Analysis of Optical Satellite Communication Technology and Its Development Trend

Wenyi Fu*

School of Communication Engineering, Beijing Jiaotong University, Weihai Campus, Weihai, Shandong, China 264401

ABSTRACT: As the demand for information and high data transmitting rate is becoming increasingly crucial, modern communication technology has attached more significance to optical satellite communication study. This paper will mainly concentrate on the development trend of optical satellite communication technology. Firstly, this technology will be introduced with its basic system illustration and block diagram. Moreover, the key technologies will be demonstrated, including optics, signal processing, Acquisition, Tracking, Pointing (ATP) and mechanics. In the final section, a comparison between optical satellites and other communication technologies will be conducted to analyze the future tendency of satellite communication. As shown, it will be fused with 5G technology; also, it might develop in the direction of realizing terminal device miniaturization, space-air-ground integrated network (SAGIN) and intelligent optical satellite communication. Finally, free-space optical (FSO) communication will be of great benefit to humans, as it can bring convenience, enhance communication efficiency and boom the economy. Therefore, scientists should take optical satellite communication technology more seriously and do more research concerning it, helping people live better lives.

1. INTRODUCTION

The increasing demand for information in modern society promotes the development of modern communication technology in the direction of wideband and high speed, leading to the fact that communication frequency bands are continuously modified to a higher frequency band, and eventually to the light wave band. Furthermore, due to wider coverage of satellite communication, it has become increasingly vital in the modern communication research realm. In the year of 2008, Germany's new generation of high-resolution radar satellite TerraSAR-X and the United States near field Infrared experimental satellite NFIRE have successfully carried out a two-way optical communication test with a rate of 5.625Gbit/s. In 2011, the Optical communication terminal and optical ground station on the Haiyang-2 satellite successfully carried out a satellite-earth link optical communication test, which was the first satellite-earth optical communication test in China. [21] Owing to the high demand for high-speed data transmitting rate, low power consumption and flexible link connection, the future direction of optical satellite communication should be taken into consideration. Thus, it is inevitable that satellite communication will be playing a vital role in human communication. In this circumstance, the trend can be clear to make human life more convenient. This paper will adopt the method of doing a survey on different optical satellite communication technology and current dilemmas in order to invent more advanced devices so that humans can benefit from high-speed communication to enhance life quality. This type of communication technology will be compared to other kinds to summarize the advantages and disadvantages, analyzing the trend. Additionally, several optical satellite communication development tendencies will be concluded to be conducive to further study.

2. OPTICAL SATELLITE COMMUNICATION

2.1. Optical Satellite Communication Introduction

Optical satellite communication is defined as communication through the light which carries information between satellites or between satellites and the ground. [1] The optical system consists of the light source, transmitting, receiving and capturing subsystems. [2]

*Corresponding author. Email: 19723046@bjtu.edu.cn

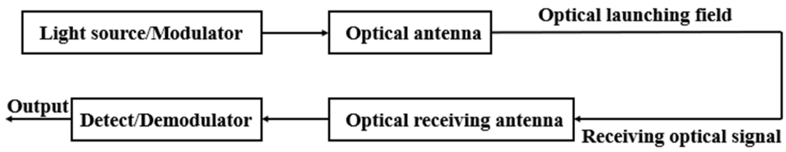

Figure 1 Optical satellite communication system [2]

As shown in Figure 1, it can be concluded that communication signals processed by baseband, encryption and modulation will be sent through optical antennas and received by optical receiving antennas. Finally, the optical impulse modulated signals will be detected and demodulated into the signals that carry the messages, realizing full-duplex optical communication.

Additionally, optical satellite communication can be divided into satellite-satellite and satellite-ground optical communication, and intersatellite optical communication is categorized into inter-satellite link (ISL) (containing GSO-GSO, LEO-LEO) and inter-orbit link (IOL) (containing GEO-LEO). [3] High orbit GEO satellite has a wide range of coverage, which makes 3 GEO satellites covering the whole Earth possible. Thus, it is stated that the high orbit GEO optical satellite, acting like the relay satellite of the LEO optical satellite, mainly constructs the connection with the ground optical stations, which eventually produces space-earth integration optical communication network. [4]

