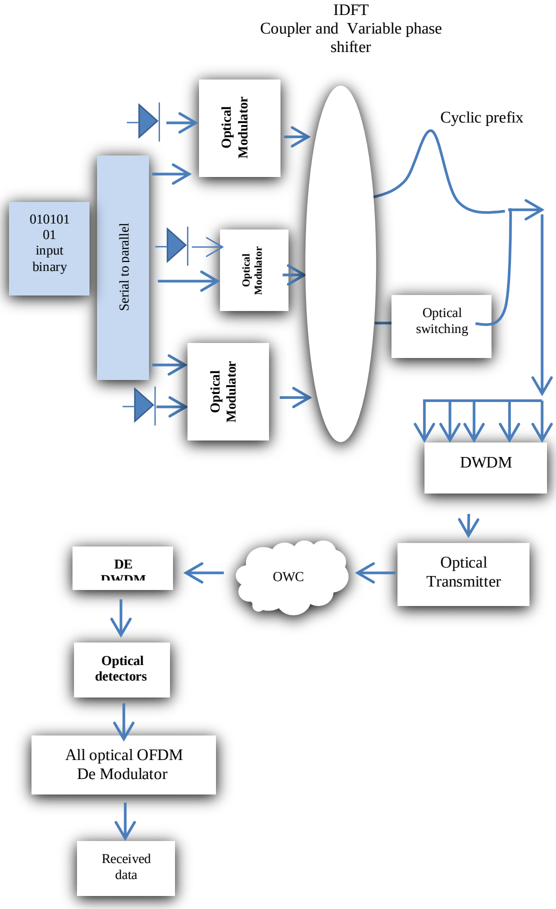

Figure 1. Proposed QAM DWDMAO-ODFDM System

TABLE 1. parameters of proposed system

Parameters	Values
Data rate	12 Gb/s
Laser power	-5 dbm
Link range	variable
Channel space	50 GHz
No. of users	Depend on usage
Line code	NRZ
Modulation technique	QAM
Subcarriers	512
Number of IFFT points	1024
Numbers of prefix points	64
DWDM channels	16

The received signal by DWDM is demultiplexer. After this section the received signal enters coherent detection parts. These parts consist of optical null, x coupler, phase shift, PIN photo detector, electrical substractor. An OFDM demodulator and QAM detectors to get the recovered data.

5. WEATHER CONDITIONS OWC

The simulation environment for the OWCDWDM AO-OFDM was set to model the Iraqi environment. The optical signals transmitted through the channel will suffer from the atmospheric effects like particles dust and different rain rates in the channel. We take the carrier wavelength 1550 nm wavelen as shown in Table 2 focusing on 1550 nm because of less attenuation due to rain and dust effect [8]. The scattering effect of the atmosphere on the laser signals is related to the number and size of the particles. When the number of particles increases, the scattering attenuation becomes more serious. The change in weather concerning dust and rain will vary the scattering attenuation caused by these particles. In different weather conditions, the amplitude and phase noise of the signals are brought to a different extent. This will affect the communication quality, shorten the communication distance, and even leads to communication interruption. The model for the OWC path loss for rainy weather conditions [9].
In the rainy weather conditions

$$\mathrm{P}_{\mathrm{received}} = \mathrm{P}_{\mathrm{transmitted}} \frac{\mathrm{d}_{\mathrm{R}}^2}{(\mathrm{d}_{\mathrm{T}}+\theta\mathrm{R})^2} 10^{-\alpha\frac{\mathrm{R}}{10}} \tag{8}$$

where, d_{R} is the received diameter aperture (m), d_{T} is the transmitted diameter aperture (m), θ is the beam divergence, R is the distance in Km, and α is the atmospheric attenuation .

6. ATMOSPERIC EFFECTS ON OPTICAL SIGNALS

To study the performance of DWDM AO-OFDM OWC system under various weather conditions we take rain effect where the channel parameters under rain effects are shown in Tables 2-4.

