Next-Generation Telecommunications Infrastructure

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1. INTRODUCTION

With expanding efforts to accelerate digitalization worldwide, telecommunications services that we depend on in our daily lives, such as communication and electronic payment for public transportation by personal computer or smartphone, have already been adopted widely throughout the world, and the high-capacity communication networks that support those services have become indispensable social infrastructure for our lives. The Cabinet Office of Japan has also proposed a vision called Society 5.0 and is strongly promoting the development of the telecommunications environment as a critical part of social infrastructure. Society 5.0 is defined as “a human-centered society that balances economic advancement with the resolution of social problems by constructing a system that integrates cyberspace (virtual space) and physical space (real space).” As part of Society 5.0, introduction and implementation of the concept of B5G (Beyond 5G)/6G, which is expected to become the next-generation wireless telecommunications infrastructure, will also drive the creation of new value.

In the world of the future, telecommunications will be something that we take for granted, like the air around us, and will become increasingly important as essential infrastructure, like electric power and water. Based on this social trend, this paper presents a commentary on the most recent technological trends related to digital communication networks, and discusses the importance of the telecommunications infrastructure in the maritime industry of the future.

Note: In this paper, the future 6G technology called B5G (Beyond 5G) is referred to as “B5G” in the following.

2. WHAT IS TELECOMMUNICATIONS?

Telecommunications is a means of sharing information between senders and recipients. Until now, people have tired various methods of communicating messages to counterparts separated by some distance.

In the world of ships, since the distant past, seafarers have also continued to develop methods for transmitting “visible information” to surrounding ships and persons on land by raising national flags and displaying navigation lights and emergency signals, and communicating the ship’s own position and movements to surrounding vessels by using steam whistles and other auditory signals as “audible information”. Even today, these communication techniques, some of which have been used for centuries, continue to play a key role in maintaining communications between ships and ensuring safe navigation.

The modes of telecommunication also evolve together with the technological progress and social change. At present, they can be divided into the two categories of telecommunications by fixed lines, which are suited for stability and high-speed telecommunications, and wireless telecommunications, which are superior in terms of mobility and flexibility. The primary role of telecommunications infrastructures, including the internet, is transmission by fixed lines, while wireless telecommunication tends to be used for “last one mile” delivery of messages. In telecommunications, this means that major data transfer routes and backbone networks are normally implemented using fixed lines. In telecommunications by fixed lines, physical cables are laid and information is transmitted over those cables, so large volumes of data can be transmitted with high efficiency, while simultaneously securing high bandwidth and reliability. For this reason, fixed lines are generally used as much as possible as transmission routes in the internal and external telecommunications infrastructure of companies and between the servers that make up cloud networks.

However, wireless telecommunications also play an important role in cases where it would be difficult to lay cables connecting transmitting/receiving devices, i.e., terminals, and in cases where the mobility of the terminals must be considered.

Wireless telecommunication is a communication method in which information is transmitted using radio waves. Wireless telecommunication began with transmission of Morse code signals by Marconi at the start of the 20th century, and analog signals

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were used until the advent of 1G (first generation) mobile wireless communication technology in 1980.

Although 1G considered a revolutionary technology at the time, the main application of 1G was voice telephone communications, and the cellphones themselves were not only bulky, but were also unsuitable for communication of data other than voice.

However, thanks to the complete transition to digital signals in the subsequent 3G technology, real-time video telephone became possible, although with some delay in transmission. The current 5G technology is capable of large volume, ultra-high speed communication, and makes it possible to share documents and search the internet while simultaneously online meeting.

In parallel with mobile wireless telecommunication technology, in which technological improvement has progressed from 1G to the current 5G and is now advancing toward the next-generation B5G/6G, a large number of new wireless communication technologies premised on digital systems are also reaching practical application, and today, the wireless communication technology called Wi-Fi (Wireless Fidelity), which is applied to short-range wireless transmission over distances within a few 10s of meters, and the short-range wireless technology called NFC (Near Field Communication), which enables instantaneous completion of non-contact information sharing and ticketing for public transportation system to mobile payments, are used in cities as a matter of course.

3. WIRELESS COMMUNICATION

Wireless communication is a telecommunications method in which information is transmitted to a remote location by propagation of radio waves through space.

