Performance analysis of M-QAM OFDM for satellite laser communication systems

1st Yuying Sun
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications
Beijing, China
sunyuying@bupt.edu.cn

2nd Lei Yang
China Transport Telecommunications & Information Center
Beijing, China
yanglei@cttic.cn

3rd Xueguang Yuan
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications
Beijing, China
yuanxg @bupt.edu.cn

4th Yang'an Zhang
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications
Beijing, China
zhang@bupt.edu.cn

5th Mengting Qu
State Key Laboratory of Information Photonics and Optical Communications
Beijing University of Posts and Telecommunications
Beijing, China
qumengting@bupt.edu.cn

***Abstract*—This paper proposes a satellite laser communication system based on M-QAM OFDM and analyzes the system performance. The relationship between the link bit error rate and the transmission power under different conditions of atmospheric turbulence intensity and QAM modulation order is simulated.The results show that as the turbulence intensity increases, the QAM modulation order M increases, and the performance of OFDM optical links continues to deteriorate. This provides a reference for parameter optimization and performance evaluation of OFDM optical links in satellite laser communications.**

***Keywords*—OFDM, M-QAM, satellite laser communication**

I. Introduction

With the development of high-resolution cameras, synthetic aperture radars and high-capacity satellite communications, the amount of information transmitted by various spacecraft has grown exponentially. At present, the microwave communication methods mainly used by satellites have been unable to meet the corresponding requirements, which has promoted the development of the laser communication industry. Data transmission rate of satellite laser communication technology is 100 times higher than that of microwave communication. It will meet the increasing demand for space data transmission rate, transmission volume and real-time performance, and it is expected to become the main form of space communication in the future. In addition, satellite laser communication can achieve safe and high-speed communication due to its strong beam directivity, high frequency and high bandwidth[1].

However, the channel of satellite laser communication will be affected by the scattering of particles such as dust, raindrops and fog. Moreover, the combined effects of atmospheric turbulence, geometric transmission loss, and pointing error also affect the performance of the space laser link. The atmospheric scattering channel is a frequency selective fading channel[2]. Orthogonal frequency division multiplexing (OFDM) modulation is the best choice to overcome the frequency selective fading effect. OFDM is a multi-carrier modulation method, and the subcarriers can adopt a variety of different modulation methods, usually phase shift keying(PSK) or quadrature amplitude modulation(QAM). It has the advantages of good anti-turbulence performance, strong anti-interference ability, high data rate and high spectral efficiency[3-5].

This paper proposes a satellite laser communication system based on M-QAM OFDM and analyzes the system performance. The relationship between the link bit error rate and the transmission power under different conditions of atmospheric turbulence intensity and QAM modulation order is simulated[6-10].

The rest of paper is organized as follows. In the nextsection we present MQAM-OFDM system, experimental setup and results and the last section is conclusion.

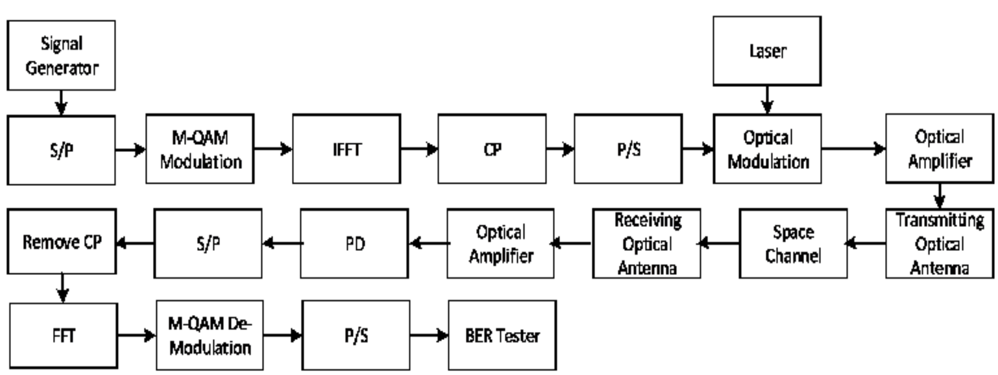

Fig. 1. M-QAM OFDM system principle structure

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II. THE SYSTEM MODEL

A. Modulator

M-QAM OFDM system principle is shown in fig 1.

