A Review of Two Types of New Key Technologies of 6G

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Abstract. The increasing need of future 6G wireless communication of higher transmission rate, larger network capacity, higher energy efficiency has been calling for the development of new key technologies. Among them, the two most popular and promising technologies are new spectrum access technology and efficient wireless transmission technology. New spectrum access technology intends to achieve the utilization of more available spectrum resources with higher frequency and wider bandwidth so that it can highly improve the data transfer rate and expand the network capacity. It includes Terahertz communication technology and visible light communication technology. Efficient Wireless Transmission technology aims to make new breakthroughs in traditional signal transmission mode and achieve larger channel capacity so that network coverage and security can be improved, and signal transmission loss can be decreased. It contains IRS technology and Spatial multiplexing technology. Properties of each technology, such as principles, advantages, application scenarios, are discussed in this paper. In chapter 2, new spectrum access technology is introduced, and efficient wireless transmission technology is introduced in chapter 3.

Keywords: Terahertz communication technology; Visible Light communication; rtt; GPRS; Wi-Fi; radio transmission technologies.

1. Introduction

With the commercialization and popularization of 5G, the research and development of 6G has also begun in full swing. Many emerging new services and applications have put forward higher requirements for wireless network performance and exposed some defects and shortcomings of 5G. In terms of communication spectrum, although 5G has already expanded the spectrum resources to millimetre waves, it’s unable to meet the requirements of ultra-large capacity and ultra-high speed of future wireless networks. Therefore, there is an urgent need of 6G to expand the spectrum further and develop new technologies to achieve the utilization of more available spectrum resources with higher frequency and wider bandwidth [1]. In terms of network coverage, to achieve the future communication era of Internet connecting everything, new breakthroughs of 6G technology for traditional wireless access technology are also required. In terms of network security, with more and more important data stored and transmitted online, it calls for new technologies to prevent them from being stolen and tampered [2]. Lastly, in terms of energy efficiency, new spectrum resources are also needed to lower the energy consumed and improve the energy efficiency in future wireless communication [3].

To meet these challenges mentioned above and promote the development of 6G, two types of new key technologies for 6G are introduced in this paper shown as Figure 1, which are New Spectrum Access Technology and Efficient Wireless Transmission Technology. In terms of New Spectrum Access Technology, the two most promising and popular technologies are Terahertz Communication Technology and Visible Light Communication Technology. And in terms of Efficient Wireless Transmission Technology, the two most promising and popular technology are IRS technology and spatial multiplexing technology. In the section of Terahertz Communication Technology, its advantages, problems, and application scenarios are introduced and summarized. In the section of the other three technologies, their principles, advantages, and application scenarios are introduced and summarized.

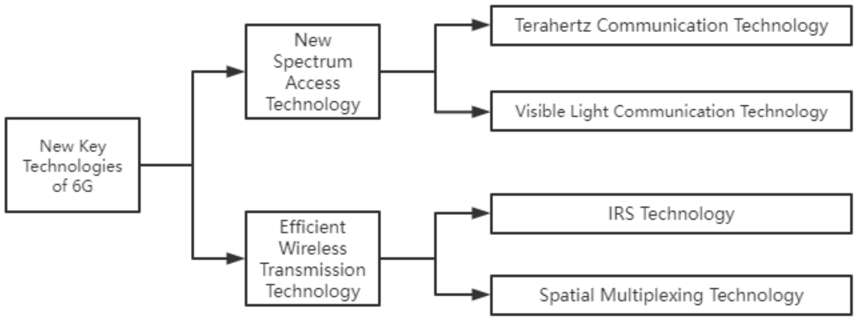

Figure 1. New Key Technologies of 6G

2. New Spectrum Access Technology

In order to achieve greater data transfer rate in 6G era, more available spectrum resources are needed to be developed and applied. There are basically two ways to achieve the better utilization of spectrum resources. One of them is to improve the utilization efficiency of existing spectrum. However, the existing spectrum resources is fixed and allocated to the corresponding communication systems to avoid interference, which means even though there is no data to transmit in some frequency bands, they cannot be used by other systems as well [4]. Therefore, a more promising way is to develop more spectrum resources with higher frequency and wider bandwidth, among which the most popular are terahertz waves and visible lights bands.

