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Study on Optical MIMO Technique of Space Optical Communication System

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Abstract

Optical MIMO technology of spatial optical communication system is proposed, the characteristics are analyzed and the system modeling is simulated. Optical MIMO technology mainly solves the generated multipath effect of atmospheric channel for the laser signal transmission in space laser communication system, which enhances anti-jamming and anti-fading capability of the system.

1. Introduction

Space laser communication transmission has the advantage of high rate, high security and good anti-interference ability , the world has been carried out years of research work, but due to the channel of space laser communication system is an open air channel , whose features have strong randomness, atmospheric turbulence and scintillation phenomena which influence the transmitted laser beam seriously , it will cause the error rate increase, it even will cause the laser communication interrupted[1]. MIMO technology is a major breakthrough for smart antenna in the field of wireless mobile communication technology, the technology can exponentially increase the capacity of communication system and spectrum efficiency without increasing the bandwidth, it is the key technology which the next generation mobile communication system must use. Making use of this technology to the space optical communication system to resolve multipath effects resulting from beam drift and expansion phenomena caused by the atmospheric turbulence and other atmospheric conditions, optical MIMO system combines spatial

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multiplexing and diversity combining techniques, which can convert unfavorable factors such as optical signals drift and multipath propagation into transmission rates and band gain.

2. Optical MIMO technology

MIMO (Multiple Input Multiple Output) technology is to use multiple transmit antennas and receive antennas at the transmitter and the receiver, the signals are transmitted and received through a plurality of transmit antennas and receive antennas, MIMO technology can improve the capacity of the channel, and it can also improve the reliability of the channel and reduce the error rate. Fading is an important factor affecting the performance of the communication system transmission, increasing the transmit power can overcome the effects of fading appropriately, but if the depth of the decline will reach 30 ~ 40dB, and then increasing the transmission power cannot meet the system requirements, and it will serious interfere other transmitters. [2]

The essence of diversity is to send multiple copies of the same information through multiple optical antennas, the taken way can be considered in terms of time and space. The signal light from optical transmitter generate different channel fading due to the different atmospheric transmission characteristics , the receiver will merge, detect and judge the contained information of copies by a plurality of receive optical antennas , and accurately restore the signal . At the premise of poor atmospheric channel and noise-limited, not using diversity techniques it needs to rely on to enhance the transmit power to ensure normal communication link.

Diversity techniques can be divided into space diversity , frequency diversity , angle diversity , time diversity and geographical diversity based on the different way to achieve the signal "irrelevant ", wherein the system performance of space diversity is the best, because it is not limited by delay and environmental factors. Spatial diversity has the biggest advantage compared with other diversity scheme is that it can improve system performance to a large extent without loss of transmitted bandwidth, in particular to improve the anti -fading capability of the system. Spatial diversity can be divided into Multiple Input Single Output and Single Input Multiple Output. Rational choice or merger may reduce impact for signal transmission by atmosphere turbulence and multipath fading, reduce the error rate of communications systems, and improve system performance. The diversity system making use of multiple optical transmitting antennas and a plurality of optical receiving antenna is called Multiple Input Multiple Output. Using diversity techniques can provide some diversity gain, but diversity gain depends on the merging technical of the receiving end. How to effectively merge multiple receiving copies and improve the signal to noise ratio is an important measure of diversity techniques on the performance improvement degree of the communication system. There are three common merging techniques: the best choice combining, equal gain combining and maximal ratio combining.

By comparing the performance of the three what can be obtained is: For the improvement of the SNR, when the number of multiplicity diversity is same, the maximum ratio combining is the best way, equal gain combining method follows; When multiplicity diversity is small, the performance of equal-gain combining close to that of maximum ratio combining, selective merge is the worst. Moreover, the performance of equal gain combining is not the best of the three mergers, but its complex of implementation is less, which is a more practical way of merger, MIMO system in this paper chooses this merged technology.

3. Optical MIMO model

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Optical MIMO technology means beam emitting and multi-porous receiving technology. Summary of experimental results shows that, MIMO technology is an effective way to decrease the light intensity fluctuation [3]. Communication conditions are listed below: in the near-earth atmospheric levels link, transmission distances are taken 1.2km and 10.4km respectively, when the numbers of emitted beams are 1, 2, 4, 8, 16, the receiving antenna diameter is 5.1cm, with the increase of the number of beams, the light intensity fluctuation in turn weakens. The light intensity distribution of 1.2km transmission distance is better than 10.4km transmission distance, the light intensity fluctuation variance of the former is much smaller than the latter. For the single-beam emission, the figure shows the intensity fluctuation is very large; the curve is close to the negative exponential distribution. With the number of the emitted light beam increasing, the curve is closer to the lognormal distribution.