6. 1. Rain Effect

The specific attenuation (A_{rain}) caused by rain, depends on the rain rate as given by Table 4.

$$A_{rain} = 1.07R^{\frac{2}{3}} \quad \left[\frac{dB}{km}\right] \tag{9}$$

Where, R is the rain rate in mm/hr. Rain intensity factor is capable of attenuating laser power and cause system under performance in a free space optical (FSO) communication system. The attenuation of the laser power in the atmosphere is described by Beer's law [10].

$$\mathrm{P(R)} = \mathrm{P(0)}e^{-\beta\mathrm{R}} \tag{10}$$

where, P(R) is the received power, P(0) is the initial power, and β is the scattered coefficient. The scattering coefficient can be calculated using Stroke's law [8].

$$\beta_{\mathrm{rain\ Scat}} = \pi a^2 \mathrm{Na} \mathrm{Q}_{\mathrm{Scat}}(\frac{a}{\lambda}) \tag{11}$$

where, a is the radius drop (0.001- 0.1 cm), Na, is the rain drop distribution, $\mathrm{Q}_{\mathrm{Scat}}$ is the scatter efficiency.
The rain drop distribution can be modeled as [10]:

$$\mathrm{Na} = \frac{\mathrm{Za}}{4/3(\pi a^3)\mathrm{Va}} \tag{12}$$

where, Za is rain fall rate (cm/s), a is the droplet radius, Va is the limit speed precipitation.

$$\mathrm{Va} = \frac{2a^2\rho_w g}{9\eta} \tag{13}$$

where, ρ_w is the water density, g is gravitational constant, and η is viscosity of air.

TABLE 2 Parameters of 1550 nm [8]

Parameters	**Values**	**Rain type**
Rain Attenuation	5 dB/km	Light
Rain Attenuation	9 dB/km	medium
Rain Attenuation	18 dB/km	Heavy

TABLE 3. Parameters of 1310 nm [8]

Parameters	**Values**	**Rain type**
Rain Attenuation	7 dB/km	Light
Rain Attenuation	11 dB/km	medium
Rain Attenuation	22 dB/km	Heavy

TABLE 4. Optical wireless channel parameters [9]

(a) Constant Values

Parameters	**Values**
Gravitational constant	980 cm /s2
Water density	1 g/cm2
Viscosity of air	$1.8*10^{-4}$ (g/cm)s
Droplet , a	0.001-0.1 cm
Wavelength	1550 nm
$\mathrm{Q}_{\mathrm{Scat}}$	2

(b) Za, rainfall rate

Type	**mm/h**	**Cm/s**
Light	26	$7.22*10^{-4}$
Medium	40	$1.11*10^{-3}$
Heavy	80	$2.22*10^{-3}$

6. 2. Dust Effect Dust is defined as suspended particles in atmosphere that come from various sources such as soil or dust lifted by weather (an aeolian process), volcanic eruptions, and pollution [11]. The electromagnetic absorption effect is relatively small compared with Mie scattering. Therefore, the scattering coefficient can be calculated depending on the viewing distance and the frequency of the incident beam. The visibility is linked to concentration of dust through Equation (3) [10]:

$$V=7080\times C^{-0.8} \tag{14}$$

where, C = concentration of the scattering coefficient and was calculated depending on visibility and the wavelength of the incident beam [12].

$$\alpha_d = \frac{3.19}{V} \times \left(\frac{\lambda}{8.55nm}\right)^{-q} \tag{15}$$

in which, V = visibility (km) , λ = wavelength,
q = The size of the particles dispersed coefficient and is calculated by the Kruse model [13].

$$q = \begin{cases} 1.6 \text{ if } V > 50\text{km} \\ 1.3 \text{ if } 6\text{km} > V > 50\text{km} \\ 0.585\, V^{\frac{1}{3}} \quad \text{if } V < 6\text{km} \end{cases} \tag{16}$$

7. RESULTS AND DISCUSSIONS

All the results for OWC DWDM AO-OFDM system are shown in the Figures 1-3 and Tables 5-7. Table 5 reports the results of light rain effect in OWC at distance 6 Km while, Table 6 and Figure 2 a,b illustrate the effect of medium rain on the received data consultation and BER performance. After completing the rain effect, we report the effect of dusty weather in Figures 3 a,b.

