Performance simulation of heterodyne synchronous receiving system in coherent optical communication

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ABSTRACT

Coherent optical communication technology is currently a hotpot research of communication. Coherent optical communication heterodyne synchronous receiving system is researched. The basic principle of coherent optical communication is introduced in briefly, the heterodyne synchronous receiving system is established in the basis of the principle. A simulation model, charactered as Synchronous receiving system of Coherent Heterodyne, was rightly set up. In addition, with regarding actual device parameters as reference，and under the situation of 2.5Gbps communication rate and 10km as communication distance, Optisystem was operating to accomplish simulation analysis for capacity of this system in different signal-radiation rate and distinguish weather condition. The consequence of simulation demonstrated: as the receiving sensitivity is relatively high when compared communication system of coherent heterodyne to that of IM/DD, the coherent optical communication system has lower requirement to signal rate of radiated laser in the same condition. Consequently, it can be concluded that coherent heterodyne system has high receiving sensitivity, and strong capacity of resisting disturbance, moreover it is appropriately communicated in channel with relatively high disturbance, it possesses great advantages to IM/DD method in atmosphere channel which has strong disturbance.

Keywords: coherent optical communication, heterodyne detection, heterodyne synchronous receiving, simulation

0. INTRODUCTION

Comparing to intensity modulation/direct detection (IM/DD), Coherent detection possesses such merits as high sensitivity, high communication rate and various modulating methods. Recently coherent detection has become hotpot in the research of wireless laser communication. In this paper, we set up a heterodyne synchronous BPSK coherent optical communication system, and take use of Optisystem simulation software to conduct simulation analysis for the plan in diversified weather conditions. Consequently we testify the advantage of sensitivity for coherent optical communication heterodyne synchronous receiving system.

1. THE PRINCPLE OF CONHERENT LASER COMMUNICATION HETERODYNE DETECTION

In the coherent detection system, the received signal light and the local oscillator light are mixed in the optical mixer, and than the light enters into the balance detector. The balance detector turns the change of optical carrier signal into the change of the light intensity, the electrical signal is processed and the data is exported. The transmitter can use the digital information of the transmitter to modulate the carrier light, if using the phase of the digital information to modulate carrier light, we call it BPSK.

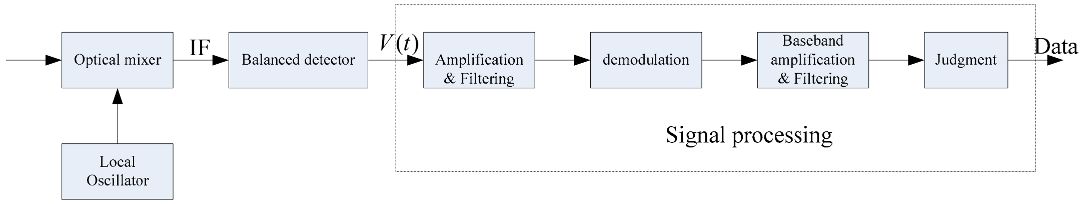

Figure 1 Schematic diagram of heterodyne coherent optical communication receiver

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Analysis on the principle of coherent detection:
Providing the electric field of the received signal light and the local light and the electric field are

E_S and E_L .

$$E_S = \sqrt{2P_S}\cos(\omega_S t + \phi_S(t)) \tag{1}$$

$$E_L = \sqrt{2P_L}\cos(\omega_L t + \phi_L(t)) \tag{2}$$

Where P_S , ω_S and $\phi_S(t)$ are power, frequency and phase of the received signal light,

P_L , ω_L and $\phi_L(t)$ are power, frequency, and phase of the local light.

The output voltage signal from the balanced detector is written as

$$V(t) = 2Rr\sqrt{P_S P_L}\cos(\omega_{IF}(t) + \phi_S(t) - \phi_L(t)) + n_r(t) \tag{3}$$

Where R is the detector responsivity, $n_r(t)$ is Shot Noise, $\omega_{IF} = \omega_S - \omega_L$ is IF.

If $\omega_{IF} = 0$, it is regarded as the Homodyne detection method, if $\omega_{IF} \neq 0$,it is regarded as the Heterodyne detection method. The power of the received signal enhances which is obtained from P_L and P_S .When it is the Homodyne detection, the intensity of signal which is from the balanced detector is stronger than heterodyne detection and the detection sensitivity is 3dB higher than heterodyne. As it is the Homodyne detection, the output signal from the detector is baseband signal, but it must be an extremely high demand of the sensitivity of phase. It has the requirements that frequency and phase of the received signal and the local oscillator signal is equal strictly and it also needs to design an optical phase-locked loop which has a strong performance. The Homodyne detection demands a light source with a high frequency stabilization, narrow linewidth and larger frequency tuning range, so it is too difficult to achieve the Homodyne detection entirely, it is so important to research heterodyne detection.