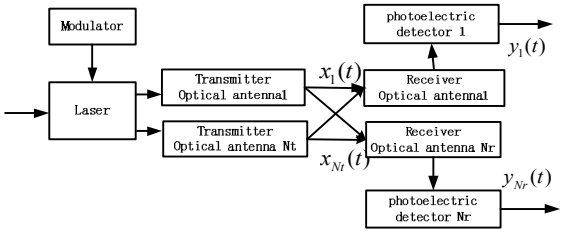

Fig.1 Channel model of optical MIMO system

An optical MIMO system is constructed, the channel model is shown in Figure 1 , the mission matrix is set as $x(t)=\left(x_1(t),x_2(t),\ldots,x_{N_t}(t)\right)^T$, $x_i(t)$ indicates the signal laser emitted from the i optical antenna. Receiving matrix is $y(t)=\left(y_1(t),y_2(t),\ldots,y_{N_r}(t)\right)^T$, $y_j(t)$ represents optical signal received from the j optical antenna, channel model of the system is

$$y(t)=\eta Hx(t)+n(t) \tag{1}$$

Wherein η is the conversion efficiency of photoelectric detector. Noise matrix is $n(t)=\left(n_1(t),n_2(t),\ldots,n_{N_r}(t)\right)^T$, where each element are met with the Gaussian white noise of zero mean and σ^2 variance .Let H be channel fading matrix, then

$$H=\begin{bmatrix} a_{11}^2 & a_{12}^2 & L & a_{1N_t}^2 \\ a_{21}^2 & a_{22}^2 & L & a_{2N_t}^2 \\ L & L & L & L \\ a_{N_r1}^2 & a_{N_r2}^2 & L & a_{N_rN_t}^2 \end{bmatrix} \tag{2}$$

Where, a_{ji}^2 means light intensity attenuation coefficient from the i-th laser to the j-th detector, assuming it obeys lognormal distribution.

4. Simulation Results

For the system model established above, free-space optical communication system based on MIMO is simulated taking use of Matlab software: space-time coding respectively uses the traditional Alamouti space-time block codes and quasi- orthogonal space-time block code encoding scheme, the modulation respectively uses Q-PPM modulation, decoding method is maximum likelihood decoding, the performance analysis curve is shown below.

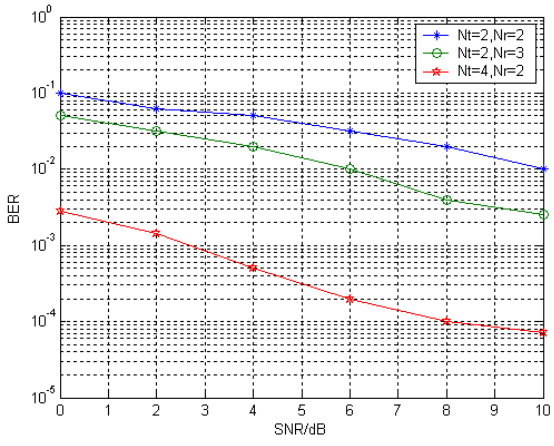

Fig.2 BER of Alamouti scheme and quasi-orthogonal scheme

The BER performance of communication

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system under the Alamouti space-time block coding scheme $N_t = 2, N_r = 2$ and $N_t = 2, N_r = 3$, quasi-orthogonal space-time block code encoding scheme $N_t = 4, N_r = 2$ are shown in Figure 3. As can be seen from the above figure, with the number of receiving antennas increasing, the error rate of the system is effective improved; under certain circumstances to noise ratio, the error rate of quasi-orthogonal space-time block coding scheme is lowest, and the system performance is best, indicating that the encoding method is applicable to free-space optical communication, it can effectively inhibit the effects of atmospheric turbulence for optical communication.

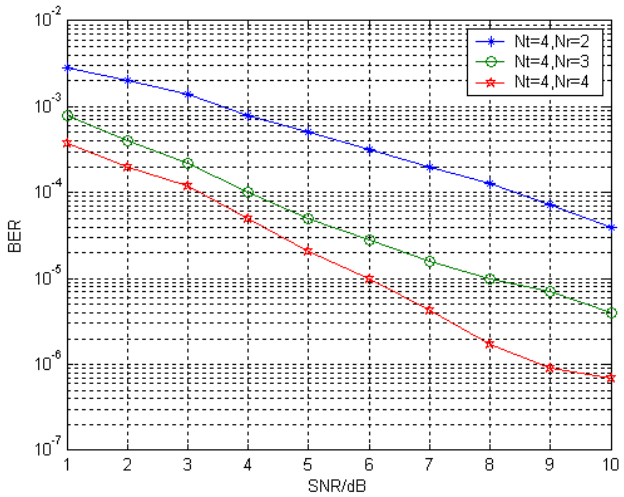

Fig.3 BER of quasi-orthogonal space-time block coding scheme under different reception diversity circumstances

Figure 3 shows BER of quasi-orthogonal space-time block coding scheme under different reception diversity circumstances, the reception diversity respectively is $N_t = 4, N_r = 2$, $N_t = 4, N_r = 3$, $N_t = 4, N_r = 4$. As can be seen from the figure , under the same signal to noise ratio , the higher of the diversity, the more evident of BER performance improvement; when BER of the system is the same (e.g., BER is up to 10^{-3}) , the SNR can improve 4dB when the diversity degree is 3 compared to the diversity degree of 2; the system has the best performance when SNR is $N_t = 4, N_r = 4$, when the SNR is greater than 6dB, error rate of the system can be low to 10^{-5},which describes quasi-orthogonal space-time block coding can effectively improve system performance.

5. Conclusion

This paper study on optical MIMO technology of the space optical communication system, the channel capacity of optical MIMO increases linearly with the number of transmitting antenna growing theoretically, which describes optical MIMO systems with huge capacity potential; optical MIMO system makes division multiplexing for time and space using multiple optical antenna, enhanced anti-jamming and anti-fading capability of the system; If the performance of free-space optical communication systems is further improved, considering to combine MIMO technology with advanced channel coding techniques.

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