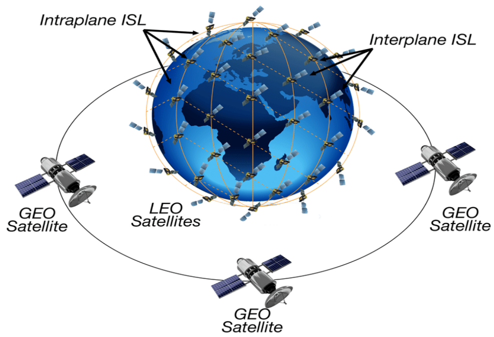

Figure 2 Satellites distribution [5]

2.2. Optical Satellite Communication Key Technology

Optical satellites communication technology is a multidisciplinary research, concerning optics, mechanics, mathematics and computer science. Figure 3 has shown the system of optical satellite communication link transmission.

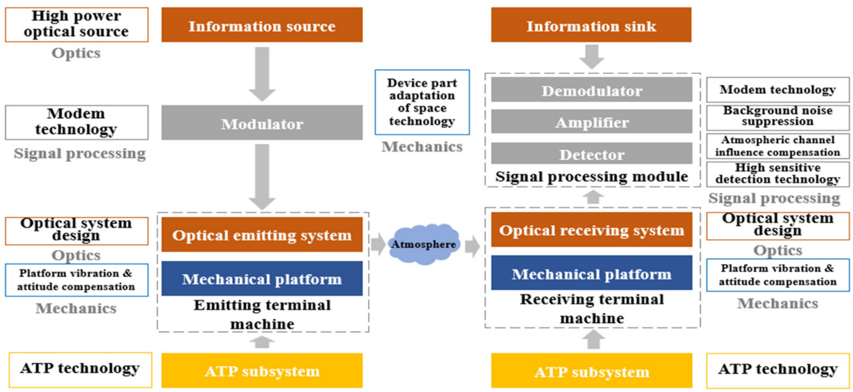

Figure 3 Optical satellite communication system key technology [6]

2.2.1. Optics Technology

It is shown in Figure 3 that optical key technology is consisting of a high-power optical source and high-quality optical system design.

Super high-speed data transmission is one of the prior requirements of optical satellite communication. As satellite communication possesses long-distance, approximately 40,000 kilometers per single trip, ground and satellite stations have to produce lasers to obtain emission power high enough to reach other stations. [3] Moreover, a high-quality optical system design contains two main cores, wavelength selection and optical path design. Power loss through the atmosphere, the influence of solar radiation and responsiveness under that wavelength should be taken into consideration during the determination of wavelength. Thus, with all those factors, scientists have determined to study wavelengths of 800nm, 1000nm, and 1500nm, corresponding to the semiconductor lasers, solid lasers and fiber lasers. Additionally, the wavelength of 1550nm, 850nm and 10,000nm is used in ground-satellite links, according to weather and atmospheric turbulence conditions. [6] In conclusion, wavelength determination and design depend on transmission type, transmission environment and service request.

Furthermore, another core technology of optics is optical path design, of which the most vital section is optical antenna design, for the reason that optical signals are sent and received by those antennas in satellite communication links. Nevertheless, traditional optical path design cannot satisfy the miniaturization trend, due to the disadvantages of large volume and heavyweight. Hence, a type of integrated optical antenna was invented, which can be adapted into small laser communication satellites. These antennas were designed on a silicon-on-insulator (SOI) having two different optical couplers (OC). [7]

2.2.2. Signal Processing Technology

There are mainly two parts to signal processing technology: modem technology and background noise suppression technology.

Modem technology is comprised of modulation and demodulation. Modulation is using baseband signal to control the change of one or several parameters of the carrier signal and form modulated signal transmission with information loaded on it. Demodulation is the reverse process of modulation, as the original baseband signal will be recovered from the change of parameters of modulated signal through specific methods. Modulation is divided into linear and non-linear. Linear modulation includes Amplitude Modulation (AM), Double Side Band with Suppressed Carrier (DSB-CB), Single Side Band (SSB), Vestigial Side Band (VSB), etc. and non-linear modulation, having strong anti-interference performance, includes Frequency Modulation (FM), Frequency Shift Keying (FSK), Phase Shift Keying (PSK), Differential Phase Shift Keying (DPSK) and etc. Optical satellite communication is capable of supporting various binary and multi-level modulation formats, of which binary is the easiest and most effective one. On-Off Keying (OOK) and Pulse Position Modulation (PPM) are the two most common approaches. It is suggested that the adaptive threshold of OOK can achieve the best weakening effect under turbulent atmospheric conditions. [8]