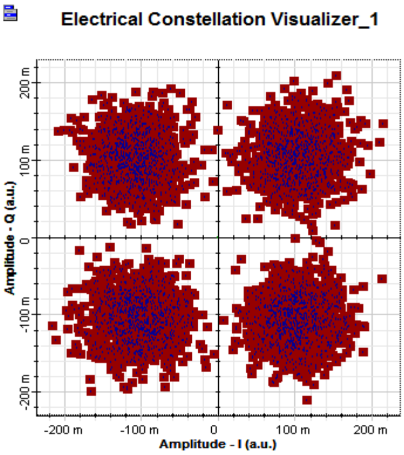

Figure 1a. Illustration of constellation diagram of the received data at light rain 6km distance

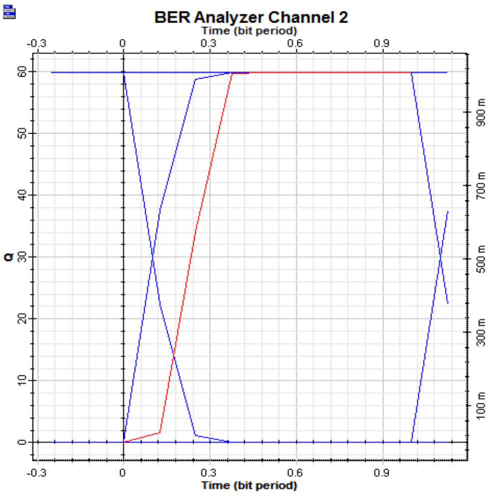

Figure 1b. Illustration of the constellation diagram and BER of the received data at light rain 6km distance

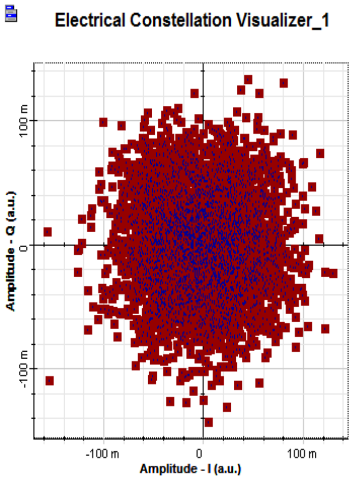

Figure 2a. Illustration of the constellation diagram of the received data at medium rain 6km distance

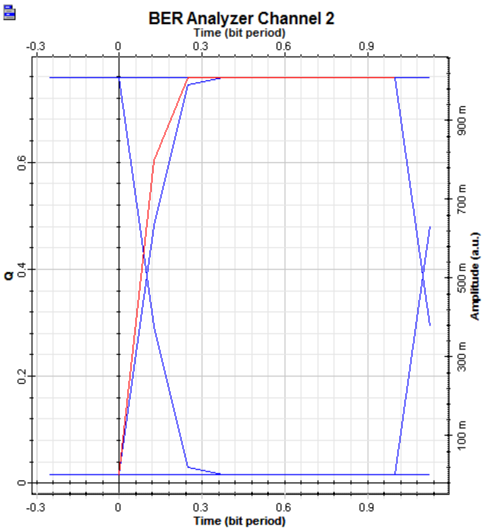

Figure 2b. Illustration of BER of the received data at medium rain 6 km distance

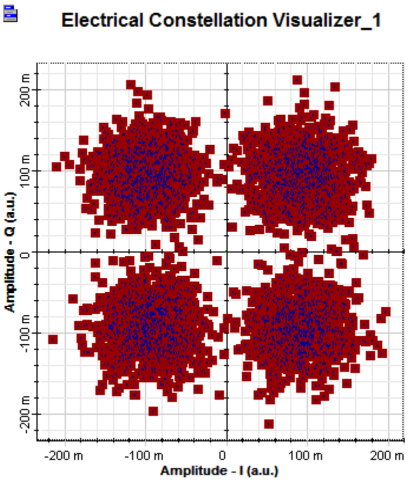

Figure 3a. Illustration of the constellation diagram of the received data at wavelength 1550 nm