Radio waves are one type of electromagnetic wave, which are formed by an electric field and magnetic field alternating at right angles. In this phenomenon, a magnetic field is formed in the surrounding area by an electric current passing through an object with a certain electrical charge, and an electric field forms naturally in the direction that prevents change in that magnetic field. Radio waves are transmitted through space by an interaction in which the magnetic field is formed again by changes in this electric field. Because the electric field and magnetic field propagate while mutually interacting with each other, they can be transmitted even through a vacuum which does not contain a vibrating medium, such as outer space. Electromagnetic waves also have a wide frequency range (band), and exist as waves with diverse properties as a result of having different wavelengths and energies.

In wireless communications, the frequency, wavelength and bandwidth of these electromagnetic waves are important elements that determine the propagation characteristics of communications. The mechanism of these basic propagation characteristics is the same in both analog and digital signals.

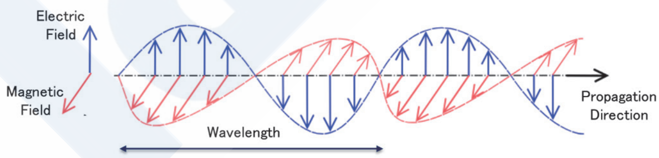

Fig. 1　Basic characteristics of radio waves

The following explains the wavelength, frequency and bandwidth of electromagnetic waves, and describes their relationship with propagation characteristics.

3.1 Frequency

The electromagnetic waves used in wireless communications are “waves”, and have the related properties of wavelength and frequency.

Wavelength is a periodic characteristic of continuous waves showing the distance to the same position in an adjoining wave. It is expressed in units of meters (m) or a multiple thereof (e.g., centimeter, millimeter, nanometer, *etc.*).

Frequency is the number of times that a wave is repeated in a unit of time, and indicates the number of waves that appear per second. Its unit is Hertz (Hz). One Hertz (1 Hz) means 1 vibration per second.

The propagation velocity of radio waves is constant regardless of frequency and is the same as the speed of light, that is, approximately 300000 km/s. The wavelength of a wave is obtained by dividing this propagation velocity by the frequency of the wave. The speed at which a wave is transmitted does not change regardless of whether its frequency is high or low. The relationship between wavelength and frequency is expressed by the following equation.

$$\lambda\ (wavelength) = \frac{c\ (speed\ of\ light)}{f\ (frequency)} \tag{1}$$

3.2 Data Bandwidth

Data bandwidth refers to the usable frequency width, and is calculated as the difference between the highest frequency and the lowest frequency. In other words, it is the frequency range that can be used to transmit data, and shows the speed of data (data transfer rate). The transfer rate is expressed in units of bits per second (bps), which indicates how many bits of data can be transferred in 1 second. For example, a data bandwidth of 1 Mbps means that a maximum of 1 megabit (1 million bits) of data can be transferred per second. The relationship between data bandwidth and the data transfer rate can be expressed by the following relational expression.

$$Data\ transfer\ rate = \frac{Data\ bandwidth}{Number\ of\ bits\ in\ a\ digital\ signal} \tag{2}$$

Because the basic concept is that a larger volume of data can be transferred as bandwidth increases, the transfer rate also becomes faster. However, the above-mentioned relational expression is used to calculate the ideal maximum data transfer rate, which means it is also necessary to take other factors into account in actual data communications; these factors include noise and signal modulation systems, error-correcting code, protocol overhead and the like. Therefore, the following equation is frequently used to find the data transfer rate.

$$R = B \times log_2(1 + \frac{S}{N}) \tag{3}$$

Here, R is the data transfer rate (bitrate), B is data bandwidth (Hz), log_2 is a base 2 logarithm, and S/N is the signal to noise ratio, where S is mean signal power and N is mean noise power. S/N expresses an effect of the quality and noise of a communication channel, and also has an effect on the performance of telecommunications system. Specifically, as S/N increases, a higher data transfer rate can be achieved. In addition, the number of bits of digital signals (bps/Hz) is determined by the digital signal efficiency and modulation method. In other words, if a more efficient modulation method is used, the number of bits per Hz will increase, and as a result, the data bitrate will also improve.

Although this relational expression is the framework of information theory and is used as an equation for calculating the data bitrate, in actual communication systems, it is necessary to determine the possible bitrate in consideration of various requirements.