Moreover, as proven, the main noise originates from solar radiation and the radiation intensity decreases when the wavelength increases. In order to suppress the background noise, the technology of spatial filtering and signal modulation is applied. The design of wave filters should consider a variety of factors, including signal reaching angle, doppler frequency shift laser width and the number of time patterns. [9] One of the most common approaches is Multi-Pulse Position Modulation (MPPM), which is currently combined with other formats of modulation to enhance transmission efficiency. For instance, Quadrature Amplitude Modulation (QAM) combined with MPPM can be applied with no turbulence and gamma-gamma Free-Space Optical (FSO) channels to reduce Bit Error Rate (BER). [10]

2.2.3. ATP Technology

Acquisition, Tracking, and Pointing (ATP) is the foundation of long-distance spatial optical communication, especially the core technology of satellite-to-ground links. Figure 4 has shown the rudimentary construction of the ATP system. A gimbal is capable of rotating in numerous directions, for a wide pointing range directing the light beam to the receiving terminal and obtaining coming optical signal from the sending terminal is required in ground-to-satellite and satellite-to-satellite FSO communication. [11]

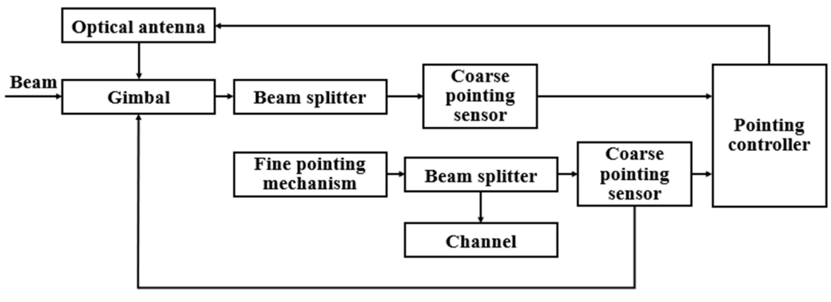

Figure 4 ATP system construction

Due to the vital role of the ATP system in FSO communication, ATP technology is the main factor determining whether the data transmission is successful. Therefore, it has been highly paid attention to by scientists globally. To take Arvizu as an example, he has established an ATP system prototype of optical quantum communication links between CubeSat and optical ground stations. [12]

2.2.4 Mechanics Technology

Device manufacturing is required to have the property of spatial adaptability in a bid to reduce the negative effects of the spatial environment. Mechanical technology mainly includes mirror surface performance protection, mechanical components anti-cold welding, amplifier anti-radiation technology, etc. With the increasement of miniaturized LEO satellites, optical satellite communication is transforming into the development of high data rate, low power consumption, ministration and low cost.

3. CURRENT CIRCUMSTANCE OF DEVELOPMENT OF OPTICAL SATELLITE COMMUNICATION TECHNOLOGY

3.1. Comparison Between Optical Satellite Communication Technology and other Communication Technology

There are mainly three common types of communication currently, optical fiber communication, radio frequency (RF) communication and optical satellite communication.

Optical fiber communication is a communication mode in which light wave is used as an information carrier and the optical fiber is used as a transmission medium. [13] Despite the advantages of great capacity, long-distance transmission, small-signal crosstalk and electromagnetic interference resistance, it has a vulnerable texture, as the optical can only be bent with a small curvature (the radius should be greater than 20 centimeters). Moreover, the cutting and connecting of optical fibers require a certain type of devices and technology; also, optical fiber communication branching and coupling are not flexible.

Another communication technology is RF. RF is radiofrequency current, short for high frequency alternating electromagnetic waves. When the frequency of an electromagnetic wave is higher than 100kHz, the electromagnetic wave can spread in the air and be reflected by the ionosphere at the outer edge of the atmosphere, forming long-distance transmission. Such high-frequency electromagnetic waves with long-distance transmission capability can be named RF. RF communication, applying radio frequency to transmit information, is a kind of wireless communication. It has the property of multi-direction. However, owing to the fact that microwave possesses high frequency and short wavelength, it may be obstructed by mountains or buildings, then weakening the signal, which might finally affect the transmission quality. Furthermore, transmitting in the air, the microwave is susceptible to other interference, as the same frequency cannot be used in the same circuit in the same direction. Consequently, there should be a department established to manage wireless communication.

