Research on the Performance of 40 Gbps UV Communication System Based on DWDM

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Abstract. Due to the atmospheric transmission attenuation, the rate of UV communication is low and range is limited at present. According to the idea of DWDM in optical fiber communication, we proposed a 40 Gbps UV communication scheme, which has 8 channels in total. The transmission rate of each channel is 5 Gbps. And its performance was simulated by the optical communication system simulation design software which is called OptiSystem. Simulation analysis shows that the maximum transmission distance of the designed system is up to 1200 meters under the transmission rate of 40 Gbps without any compensation scheme. On the 280nm channel, the minimum error rate and Q factor are 1.56×10^{-14} and 7.59201 at 1 km respectively. When the transmission distance reaches 1.5 kilometers, the bit error rate becomes very high and the communication effect is very poor. The simulation results can provide reference for the design of UV communication system.

1. Introduction
With the development of digital communication technology and optical device, in the field of special communication such as close LAN communication, ultraviolet communication has been found to be an ideal means of communication that meet requirements of non-line-of-sight, anti-interference and close communication. UV (Ultraviolet) combined with communication is due to the unique characteristics of UV atmospheric channel\cite{1,2}. The ozone layer located in the atmospheric can strongly absorb UV of 200nm~280nm band (namely solar blind area), but in the troposphere close to the ground the UV background noise of this band is lower than 10^{-13} W/m^2, so the natural noise can reach the ground is very little\cite{3,4}.

Solar-blind band UV appears scatter communication effect under the scattering action of aerosols, particles, dust and other particulates\cite{5}. Due to the presence of atmospheric turbulence, UV atmospheric channel quality will affect the quality of communication. So the rain, smoke, fog and other bad weather conditions have great influences on UV communication link\cite{6}.

In order to solve these problems, there are many techniques to improve the UV communication link performance, such as the technology of diversity, aperture average and light signal amplification and so on. At the same time, in order to solve the bandwidth problem in wireless optical communication, this paper proposes a wavelength division multiplexing (WDM) technology. By compressing channel space, WDM technology realizes the increase of channel number, in order to improve the channel capacity\cite{7}.

WDM is divided into coarse WDM and dense WDM. Coarse WDM(CWDM) provides 3-5 bands, if bands are more than 5, we call it dense WDM(DWDM). In recent years, in the field of wireless communications, WDM technology has been deeply studied thanks to its high data transfer rate and low error rate. The research focus of WDM which is applied to the next generation of wireless optical communication system is high rate, scalability and low complexity\cite{8}. 
In this paper, a 40 Gbps UV communication solution is proposed combined with the DWDM technology. There are 8 channels, and each channel is of 5Gbps transfer rate. Then the solution performance is simulated by the optical communication system design software OptiSystem.

2. Project design

2.1. Fundamental principle
The system performance is simulated based on OptiSystem software to observe the received power, calculate the link margin, so the influencing factors on the quality of the link can be determined. Link margin is the ratio of receiving power (PR) and the receiver threshold or sensitivity (S), usually expressed in dB:

$$\text{Link Margin} = 10 \log \frac{PR}{S}$$

(1)

In order to restore the signal at the receiver end, the power must be higher than the receiver sensitivity. Sensitivity is usually given by manufacturers, its scope -20~40dBm. Received power can be expressed as:

$$P_R = P_T \times e^{-\alpha} \times \frac{A_{RX}}{(\theta L)^2}$$

(2)

$P_T$ and $P_R$ respectively is the receiver and the transmitter power, $A_{RX}$ is receiving aperture area, $\theta$ is divergence angle, $\alpha$ is the atmospheric attenuation, $L$ is the distance between the transmitter and receiver. As can be seen from the formula, the received power is proportional to the transmitted power and receive aperture area, but is inversely proportional to the transmission distance and the divergence angle. Index part of the equation is related to the atmospheric attenuation, it had the greatest influence on the link quality. Increasing the power of transmitter and receiving aperture area or reducing transmitter beam divergence angle can increase the received power.