3.3 Decay of Radio Waves

Low frequency radio waves have a long wavelength and generally have the propagation characteristic of passing easily through comparatively obstacles. Conversely, high frequency radio waves have short wavelengths and tend to decay or be reflected easily by obstacles, but have the potential to achieve high speed data transfer rates. Moreover, as implied by the wave nature of radio waves, it is assumed that radio waves will decay even in free space. The following concept based on the Friis transmission equation can be used to express the degree of this decay.

The power density PD of a radio wave, which controls signal transmission, has a value of the power, p, divided by the surface area of a sphere, $4\pi d^2$, having a radius equal to communication distance d, and therefore has the property of "attenuation proportional to the square of distance". For example, when the distance increases by 2 times, the area increases by 4 times, so the power density decreases to 1/4. This equation is expressed as follows:

$$PD = \frac{p}{4\pi d^2} \tag{4}$$

That is, in the decay of radio waves, this equation shows that the energy of the radio wave expands in space and becomes less dense as the communication distance increases, and as a result, the strength of the signal decreases. Attenuation of electric power is calculated as follows based on the Friis transmission equation.

$$PL = 20log_{10}\left(\frac{4\pi d}{\lambda}\right) \tag{5}$$

where, PL is propagation loss, d is the distance from the sender to the receiver, i.e., the distance from the transmitting antenna to the receiving antenna, and λ is the wavelength of the radio wave.

As can be understood from this equation, as tendencies of radio wave decay, decay not only increases as the propagation distance becomes longer, but also has the characteristic of "decay in inverse proportion to the square of the wavelength".

Because these equations assume a free space, they do not take into account the effects of obstacles and reflection, scattering, diffraction, interference and the like. Therefore, when considering real-world telecommunications, a response based on those phenomena is necessary.

4. B5G FOR NEXT-GENERATION WIRELESS COMMUNICATION TECHNOLOGIES

Because the goal of digitalization in recent years is to realize an advance digital society that integrates physical space and cyberspace, it is essential to construct and realize a social infrastructure that can realize all the events that occur in the world as desired, without consciousness of physical constraints.

In order to construct and realize a secure next-generation infrastructure with high speed, large volume and low latency in the next-generation wireless communication network system B5G, which is scheduled for release in 2030 toward the achievement of this goal, it will be necessary to secure a wider data bandwidth in the region higher than the frequency bands used up to 5G.

In the technological improvements prior to 5G until now, improvement of telecommunications methods was promoted in a form that utilized the limited frequency bandwidth under approximately 300 GH_Z called millimeter waves (milliwaves), which had been used until that time. This was because higher frequencies have stronger electromagnetic wave straightness, and thus are unable to circumvent obstacles, and are also subject to large attenuation in the atmosphere, which means that transmission over long distances exceeding a few meters is technically difficult.

However, the market demands high transmission quality with these difficulties, and allocation of frequency bandwidth that can be used in telecommunications is also tightening. In response to these issues, technological innovation has progressed in recent years, as can be seen in semiconductor devices that use high frequency bands in telecommunications, polarization that captures the phase and the distribution of vibration directions of light, which is a further development of the wireless communication technology used to date, and the like. Thus, arrangement of the various groups of technology necessary in order to use new high frequency regions is beginning.

Backed by the above-mentioned technological advances, the first aim of B5G is to utilize the region up to 30 THz, which is called the "terahertz gap", envisioning future use of frequencies up to 800 THz, which is the region of visible light that lies beyond the terahertz gap.

4.1 Wireless Communication Using Light

After first touching on the characteristics of radio waves and light shown in the following Fig. 2, wireless communication using light will be described.

Since the radio waves that control wireless communication and light are both electromagnetic waves and share the same space, they have the same basic characteristics for wireless communication described in Chapter 3, regardless of whether the transmission medium is radio waves or light.

The property that determines the transmission capacity when transmitting information is wavelength. If a wave oscillates gently, its wavelength is long and its frequency is low, and its information transmission rate is also slow to a corresponding degree. Conversely, rapid waves have a short wavelength and high frequency, and a large volume of information per unit of time can be transmitted due to the large number of waves that pass through a certain point, and in this case, the information transmission rate is fast. Thus, there is an inseparable relationship between wavelength and frequency.