Therefore, optical satellite communication is coming into the stage of being studied by scientists. With the advantages of wide range, robustness to terrestrial catastrophe, multiple access properties and flexible circuit setting, optical satellite communication is more likely to be convenient for humans. It is shown in figure 5 that optical communication has smaller antennas, lighter mass and lower power. Thus, it has better performance than RF communication.

Link senario	Data rate	Frequency band		
		Optical	Ka-band	Millimeter-band
GEO-LEO				
Antenna dia.	2.5 Gbps	10.2 cm (1.0)	2.2 m (21.6)	1.9 m (18.6)
Mass		65.3 kg (1.0)	152.8 kg (2.3)	131.9 kg (2.0)
Power		93.8 W (1.0)	213.9 W (2.3)	184.7 W (2.0)
GEO-GEO				
Antenna dia.	2.5 Gbps	13.5 cm (1.0)	2.1 m (15.6)	1.8 m (13.3)
Mass		86.4 kg (1.0)	145.8 kg (1.7)	125.0 kg (1.4)
Power		124.2 W (1.0)	204.2 W (1.6)	175.0 W (1.4)
LEO-LEO				
Antenna dia.	2.5 Gbps	3.6 cm (1.0)	0.8 m (22.2)	0.7 m (19.4)
Mass		23.0 kg (1.0)	55.6 kg (2.4)	48.6 kg (2.1)
Power		33.1 W (1.0)	77.8 W (2.3)	68.1 W (2.1)
Moon-satellite				
Antenna dia.	155 Mbps	15.7 cm (1.0)	3.5 m (22.3)	3.2 m (20.4)
Mass		100.5 kg (1.0)	243.1 kg (2.4)	222.2 kg (2.2)
Power		144.4 W (1.0)	340.3 W (2.4)	311.1 W (2.2)

Figure 5 Comparison between optical and RF communication systems with transmit power of 10, 50, and 20 W for optical, Ka and millimeter band systems, respectively. [14]

In the figure above, the values in parentheses are normalized to the optical parameters.

3.2. Optical Satellite Communication Technology Current Problems

3.2.1. Atmospheric Factors

The influence of atmosphere on FSO communication is mainly manifested in two aspects, atmospheric attenuation and beam flickering, diffusion and bending. Atmospheric attenuation refers to the weakening of signal energy caused by the absorption and scattering of light beam by the atmosphere. Absorption is caused by the absorptive action of light by water vapor, carbon dioxide, ozone molecules. There are three main solutions to overcome atmospheric attenuation, selecting wavelength placed in atmospheric window with high transmittance, enhancing output power of the lasers and increasing sensitivity of the receivers. In addition, to overcome the dilemma of beam flickering, diffusion and bending, the area of receiving antenna can be increased and adaptive optics technology at both ends of transmitting and receiving can be applied. [15]

3.2.2. Anti-interference Technology

Satellite communication is vulnerable to certain human and natural factors, which can negatively affect transmission quality or even make signals disappear. As a result, research on satellite communication interference factors and their resolutions should be conducted to reinforce optical satellite communication. One of the technologies is the spread spectrum, the mainstream in anti-interference technology. Based on different patterns, it can be categorized into a direct sequence (DS), frequency-hopping (FH) and mixed, which is able to realize encrypted satellite communication with large capacity, long-distance and low power. Another is on board processing technology, decoupling up and downlinks, which avoids the transponder being pushed to saturation. It mainly includes demodulation, encryption, speed change and multiple access multiplexing conversion. Therefore, onboard processing technology is an inevitable requirement for the future survival and development of optical satellite communication. [16]

3.3. Optical Satellite Communication Technology Tendency Analysis

China, America, Europe and Japan have been studying optical satellite communication for decades and numerous progress have been made in the direction of bringing humans more convenience in communication. For instance, Thermo Trex first introduced Faraday Anomalous Dispersion Optical Filter (FADOF) into the ATP system. [17]