In OFDM system the received data will be divided into N parallel data, which we call as from now serial to parallel conversion,then inverse Fourier transform (IFFT) is performed on the modulated signal, namely, M-QAM and a guard interval is added. IFFT transforms the spectrum expression of the data into the time domain, allocates the bits to be transmitted to each subcarrier, and maps it into the amplitude and phase of the subcarrier. The role of adding a guard interval is to maximize the elimination of intersymbol interference (ISI). There are two ways to achieve this. One is to set all the symbols of the guard interval to zero. Another effective method is a cyclic prefix. Part of the symbol is added cyclically to the head of the frame. Then, it is transmitted to the PD and the light receiving antenna through the laser and the light transmitting antenna in the space channel.

B. Space Channel

By studying the channel characteristics of satellite-to-ground and inter-satellite optical communication links, a corresponding spatial optical channel model is established, and corrections are applied in combination with application scenarios. In space optical communications, the analysis of optical links mainly considers the effects of atmospheric turbulence effects. At present, many different statistical models have been proposed for the description of light intensity flicker caused by atmospheric turbulence, such as negative exponential distribution, lognormal distribution, and Gamma-Gamma distribution model. The two parameters are close to the physical characteristics of atmospheric turbulence, which can more accurately Describe the fluctuation of light signal intensity caused by atmospheric turbulence. The probability density function of the atmospheric turbulence influencing factor h_t in accordance with the Gamma-Gamma distribution model is[11]:

$$f_{h_t}(h_t) = \frac{2(\alpha\beta)^{\alpha+\beta/2}}{\Gamma(\alpha)\Gamma(\beta)}(h_t)^{(\alpha+\beta/2)-1}\mathrm{K}_{\alpha-\beta}\left(2\sqrt{\alpha\beta h_t}\right) \quad (10)$$

In the equation:

$$\alpha = \left\{exp\left[\frac{0.49\sigma_0^2}{(1+1.1\sigma_0^{12/5})^{7/6}}\right]-1\right\}^{-1} \quad (11)$$

$$\beta = \left\{exp\left[\frac{0.51\sigma_0^2}{(1+0.69\sigma_0^{12/5})^{5/6}}\right]-1\right\}^{-1} \quad (12)$$

$\mathrm{K}_{\alpha-\beta}\left(2\sqrt{\alpha\beta h_t}\right)$is a second-class modified Bell function of order $\alpha-\beta$, $\Gamma(\alpha)\Gamma(\beta)$ b is a Gamma function, and σ_0^2 is RytovVariance,namely, $\sigma_0^2 = 1.23C^2\mathrm{K}^{7/6}\mathrm{z}^{11/6}$ C_n^2 is the atmospheric refractive index structural constant, K is the plane wave number, $\mathrm{K} = 2\pi/\lambda$ is the link operating wavelength, and z is the speed of light propagation distance.

In addition to the atmospheric turbulence, the factors that affect the fluctuation of the optical signal intensity are the pointing errors of the optical links between the platforms. According to the pointing error theory, the probability density function of the pointing error factor of the optical link between platforms can be expressed as[11,12]:

$$f_{h_p}(h_p) = \frac{\xi^2}{A_0^{\xi^2}}(h_p)^{\xi^2-1} \qquad 0 \le h_p \le A_0 \quad (13)$$

In the equation:

$$v = \sqrt{\pi r}/(\sqrt{2}\,w_z) \quad (14)$$

$$w_{z,eq}^2 = \frac{w_z^2\sqrt{\pi}ef(v)}{[2vexp(-v^2)]} \quad (15)$$

ξ is the ratio between the equivalent beam radius at the receiving end and the standard deviation of the pointing error offset,$\xi = w_{z,eq}/2\sigma_s$,$A_0 = [\mathrm{erf}\,(v)]^2 w_{z,eq}$is the equivalent beam width at the receiving end, σ_s is the standard deviation of the pointing error offset at the receiving end, erf (v) is the error function, and w_z is the beam width at distance z, $w_z = \theta z$, θ is the beam emission angle, and r is the receiver radius.

C. Demodulator

At the receiver side, the data converted to parallel and added cyclic prefix removed then FFT is taken to take it back freq. domain which is vice versa processing of transmitter side, and finally performing De-Modulation[13-14].Now we use specific number to explain the progress of modulation and demoduiation. *N* symbol data becomes *N*+*L* symbol data, which is done after taking of IFFT of the input symbols, with addition of cyclic prefix. In easy saying it is taking last *N* symbols and adding beginning of data streams. The OFDM signal is produced by taking the Inverse Fast Fourier Transform of modulated signal at baseband. An OFDM symbol size is predefined. Suppose the required period of an OFDM symbol is T. At the beginning of every OFDM symbol there is a cyclic prefix of length T_g, created by taking last L symbol in a OFDM sysmbol and adding to begining. T_g must be greater than channel impulse response time to be useful. For each subcarrier the following formula given as:

$$v(t) = \sum_{k=-N}^{N} C_k \exp(j2\pi f_k t)\,, 0 \le t \le T \quad (16)$$

Where $f_{k=}k/T$ is the frequencies of complex exponentials of one OFDM symbol and *2N+1* is number of subcarrier. This signal is up converted and transmitted through a channel. Atthe receiver it is down converted, timing synchronization is done, cyclic prefix is removed and FFT is applied.