In the same conditions, the sensitivity of heterodyne detection is 3dB lower than Homodyne detection, the output signal which is from the balanced detector is IF signal, it needs secondary demodulation to obtain baseband data. But the heterodyne detection system don’t demand frequency and phase of the received signal and the local oscillator signal to be locked strictly, thus it reduces the requirement of the stability on the frequency and phase of the received signal and the design of the receiver is relatively simple. It is a more practical solution in the coherent optical communication.

2. HETERODYNE COHERENT OPTICAL COMMUNICATION RECEIVER SYSTEM

There are two kinds of demodulation modes in heterodyne coherent receiver: 1.heterodyne asynchronous demodulation, 2. heterodyne synchronous demodulation.Heterodyne asynchronous demodulation system don’t need carrier recovery, and it is applied for ASK，FSK，DPSK and so on. But heterodyne synchronous demodulation system needs carrier recovery. In this paper, we design heterodyne coherent optical communication system using BPSK modulation which has a strong anti-jamming performance. Selecting phase modulation in coherent optical communication system can improve the anti-interference performance. In the coherent heterodyne mode, the mixing signal is the IF carrier signal which needs secondary demodulation to the baseband.

2.1 Heterodyne asynchronous demodulation

Heterodyne asynchronous demodulation is relatively easy which doesn't need electrical phase-locked loop (EPLL).The IF signal is exported after the signal light and the local oscillator light are mixed, the output signal passing the balanced detector is enlarged via the amplifier and then it conducts the enveloping demodulation. The modulated data can be exported through the low-pass filter. Heterodyne asynchronous coherent optical communication system is shown in Figure 2.

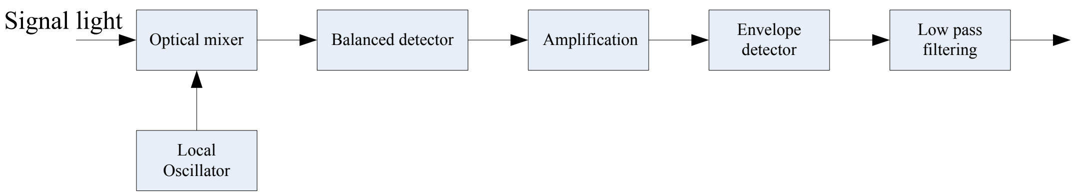


Figure 2 Schematic diagram of coherent heterodyne asynchronous demodulation receiver

2.2 Heterodyne synchronous demodulation

Heterodyne synchronous receiver has a higher sensitivity which is hard to Achieve. It requires EPLL to recover the IF carrier from the received data in order to achieve synchronous demodulation. Its sensitivity is higher than heterodyne asynchronous demodulation system and the receiver is more complicated.The block diagram of Coherent heterodyne synchronous receiver is shown in Figure 3.

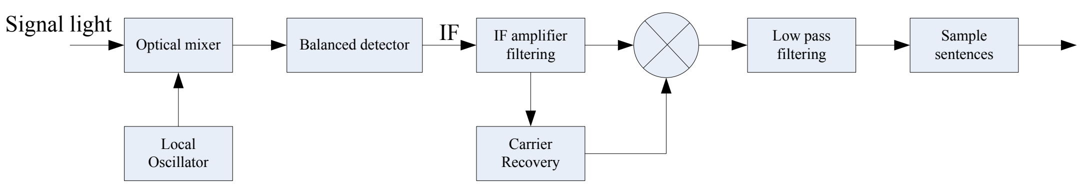


Figure 3 Schematic diagram of coherent optical communication heterodyne synchronous receiver

3. HETERODYNE COHERENT OPTICAL COMMUNICATION RECEIVER SYSTEM BASED ON OPTISYSTEM SOFTWARE

As shown in figure 4，Heterodyne coherent optical communication receiver system mainly consists pulse generator, modulation module, laser, atmospheric channel module, optical mixing module, photodetector APD and synchronous demodulation module. Figure 4 shows each module's parameters. Atmospheric channel module select OWC channel. Optical signal's degree of attenuation varies in the different weather conditions, and it has attenuation of 0-1dB/km when sunny, 1-4dB/km when cloudy or rainy, 5-14dB/km when misty, 14-34dB/km when foggy. In this paper, atmospheric channel module simulates the receiver's performance under variety of weather conditions, and synchronous demodulation module mainly consists of electronic PLL.