Measurement time of BER will be long. For a link whose data rate is 10Gbps and BER is $10^{-12}$, detecting 100 errors takes about 2.8 hours. In order to shorten the test cycle, Q factor technology can be used. Although there may be some errors, but it can reduce the test cycle to a few minutes. It changes the receiver threshold, causing the bit error rate increasing, thus time is shorten. The Q factor is mainly used to measure the eye diagram noise-signal ratio (SNR) parameters, and defined as the ratio of signal power to noise power under the receiver best decision threshold:

$$Q_{\text{factor}} = \frac{P_{\text{up}} - P_{\text{base}}}{\sigma_1 + \sigma_0}$$

(3)

Where: the eye range is the difference between the average value of ‘1’ level and ‘0’ level, the signal noise RMS is the sum of ‘1’ noise RMS $\sigma_1$ and ‘0’ noise RMS $\sigma_0$. Q factor comprehensively reflects the eye diagram quality problems. The greater the Q factor is, the greater the eye, the better the eye diagram quality is, and the higher the SNR is. Q factor is generally influenced by factors such as the optical power, noise, whether the electrical signal is impedance matched from the beginning to the terminal and so on. The more fine and smooth line of ‘1’ level is, the greater the Q factor is. In the case of without light attenuation, Q factor of emitter eye diagram is normally greater than 12, and the receiver’s Q factor is generally not less than 6.

2.2. System scheme
Atmospheric UV communication DWDM system simulation model is shown in figure 1, and mainly includes the light emitting part, wavelength division multiplex, atmospheric channel, shunt device and light receiving part, etc. Light emitting part converts electrical signals into modulation optical signal and launches out it, and the 8-channel signal propagates in atmospheric channels after passing through the wavelength division multiplexer. Then the signals pass through the optical divider, under the help
of triangle light filter each channel is separate at a distance of 2nm. The separated signals are just contrary to the signals launched from the WDM transmitter, and received by each optical network unit of receiver. The photoelectric detector converts the light signals of each road into the electrical signal, and then performs the data analysis by the signal analyzer after completing the signal processing. The light emitting part consists of laser, drive, pseudo-random binary pulse generator and M-Z modulator. The block diagram as shown in Figure 2, the output optical power of the default single channel emitter is 30mW, the bit rate of pseudo random binary pulse generator is 5Gbps, the channel spacing between the 8-channel signals is 2nm, and the wavelength is in the range of 200~280nm solar blind band.

2.3. Parameter setting
At present, most UV communication systems use LED array or semiconductor laser as light source, and the wavelength is in the range of 200~280nm solar blind band. The wavelength range of this system is 266~280nm, and the emission light power varies in the range of 10~50mW. Considering that UV communication is mainly used for secure communication, and communication distance is short, so the distance of atmosphere channel link is 600m~1400nm. The divergence angle of laser beam in sight distance communication is generally small, and is set to 0.8mrad~1.6mrad. The atmospheric extinction coefficient during UV transmission is obtained from MODTRAN software. Under the setting of the coastal scene, combining with the geographical location of Yantai, summer of mid latitude is set up in MODTRAN software. The atmospheric extinction coefficients corresponding to different visibility are shown in Table 1.

Table 1. Calculation value of atmospheric extinction coefficients for coastal LOS UV transmission

| Visibility/km | Extinction coefficient/dB/km |
|---------------|----------------------------|
| 0.5           | 10                         |
| 1.0           | 4.9                        |
| 1.5           | 3.4                        |
| 2             | 2.6                        |
| 2.5           | 2.1                        |

The parameters reference value of the communication system designed in this paper are shown in Table 2.

Table 2. Parameter setting

| Parameter                    | Reference value |
|------------------------------|-----------------|
| Power                        | 30mW            |
| Rate                         | 5Gbps           |
| Number of channels           | 8               |
| wavelength                   | 270nm           |
| Channels spacing             | 2nm             |
| Transmitter aperture diameter| 5cm             |
Beam divergence | 1 mrad
---|---
Distance | 1 km
Extinction coefficient | 4.9 dB/km
Receiver aperture diameter | 7.5 cm
Sensitivity | 0.1 A/W

3. Simulation results and analysis

In the light communication system design software OptiSystem, the system performance is simulated in accordance with the 40 Gbps UV communication system shown in Figure 1. The main test instrument is the eye diagram analyzer, the eye information of each channel signal can be observed through the analyzer. As shown in Figure 3, the effect of noise on intercode crosstalk can be seen, and the value of the maximum Q factor and the minimum error rate can be calculated at the same time.