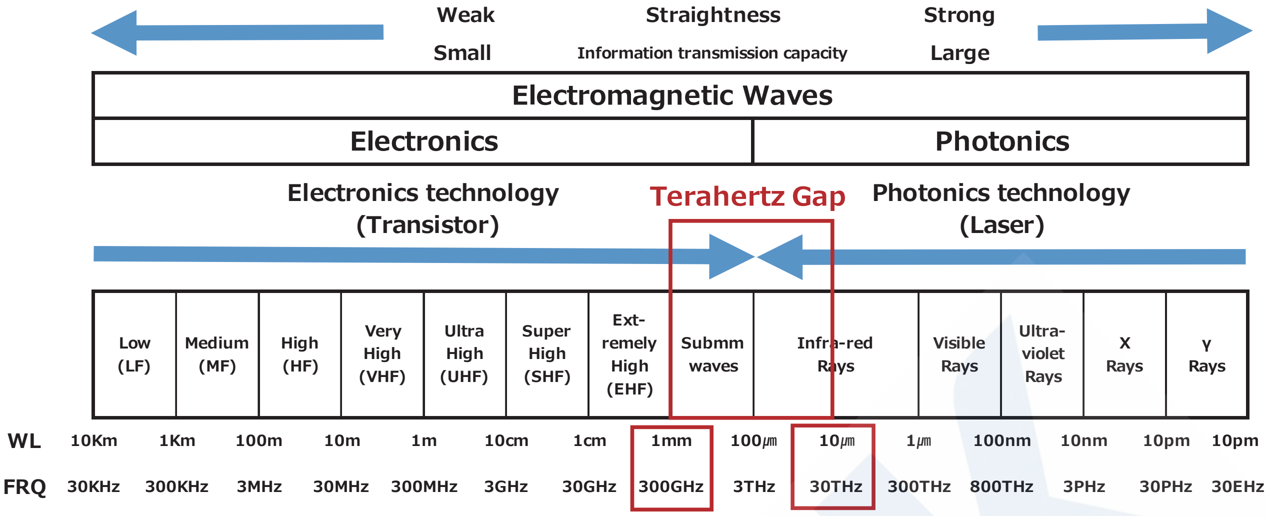

Fig. 2 Frequency bands of electromagnetic waves

Optical wireless communication uses light waves as the carrier wave, and is an access technology for sending and receiving data, in which a high frequency beam is transmitted directly through the atmosphere, forming a point-to-point communication link.

Due to the high frequency of light, it has a small energy loss during transmission is small and strong in interference and noise in comparison with electronic transmission. Because light has this feature, it is theoretically possible to achieve high speed data transmission over long distances and high signal quality. However, since light also has the transmission characteristic of strong straightness, obstacles to light propagation can easily occur due to various external factors such as physical obstacles, atmospheric scattering, absorption, weather conditions, *etc*. In addition, more than anything else, due to the high straightness of light, there are also technical situations in which good transmission is not possible without accurate positioning to receive the narrow light beam from the sending side. On the other hand, the high straightness of light is also a blessing, in that optical wireless communications are difficult to be intercepted.

A radio wave or this light “beam” indicates a shape in which light is focused and travels in a straight line. Light has the two natures of wave motion and particle behavior, and while it spreads due to its wave nature, it also has the characteristic of being focused as a beam. A focused beam of light traveling in a straight line is formed when light waves with a specified wavelength and the same phase and direction are generated so as to have an extremely high correlation. Unprecedently secure communication is possible by utilizing this characteristic of light in cybersecurity countermeasures.

With further progress and general application of these optical wireless communication technologies, cybersecurity countermeasures will also move to the next-generation phase, and accomplishment of safer wireless communication can be expected.

Optical wireless communication technologies are already used as an infrared communication function for cellphones and remote control devices for electronic products, and in recent years, a gradual expansion of their methods of use has been seen.