2.1. Terahertz Communication Technology

2.1.1. Advantages

Terahertz waves are the electromagnetic waves with a frequency spectrum ranging from 0.1 to 10 THz [5]. Terahertz band has many advantages compared with lower frequency bands used before. Firstly, with its higher frequency and wider bandwidth, according to Shannon's equation, it can offer us a faster data transfer rate in excess of Tbit/s, which can meet the requirements of many new communication methods such as VR and AR. Secondly, Terahertz waves have narrower beam, better directivity, and better anti-interference capability, which make it appropriate for secure and fast communication within 2-5 km. Thirdly, the photon energy of Terahertz waves is much lower than that of x-ray and visible light, only about 10e-3 eV, so it can improve the energy efficiency and lower the energy consumed in communication systems.

2.1.2. Problems

There are also some problems and disadvantages of terahertz communication. Firstly, terahertz waves have relatively larger free space attenuation when propagating compared to lower frequency bands because attenuation is proportional to frequency. Secondly, Terahertz waves can be easily absorbed by water molecules in air because terahertz waves can have a strong interaction with the hydrogen bonding between the polar liquid molecules. In conclusion, the effective distance and power of terahertz waves are limited, and transmission loss is caused because of these problems [6]. And these problems can be solved and improved by some new technology, such as IRS Auxiliary Communication, which will be mentioned in later chapters.

2.1.3 Application Scenarios

Terahertz communication is widely used in many fields. In the field of space communication, some terahertz waves with specific wavelengths, such as $350\mu m, 450\mu m, 620\mu m$ have a relatively transparent atmosphere window, which means they have higher transmittance and can achieve long distance communication with lower energy consumed and transmission loss. In the field of medical testing, as terahertz waves have a strong absorption effect with water molecules and human cells tend to have tissue water changes after lesions compared with normal tissue, so the application of terahertz technology can help to quickly locate the lesion and identify the size and shape of the lesion area, which improves the efficiency of medical diagnosis in class [7]. In the field of military, Terahertz radar can detect small targets more effectively compared to microwave radar. Meanwhile, terahertz radar has stronger penetration capability even in smoky and dusty weather compared with infrared radar and lidar, so it can detect the concealed enemy weapons and hidden men more effectively [8]. In the field of material detection, terahertz technology is also important because many macromolecules have obvious absorption peaks in the terahertz band and the frequencies corresponding to phenomena such as molecule vibration and rotation are also in the terahertz band, so terahertz spectrum can be used to better identify substances and organic molecules with subtle structural differences.

In conclusion, not only is terahertz band appropriate for many types of communication, ranging from nano communication, secure communication within limited distance to space communication, it can also be used in various and different fields such as medical, military and detection.

2.2. Visible Light Communication Technology

2.2.1. Principles

Visible Light Communication is to transmit information through the utilization of LEDs and other visible light resources to emit high-speed light and dark changes in light signals which naked eyes are unable to detect. For example, in the process of signal transmission of binary On-Off Keying, if bright lights represent “1” for digital communication while dark lights represent “0”, the communication rate of visible light communication system can be influenced by the speed of light and dark changes of visible light resources. As human eyes have residual vision, they are not sensitive even to the 50 Hz frequency flicker of old-fashioned fluorescent lamps. Therefore, as long as the modulation depth is shallow enough and the data transfer rate is high enough for visible light communication systems, electronic devices can detect these tiny changes in light density to achieve digital communication while naked eyes won’t be affected as well.