![Figure 3. Interface of eye diagram analyzer](image)

Figure 4 shows the change curve of the bit error rate increasing with the distance within the range of 600m~1400m communication distance. As it shown, the bit error rate becomes larger as the distance becomes larger. For example, on the third channel (wavelength is 270nm), the bit error rate rises from the 7.89E-34 at the 600m to the 6.12E-04 at the 1400m. The relationship between the bit error rate and the transmitting power is shown in Figure 5, it can be seen that the bit error rate decreases with the increase of the transmitting power. For example, on the third channel (wavelength is 270nm), when the transmitting power is 10mW, 20mW, 30mW, 40mW and 50mW, the bit error rate is 6.02E-04, 3.58E-09, 2.92E-14, 4.29E-19 and 2.66E-23. As shown in Figure 6, the relationship between the Q factor and the transmitting power shows that the Q factor increases with the increase of the transmitting power. Similarly, on the third channel (wavelength is 270nm), when the transmitting power is 10mW, 20mW, 30mW, 40mW and 50mW, the Q factor is 3.23777, 5.7862, 7.51061, 8.85179 and 9.87434. Although increasing the transmitting power can reduce the bit error rate and increase the Q factor, it is limited by the device, and the transmitting power of the UV laser cannot increase infinitely.
Figure 4. Diagram of relation between bit error rate and communication distance

Figure 5. Diagram of relationship between bit error rate and transmitting power

Figure 7 shows the change curve of different channel error rate with the communication rate in the range of 3Gbps~7Gbps communication rate. As it shows, as the rate of communication speeds up, the bit error rate becomes larger. For example, on the third channel (wavelength is 270nm), the bit error rate rises from the 4.51E-32 at 3Gbps to 2.30E-07 at 7Gbps. As the relationship between the bit error rate and the divergence angle is shown in Figure 8, it can be seen that the error rate increases with the increase of the divergence angle. For example, on the third channel (wavelength is 270nm), when the divergence angles is 0.8mrad, 1mrad, 1.2mrad, 1.4mrad and 1.6mrad, the bit error rates is 1.11E-20, 2.92E-14, 3.07E-10, 1.50E-07 and 2.53E-05. As shown in Figure 9, the relationship between the Q factor and the divergence angle shows that the Q factor decreases with the increase of the divergence angle. Similarly, on the third channel (wavelength is 270nm), when the divergence angle is 0.8mrad, 1mrad, 1.2mrad, 1.4mrad and 1.6mrad, the Q factor is 9.2503, 7.51061, 6.18636, 5.12349 and 4.05214 respectively. It’s not difficult to find that the dispersion of UV laser beams can improve the performance of the system.

Figure 6. Diagram of relationship between Q factor and transmitting power

Figure 7. Diagram of relationship between bit error rate and communication rate
Figure 8. Diagram of relationship between bit error rate and divergence angle

Figure 9. Diagram of relationship between Q factor and divergence angle

Figure 10 shows the relationship between the bit error rate and the visibility. The different visibility corresponds to the different atmospheric extinction coefficients, and the model attenuator attenuates the input light signal with the specified attenuation level. It can be seen that the atmospheric extinction coefficient gradually decreases with the increasing visibility, and the bit error rate is gradually reduced. For example, on the third channel (wavelength is 270nm), when visibility is 500m, 1000m, 1500m, 2000m and 2500m, the bit error rate is 4.76E-24, 2.01E-23, 1.13 E-19, 2.92E-14 and 1.25E-03. The effect of atmospheric extinction coefficient on the performance of the system is more obvious, and the increase of visibility will obviously improve the bit error rate.

4. Conclusion

In this paper, combining with the idea of DWDM in optical fiber communication, a 40 Gbps UV communication scheme is put forward. There are total 8 channels, and each channel transmission rate is 5 Gbps. Then its performance is simulated using the optical communication system software OptiSystem, and the relationships between bit error rate, Q factor and transmission distance, transmission power, communication rate, atmospheric visibility, divergence angle are discussed. Among them, the bit error rate is contrary to the change of Q factor. The communication performance is contrary to the change of transmission distance, communication rate and divergence angle, and the same change trend as the atmospheric visibility. The small range change of wavelength has little influence on the communication performance of the system. At the transmission rate of 40 Gbps, the maximum transmission distance of the system is up to 1200 meters without any compensation scheme. On the 280nm channel, the minimum error rate and Q factor are 1.56-14 and 7.59201 at 1km
respectively. When the transmission distance reaches 1.5 km, the bit error rate will become very high and the communication effect is very poor.

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