For example, in contrast to Wi-Fi, which uses radio waves, the technology called Li-Fi (Light Fidelity) has already been developed and is used in optical wireless communication. Like Wi-Fi, Li-Fi is also a wireless technology that uses the IEEE 802.11 standard. However, unlike radio waves, because Li-Fi optical wireless communication utilizes the infrared, visible light and UV optical frequency bands, interference is slight and Li-Fi does not cause radio disturbances. Use of optical wireless technology has also begun in hospitals, the cabins of passenger aircraft, nuclear power plants and other facilities where care is necessary when using electronic devices, suggesting that optical wireless communication using these characteristics of light has the potential to become an extremely promising new means of communication in the future.

It should be noted that the available range of frequencies and concrete definitions governing wireless communication are specified not only in international standards, but are also based on the laws of specific countries, industrial standards and the regulations in each region. Since different frequencies are allocated depending on the country or region, it is necessary to confirm the local regulations governing the frequency bands available for use. Ships are required to have appropriate wireless communication devices, and in some cases, restrictions are applied to the frequency bands that can be used by each device.

According to Chapter 1, Article 2 of Japan's Radio Act, "radio waves" are defined as "electronic or magnetic waves of frequencies not exceeding 3 THz". Therefore, until now, wireless communication meant communications using radio waves with frequencies of not more the 3 THz.

4.2 Terahertz Gap

The terahertz band is the electromagnetic wave region from roughly 300 GHz to 30 THz, centering on the frequency band around 1 THz, and has wavelengths from 1 mm to 10 μm. It is positioned at the boundary between light and radio waves that have a nature close to that of light (see Fig. 2). When compared with radio waves, the terahertz band has high resolution due to its short wavelengths, and it is a wide frequency band owning to its high frequencies. On the other hand, in comparison with light waves, it has high transmittance properties and scattering is slight. As an additional advantage, it is not susceptible to interference by surrounding radio waves due to distinctive features such as the molecular absorption effect (in which an absorption spectrum specific to certain molecules appears). For these reasons, the terahertz band has attracted worldwide attention as the electromagnetic wave frequency region with the greatest potential.

However, at such high frequencies, the ability of radio waves to avoid obstacle decreases and decay occurs due to water vapour in the air, *etc*. Long range transmission was also technically difficult because the decrease in radio wave generation and oscillation efficiency invites an increase in transmission loss. For these reasons, this frequency band was almost never used in telecommunications. Since it is also a region with many technical problems for both electronic technology and photonic technology, it was called the "terahertz gap".

In order to use the terahertz band in telecommunications, technological innovation prioritizing hardware is necessary, beginning with directional antenna technology that enables sending and receiving only between target locations, as well as new circuit board materials that reduce transmission loss in high efficiency terahertz wave oscillation/detection devices in order to utilize the reflection and transmission properties of radio waves, and evaluation and control devices for high frequency propagation characteristics and communication links, *etc*.

High output characteristics are required in the light source used as the signal source in wireless communication, and high sensitivity and low noise characteristics are also required in receiving devices. The high sensitivity and low noise characteristics required here can be evaluated collectively as NEP (Noise Equivalent Power). NEP is the signal power equivalent to noise power, and is calculated by dividing the noise voltage of a receiver by voltage sensitivity. Similarly, the noise current can be found by dividing by the current sensitivity. In other words, the ratio of the magnitude of noise and sensitivity is important. Because noise power is proportional to bandwidth, the S/N ratio is improved by narrowing the bandwidth, but in this case, the response speed decreases. Therefore, it is necessary to determine the necessary bandwidth for the system to be implemented.

$$NEP = \frac{PA}{\frac{S}{N} \cdot \Delta f^{\frac{1}{2}}} \tag{6}$$

P: incident energy (W/cm^2)
A: light-receiving area of detector (cm^2)
S: signal output (V)
N: noise output (V)
Δf: noise bandwidth (Hz)

As can be understood from the above equation, NEP shows the incident quantity of light when the signal-to-noise ratio (*S*/*N*) is 1.

At present, the range of activity in research and development in the wireless communication field, which is being promoted worldwide centering on B5G, includes the development of devices and development of new wireless communication methods for utilizing the terahertz band, and international standardization envisioning the use of higher frequency bands.