2.2.2. Advantages

There are many advantages of visible light communication. Firstly, the visible light spectrum is unregulated so its resources available is plentiful. Secondly, as visible light has poor penetration capability and limited transmission range, it’s more difficult to steal information transmitted by visible light, thus communication network powered by visible light has higher security. In addition, as the signal of visible light communication is visible and easier to control, the area covered by the signal can be flexibly and easily controlled by using some cover such as lampshades and curtains. Thirdly, visible light signal is not susceptible to electromagnetic signal interference as their frequency difference is big. Lastly, visible light communication can be a both convenient and energy-saving way because the multiple functions of lighting and communication can be achieved by a single visible light resource [9].

2.2.3. Application Scenarios

As visible light communication doesn’t produce electromagnetic radiation and is not easily impacted by external electromagnetic interference, it can have a wide range of applications in some specific scenarios where electromagnetic interference is a concern, such as hospital, airplane and gas stations. In contrast, Wi-Fi signal can be affected more easily because the radio frequency signals radiated by many common electrical devices such as microwave ovens, Bluetooth devices refrigerators happen to cover the same bands of Wi-Fi and this problem can be solved by visible light communication. In addition, visible light communication is also a promising and complementary approach for underwater communication. Compared with the traditional underwater communication with acoustic waves which is only suitable for long range and low data transfer rate applications, underwater visible light communication is adequate in several situations that require faster rates, such as communication with numerous underwater sensor nodes which are required for leakage monitoring, safe operation, and pollution management [10]. Besides, visible light communication can also be used to add communication function at a low cost and high energy efficiency based on the original lighting network in some densely populated areas such as subway stations, shopping malls and meeting rooms since it can offer Internet access of greater capacity and faster rates.

3. Efficient Wireless Transmission Technology

In order to achieve larger channel capacity and more efficient wireless transmission, some new technologies are being developed to adapt to new communication frequency bands and make a revolutionary breakthrough in the signal transmission modes. Among them the two promising and popular technology are IRS technology and spatial multiplexing technology.

3.1. IRS Technology

3.1.1. Principles

IRS technology can use software to control the reflection of the signals. IRS refers to intelligent reflecting surface, which is composed of many passive and reflective units. When there are incident signals hitting on these reflective units, each of them can independently adjust and alter the amplitude and phase of the signals and then reflect them out [11]. The basic formula which reflects the function of each IRS unit is shown as below.

$$y_n = \beta_n e^{j\theta_n} x_n \, , n = 1,2, \dots \, , N \tag{1}$$

In this formula, y_n and x_n represents the reflected and incident signal waves on one reflective unit respectively. β_n is the parameter that controls the signal amplitude change while $e^{j\theta_n}$ controls the signal phase change.

3.1.2. Advantages

IRS technology is used to improve the desired signal power, decrease interference, and prevent data theft and tampering through intelligent control of the amplitude and phase of reflected signals. As the effective distance of IRS technology is limited, so IRS can be densely deployed at relatively low cost and with low energy consumption, and complicated interference management between IRS is not required as well. Besides, IRS technology can improve the wireless link performance and increase its flexibility by intelligent programming and combination with the application of AI.

3.1.3. Application Scenarios

There are basically three typical application scenarios of IRS technology shown as below.

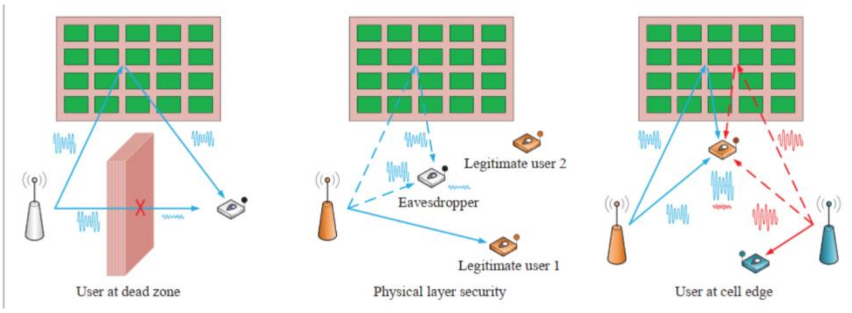

Figure 2. Three typical application scenarios of IRS technology.