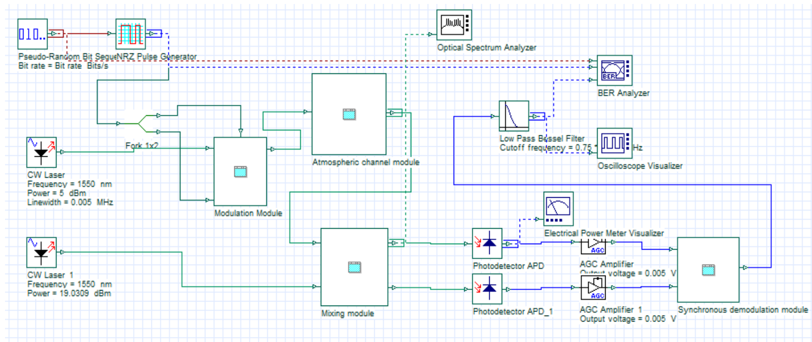


Figure4 Simulation model of coherent optical heterodyne synchronous demodulation system

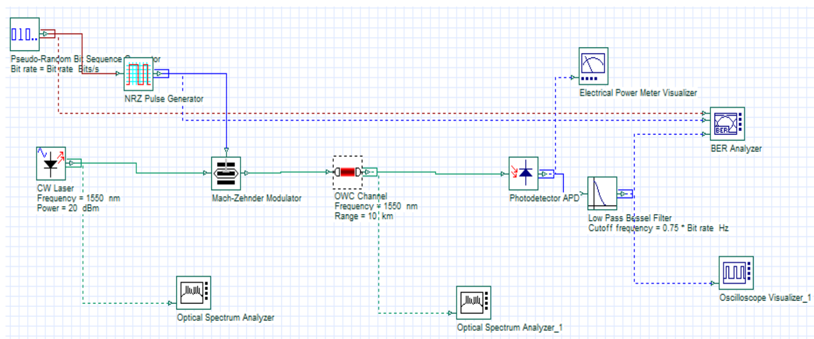


Figure5 System simulation model of IM/DD reception method

The main simulation parameters are as follows: linewidth of laser is 10 kHz, rate of communication is 2.5Gbps, wavelength of communication is 1550nm, distance of communication is 10km, and power of local oscillator is 80mW. Signal modulation module is mainly made up of phase modulator of lithium niobate. It modulates the generated data to the phase of signal light. Atmospheric channel module selects OWC channel, and transmitting antenna's diameter is 15cm as the same as the receiving antenna's. It adopts balance-receiving method along with the coupling rate of 0.5.

3.1 Receiving sensitivity simulation when cloudy

When transmitting signal power is 5dBm, local oscillator power is 20dBm and atmospheric channel attenuation is 3dB/km (cloudy), we obtain the waveforms of the transmitting and receiving signals. As shown in figure 6, when rate of communication is 2.5Gbps, heterodyne coherent reception system recovers receiving signal well.

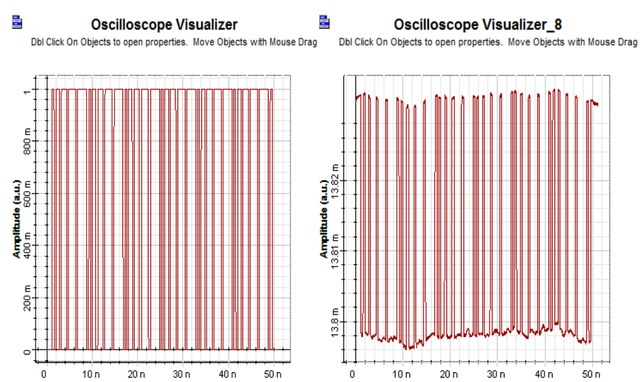
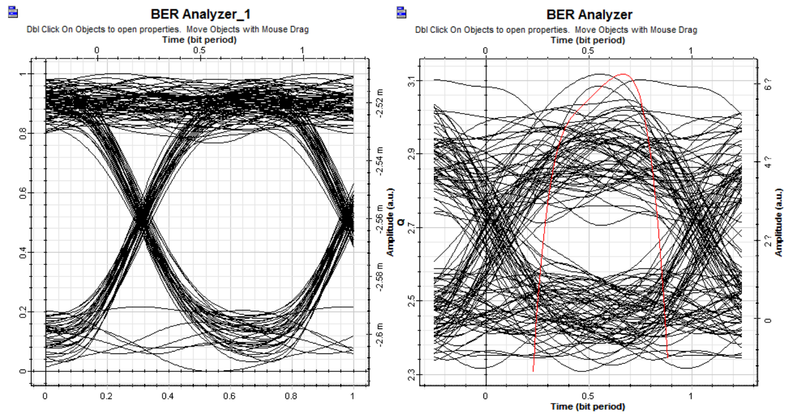


Figure 6 Waveforms of transmitting and receiving signals (a) is Transmitting signal waveform (b) is Receiving signal waveform



(a) (b)