III. EXPERIMENTAL SETUP AND RESULTS

In the simulation system,each parameter is set as follows: source generate pseudo-random sequence,bit rate is 10Gbit/s. With 4-QAM modulation and 1024-point IFFT variation, the time-domain signal is modulated onto different carriers, and the number of subcarriers is set to 512. The length of the guard interval is 1/8 of the length of the IFFT output parallel sequence. The light source is a DFB semiconductor laser. Laser's spectral width is 10MHz.

Figure 2 shows the relationship between the total average bit error rate of an OFDM link and the transmit power under different atmospheric turbulence conditions when the sub-carrier uses 4-QAM modulation. Turbulence strengths $\boldsymbol{\sigma_0^2}$ is respectively set as 0.4,1.4and 4.It can be seen from Figure 2 that with the increase of turbulence intensity, the average bit error rate of 4-QAM-OFDM link increases continuously, and the performance deteriorates continuously, with the increase of transmission power, the average bit error rate of the link decreases, and the link communication performance improves.

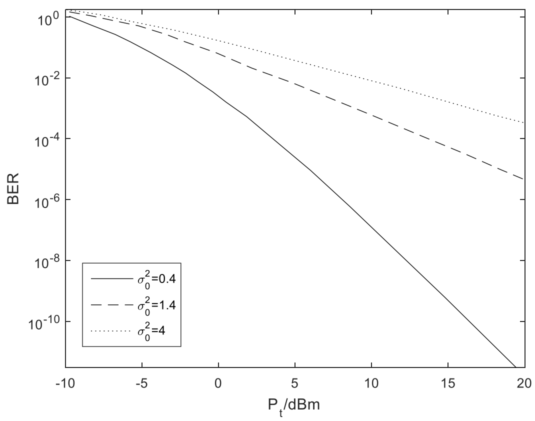

Fig. 2. The relationship of the average BER and the transmitted power P_t in different turbulence strengths $\boldsymbol{\sigma_0^2}$ when M=4

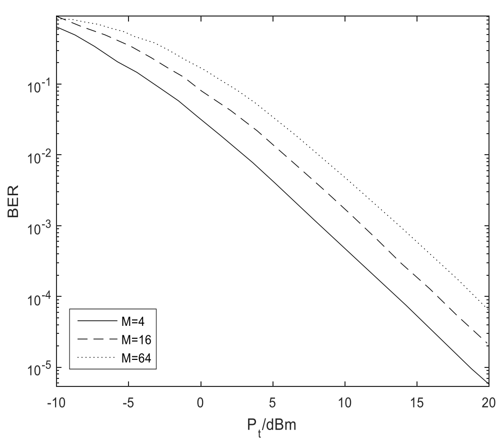

Fig. 3. The relationship of the average BER and the transmitted power $P_t$in M-QAM modulation when $\boldsymbol{\sigma_0^2 = 1.4}$

Figure 3 shows the relationship between the average bit error rate of an OFDM link and the transmit power when the sub-carriers use M-QAM modulation.Turbulence strengths. $\boldsymbol{\sigma_0^2}$ is 0.4. M is respectively set as 4,16and 64.As can be seen from Figure 3, with the increase of M, the average bit error rate of the OFDM link continues to increase and communication performance deteriorates, by increasing the transmission power, the average bit error rate of the link can be reduced to improve communication performance, With different base QAM modulation, the degree of improvement in link communication performance obtained by increasing the transmission power is approximately the same.

IV. CONCULUSION

The M-QAM OFDM is applied to satellite laser communication, and the relationship between the bit error rate of the OFDM optical link and the transmission power is analyzed under different conditions such as different atmospheric turbulence intensity and QAM modulation order. The results show that as the turbulence intensity increases, the QAM modulation order M increases, and the performance of OFDM optical links continues to deteriorate. This provides a reference for parameter optimization and performance evaluation of OFDM optical links in satellite laser communications.

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