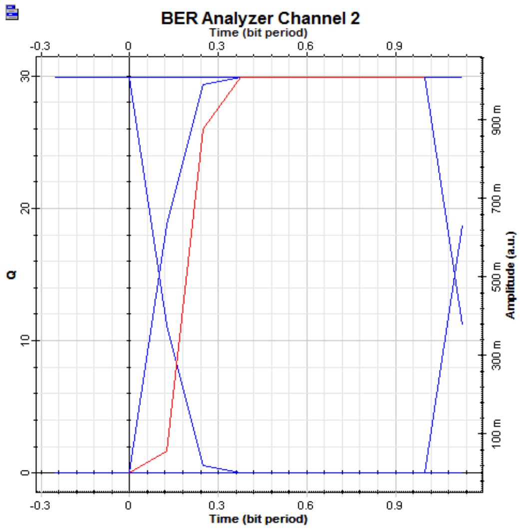

Figure 3b. Illustration of BER of the received data at wavelength 1550 nm

TABLE 5. System parameters for light rain

Parameters	**Values**
Range	6 km
Rni type	Light
Wavelength	1550 nm
BER	1.3 $*10^{-4}$
Q	59

We note from Figures 1a,b that the maximum reachable transmission distance is 6Km for BER 1.3 $*10^{-4}$ and Q-factor is 59, at 12Gb/s data rate, 1550 nm wavelength and carrier power– 5 dBm for channel spacing 50 GHz and 512 subcarrier.

TABLE 6. System parameters for medium rain

Parameters	**Values**
Range	6 Km
Rain type	Medium
Wavelength = 1550	1550 nm
BER	0.19
Q	0.7

TABLE 7. System parameters for dust effect

Parameters	**Values**
concentration dust	(9) gm/month/m2
Visibility	1.25Km
Attenuation	4.2 db /km
Wavelength	1550 nm
Rang	7km
Q	29
BER	2.7 $*10^{-4}$

Figures 2a,b show the results for the same channel parameters and the same transmission distance for medium rain. The BER and Q factor decrease to 0.19 and 0.7 respectively. In dusty weather conditions for the same channel parameters the maximum reachable transmission distance is 7Km for BER 2.7 $*10^{-4}$ and Q-factor is 29.

8. CONCLUDING REMARKS

This paper has analyzed the generation of all optical OFDM DWDM optical wireless system. The proposed system is mathematically analyzed and simulated using software package for different parameters. This technical of all optical processing give great flexibility for optical communication systems. We investigate the performance of different parameters for weather conditions that govern the optical wireless communication channel behavior. All the influencing parameters such as different levels of rain and dust has been evaluated at different channel transmission distance for 1550 nm, with bit rate 12 Gb/s, DWDM with 50 GHz channel space. The constellation diagrams, and the BER performance of the received signals are measured at the receiver and all results show that the best performance of the QAM DWDM AO-OFDM OWC at carrier wavelength 1550 nm, laser power -5 dBm, 12 Gb/s bit rate, 6 Km transmission distance for light rain, dusty weather conditions.

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Received 25 January 2017
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Accepted 21 April 2017

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Quadrature Amplitude Modulation
Optical Wireless Channel Optical Wireless Channel

چکیده

این مقاله مدلی تحلیلی برای محاسبه عملکرد مدولاسیون تسهیم موج فشرده (DWDM) برای مدولاسیون متعامد با تسهیم فرکانس تمام نوری(AO-OFDM) کانال بی سیم ارائه می دهد. کارکرد بررسی شده در سیستم ارائه شده برای پارامتر های نرخ خطای بیت(BER) و سازه Q محاسبه شده است. دیاگرام های پیکره(Constellation) و نرخ خطای بیت (BET) سیگنال های دریافت شده مشخص شده اند. تاثیر تضعیف اتمسفری سیستم مخابرات نوری بی سیم بیرونی (Outdoor) مانند باران متوسط، باران کم و گردوغبار اعمال شد (اختلال کانال) تا اثرات آنها بر عملکرد طول موج حامل سیستم پیدا شود. نتایج بدست آمده BER و دیاگرام های پیکره تحت شرایط جوی مختلف برای فواصل انتقال مختلف را با استفاده از مدولاسیون دامنه تربیعی(QAM) AO-OFDM کانال بی سیم (OWC) ، نشان می دهد.

doi*: 10.5829/ije.2017.30.07a.08*