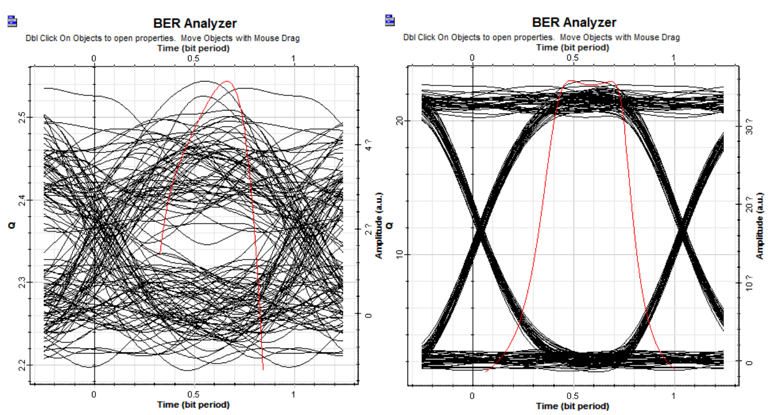
Figure 8 Eye patterns of coherent heterodyne and IM/DD receiving signals

(a) is Eye pattern of coherent heterodyne receiving signal (b) is Eye pattern of IM/DD receiving signal

As shown in figure 8, when transmitting powers are 5dBm, OWC atmospheric channels are 10km and attenuations are 3dB/km (cloudy), both the ways of coherent heterodyne and IM/DD can receive signals. At the time, coherent receiving method receives electrical power of -56.852dBm, whose minimum error rate is 0.86×10^{-16} . IM/DD method receives electrical power of -31.768dBm, whose minimum error rate is 0.57×10^{-4}. Both of the error rate and receiving signal power of coherent heterodyne method are lower than IM/DD method. Besides, coherent heterodyne recovers signals well. However, IM/DD method is difficult to make sure of correct reception of data. Above all, it is manifest that coherent heterodyne has advantage of high sensitivity.

3.2 System performance simulation when misty

Coherent heterodyne detection is badly effected by the attenuation of atmospheric channel. The atmospheric channel attenuation is different under different weather. Below is given that simulation situation of coherent heterodyne system when atmospheric channel is attenuated to 5dB/km (misty).



(a) (b)

Figure 9 Q value and eye pattern of coherent heterodyne receiving end

(a) is When transmitting power is 20dBm (b) is When transmitting power is 30dBm

As shown in the figure 9, when the channel attenuation is 5dBm/km and transmitting signal power is 20dBm, eye pattern almost closes and maximum Q value is 2.54332. When the receiving signal power is -62.87dBm, transmitting signal is completely unrecovered and collecting ends cannot normally communicate. When the transmitting power is raised to 30dBm, eye pattern's patulous situation is better. Meanwhile recovered electrical signal power is -56.364dBm, maximum Q value is 23.0227, and the recovery situation of receiving signal is better. When channel attenuation is worse and signal-transmitting power is lower, collecting ends cannot well recover the receiving signals. But when enhancing the signal-transmitting power to a certain extent, collecting ends can recover receiving signal.

3.3 System simulation when foggy

When the channel is attenuated to 10dB/km and transmitting power is 30dBm, eye pattern is almost closed. It is manifest that coherent heterodyne method is not suitable in distant communication when misty. When foggy and smoggy, the situation gets worse and coherent heterodyne method is not available any more. Therefore, we can resort to using it together with millimeter wave communication mode .

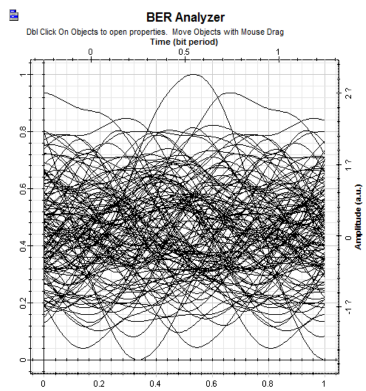


Figure 10 Receiving signal' eye pattern of coherent heterodyne method when channel is attenuated to 10dB/km

4. CONCLUSION

This paper has researched heterodyne coherent optical communication receiver system. The results of simulation indicate that when the transmitting power is 5dBm, coherent heterodyne synchronous BPSK receiving system is able to recover data when atmospheric channel' communication rate is 2.5Gb/s after 10km distance in the cloudy days. In the same conditions, the receiving sensitivity of coherent heterodyne method is higher than that of IM/DD method. In the condition that requires higher receiving sensitivity, we can use coherent heterodyne method to communicate. Besides, in the misty channel where channel attenuation is severe, coherent heterodyne synchronous BPSK receiving system can better receive data of 2.5Gb/s successfully by enhancing the transmitting power. In the foggy and smoggy channels where channel attenuations are badly worse, enhancing transmitting power can not make sure of normal reception for the transmitting signal. Therefore, other ways of communication should be considered.

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