The first one is when the wireless link between the user and the base station is blocked by one obstacle or the distance between the user and the base station is a little beyond the effective distance of the signal transmission, IRS deployed between them allows the signal to be reflected intelligently to bypass obstacles to establish a new virtual link so that the user can receive the signal. In the meantime, the received signal power can be improved by adjusting the parameter β_n. The second one is when there is an eavesdropper between the user and the base station trying to steal the information, it can be prevented by intelligently adjust the amplitude and phase of reflected signals to make the signals from the direct wireless link and the signals from virtual reflection link cancel out. In this scenario, β_n can be set to 1 and θ_n equals to some odd multiples of π [11]. The third scenario can be briefly considered as the combination of the first and second one. When the cell edge user is interfered by multiple adjacent base stations channels, IRS distributed at the cell edge can both increase the desired signal power and decrease the interference from other nearby unwanted signals at the same time.

3.2. Spatial Multiplexing Technology

3.2.1. Principles

In order to solve the problems of large electromagnetic wave loss and small coverage of 6G communication bands with higher frequency, spatial multiplexing technology is developed.

MIMO (Multiple Input Multiple Output) and beamforming technology are two branches of spatial multiplexing technology. MIMO technology is to divide the space by an adaptive antenna array to form different beams in different directions and each beam can provide a unique channel without interference from others so that the same frequency band can be reused in different space without extra energy and time consumption. There are multiple transmitters and receivers connected by multiple antennas with MIMO configuration, while the number of transmitters doesn't need to equal the number of receivers. Beamforming technology is to generate a directional beam with multiple antennas to concentrate the energy in one specific desired direction so that the quality and power of transmitted signal is improved and the interference with other users is suppressed [12].

3.2.2. Advantages

Firstly, the application of spatial multiplexing technology can improve the spectrum utilization by multiples without increasing bandwidth and antenna transmit power. Each antenna can transmit signals independent from each other, thus improving the data transfer rate. Secondly, it can increase the channel capacity and the network coverage by increasing the number of antennas. Thirdly, it can suppress the attenuation of transmitted signals through spatial multiplexing gain.

3.2.3. Application Scenarios

There are basically two application cases, one is HomoNet (homogeneous network) with only macro cells deployed and the other is HetNet (heterogeneous network) with both macro cells and small cells. There are three typical types in the case of HomoNet. The first one is multi-layer sectorization, which can further divide the traditional sectors into inner and outer sectors to increase multiplexing gain. 3D beamforming with the same horizontal orientation but varying elevation angles can be installed and used in each sector. Therefore, radio resources on the same frequency can be reused by all sectors and this can significantly increase the number of terminals that the area can serve and improve the network throughput. The second one is adaptive beamforming. Traditional fixed beamforming is to keep the weight of the signal multiplication of each element in the antenna array unchanged during the operation. However, adaptive beamforming technology can update the weights according to signals received to suppress space interference. The last one is large-scale cooperation. Compared with traditional DAS (Distributed Antenna System) technology, large-scale cooperation can further improve the coverage and achievable throughput by expanding the number of coordinated distributed antennas.

For the case of HetNet, there are also three typical scenarios. The first one is wireless backhaul. As all the SeNB (small cell node base station) needs to connect to their MeNB (macro cell node base station) through wireless or wired backhaul, it's easier to deploy wireless backhaul than wired backhaul. In this case, MeNB is equipped with a huge MIMO with high degree of freedom to support multiple wireless backhauls [13]. Besides, wireless backhaul is more flexible and less expensive than wired backhaul. The second one is Hotspot coverage. Since traditional antenna array with fixed downlink tilt is mainly used for users moving at street level and telecommunications are usually at different heights of the building, the traditional way is not appropriate anymore. SeNB with a huge antenna array can adjust the azimuth and elevation angles as necessary to directly transmit the beam to terminals on different floors of the building so that the coverage of indoor hotspot and system throughput are improved significantly. The last scenario is dynamic cell. In HetNet, since the RSRP (Reference Signal Received Power) collected from MeNB is often larger than that of SeNB, there might be more terminals linked to MeNB, which will lead to a potential imbalance in traffic between macro cell and small cell. Through the application of MIMO in SeNB, the down tilt angle of the transmitted signal is adjustable so that the radius of the cell can be adaptively expanded or reduced. Therefore, users at the edge of small cells can choose to adaptively connect to the SeNB according to the signal power level they received. And this can balance the load between macro cells and small cells.