5. OUTLOOK FOR NTN BY OPTICAL WIRELESS COMMUNICATION

NTN (Non Terrestrial Network), which is considered to be a next-generation communication network environment, is a concept which aims to use outer space as a telecommunications environment for providing high quality, stable communication services to places where it was difficult to construct infrastructure until now and areas where access to communications was limited until now. NTN will attempt to implement a global network environment that provides coverage to the entire Earth by three-dimensional linkage of geostationary orbit satellites, medium- and low-orbit satellites and high altitude platform stations (HAPS) flying in the stratosphere, and also includes linkage with base stations located on the Earth's surface. International standardization is currently underway in ITU-R WP5B (ITU Radiocommunication Sector Working Party 5B) and 3GPP RAN (Third Generation Partnership Project Radio Access Network).

It is thought that the wireless communication technologies described above will play an effective role as a means of communication by mutual linkage and connection between these artificial satellites. Although optical wireless communications on the Earth's surface are affected by various external factors, in outer space, ideal behavior close to that in free space becomes possible. By using optical wireless communication to connect various types of satellites, this will reduce the decay due to distance that occurs with radio waves, and improve the feasibility of power-saving, high speed, large volume communication. However, since there is a higher possibility that HAPS, which operate in the stratosphere, will be affected by the atmosphere, it will still be necessary to select and consider communication methods corresponding to the circumstances.

On the other hand, technological innovation from the user's standpoint is also demanded. The user's purpose is to send and receive large volumes of information at high speed by automatic selection of the optimum transmission route, without being conscious of transmission routes. Users also desire a communications infrastructure with no restrictions or gaps in the communication area, and fortunately, the ultimate goal of the NTN concept is the same. It is also worth studying the possibility that users who earnestly desire these environments may not insist on the complete form, but will incorporate new communication technologies from time to time. From this viewpoint, we hope to see continuing technological innovation in the future as well.

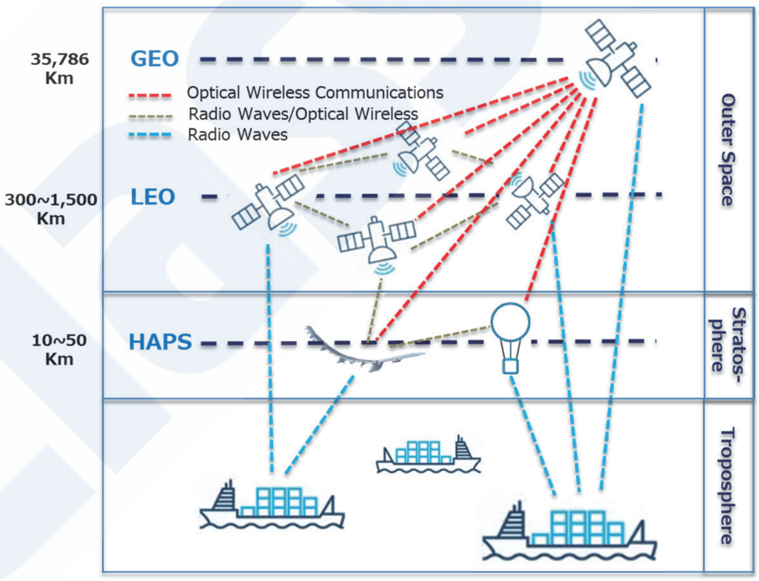

Fig. 3 Image of NTN environment

6. CONCLUSION

The commentary in this paper has been presented in order from the basics of telecommunications infrastructures to the most recent trends. If we consider the future form of communication infrastructure in the ship industry, the issues of aging seafarers and labor shortages are frequently mentioned, and as one measure that addresses these problems, the young generation particularly demands an internet environment that provides diverse kinds of connection. Against the backdrop of development and implementation of the communication environment on land, the market also demands initiatives that strengthen safe ship operation by sharing information concerning operation with the land side in real time, including shipping companies. Together with the global trend of digitalization, the wave of reform is also surging into the environment surrounding the ship industry, and IoT and automation of maneuvering and operation from remote location are driving reforms such as optimization of navigation routes and improvement of safety.

However, we realize that none of these improvements can be achieved without a stable communications infrastructure at sea. For example, if we turn our eyes to the global world, the general practice is online payment when paying utility bills or shopping, and all banks in the world are connected online, so the global economy will come to stop if the communication system goes down.

In the future, the author wishes to continue to convey the latest trends in telecommunications infrastructure to all those concerned, in order to be of assistance in the continuing development of the ship industry.

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