3.3.1. Fusion of Satellite and 5G

International Telecommunication Union (ITU) has proposed four application scenarios of satellite-to-ground 5G fusion, including relay station, cell call-back, satcom on the move (SOTM) and Hybrid multicast scenarios, and proposed supportive key factors, compatibility of Network Function Virtualization (NFV) and Software Defined Network (SDN), Multicast support, Intelligent Routing Support, etc. [18]

3.3.2. Miniaturization

Space optical communication, with its advantages of high speed, small size, lightweight and low power consumption, has become an indispensable and effective approach to high-speed communication between satellites, especially in the application of small satellites, reflecting the advantages of optical communication. Therefore, miniaturization of the optical satellite communication devices is of great significance in the future high data transmission communication technology development, which can bring convenience and enhance efficiency. [20]

3.3.3. Space-air-ground Integrated Network (SAGIN)

SAGIN integrated satellite system, aviation system and ground communication system. As shown in Figure 6, the network is consisting of GEO, MEO, LEO, airships and ground devices, which makes the integration of whole communication networks possible.

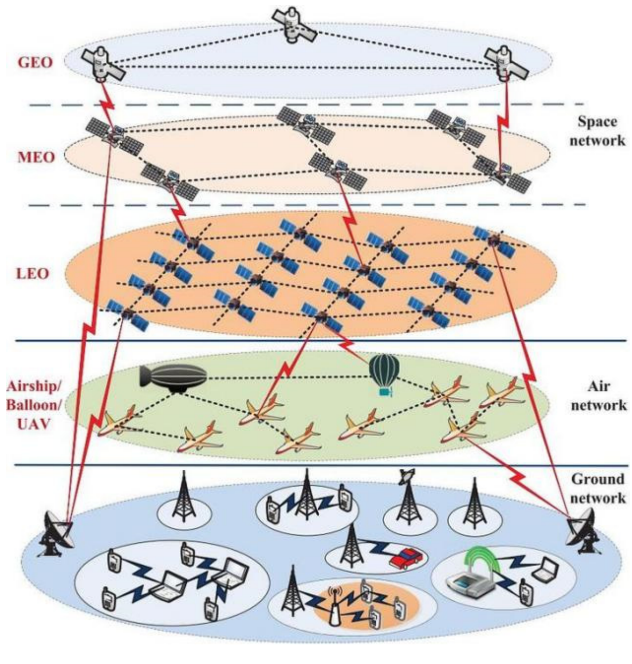

Figure 6 SAGIN structure [19]

It is the development trend of future communication networks to build an integrated network framework of SAGIN and realize the interconnection, complementarity and efficient coordination between SAGIN. The integration network of SAGIN mainly includes the integration of system, terminal and application fusion. System integration is to help the network layer protocol realize the interconnection of the whole network and achieve compatibility between systems. Terminal fusion should be compatible with each other. Moreover, Satellite-to-ground mobile communication and mobile1-and-fixed communication tend to be interconnected, so as to achieve the goal of a terminal traveling globally to implement personal communication. [18] More significantly, due to the small scattering angle of a laser beam and the tendency of dynamic change, the current satellite optical communication links are mostly point-to-point transmission. Thus, in order to further expand the satellite network, it is necessary to realize point-to-multipoint transmission with more advanced technology.

3.3.4. Intelligent Optical Satellite Communication

It will be inevitable to build a 6G network based on AI technology. The intelligent dynamic spectrum sharing technology between ground communication and satellite communication can better improve spectrum efficiency, and the intelligent seamless switching technology and intelligent interference elimination technology can realize the real space-air-ground intelligent communication. It is stated that the representative feature of 'intelligent' is the inherent full intelligence of the communication system. That is intelligent network elements and network architecture, intellectualization of terminal equipment and intelligent business supported by the carrying information. [18]

4. CONCLUSION

In conclusion, this paper mainly focuses on optical satellite communication technology and its development trend. Firstly, optical satellite communication has been introduced in the sections of satellite-to-ground optical communication systems and their key technologies. It can be summarized that there are numerous aspects of this type of technology, so scientists may make exceptional efforts to modify it. Additionally, as it was analyzed, there are approximately four trends concerning optical satellite communication, containing a fusion of satellite and 5G, terminal device miniaturization, space-air-ground integrated network (SAGIN) and intellectualization. Hence, it has become fairly essential in the communication technology realm and it should be attached of great significance.

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