4. Conclusion

In order to speed up the 6G research and development process and achieve the application of 6G in various industries, breakthroughs must be made in the new key technologies of 6G. Therefore, four new key technologies of 6G are discussed in this paper.

In terms of Terahertz Communication Technology, it significantly helps to achieve the ultra-high data transfer rate and ultra-large capacity and improves the energy efficiency of future communication networks, thus it can be widely applied in many scenarios and revolutionize various communication systems. In terms of Visible Light Communication Technology, its remarkable ability in anti-interference, convenience and energy saving makes it appropriate in some specific scenarios to offer Internet access of greater capacity and faster rates at a very low cost. In terms of IRS Technology, it’s a promising auxiliary communication technology to help improve the limited effective distance and power of some specific communication medium and ensure the network security by preventing information from being stolen by the eavesdroppers. In terms of Spatial Multiplexing Technology, it can improve the spectrum utilization by multiples without increasing bandwidth and antenna transmit power, which make it appropriate for increasing the network coverage and decreasing the power loss of 6G communication bands of higher frequencies.

With the continuous development and improvement of these new key technologies of 6G, hopefully, the future 6G era of ultra-high speed of Internet access, ultra-large capacity of Internet storage so that everything is connected, and people can communicate anywhere and anytime can finally come true.

References

[1] Chowdhury, M. Z., Shahjalal, M., Ahmed, S., and Jang, Y. M. 2020. 6G Wireless Communication Systems: Applications, Requirements, Technologies, Challenges, and Research Directions. IEEE Open Journal of the Communications Society, vol 1, pp 957–975.

[2] [Lu, Y. 2020. Security in 6G: The Prospects and the Relevant Technologies. Journal of Industrial Integration and Management, vol 05(03), pp 271–289.

[3] Huq, K. M. S., Otung, I. E., and Rodriguez, J. 2022. A Study of Coverage Probability-Based Energy-Efficiency Analysis for UAV-Aided THz-Enabled 6G Networks. IEEE Transactions on Intelligent Transportation Systems, pp 1–8.

[4] Matinmikko-Blue, M., Yrjola, S., and Ahokangas, P. 2020. Spectrum Management in the 6G Era: The Role of Regulation and Spectrum Sharing. 2020 2nd 6G Wireless Summit (6G SUMMIT).

[5] Elayan, H., Amin, O., Shubair, R. M., and Alouini, M. S. 2018. Terahertz communication: The opportunities of wireless technology beyond 5G. 2018 International Conference on Advanced Communication Technologies and Networking (CommNet).

[6] Akyildiz, I. F., Han, C., Hu, Z., Nie, S., and Jornet, J. M. 2022. Terahertz Band Communication: An Old Problem Revisited and Research Directions for the Next Decade. IEEE Transactions on Communications, vol 70(6), pp 4250–4285.

[7] Yu, L., Hao, L., Meiqiong, T., Jiaoqi, H., Wei, L., Jinying, D., Xueping, C., Weiling, F., and Yang, Z. 2019. The medical application of terahertz technology in non-invasive detection of cells and tissues: opportunities and challenges. RSC Advances, vol 9(17), pp 9354–9363.

[8] Lu, X., Venkatesh, S., and Saeidi, H. 2021. A review on applications of integrated terahertz systems. China Communications, vol 18(5), pp 175–201

[9] Matheus, L. E. M., Vieira, A. B., Vieira, L. F. M., Vieira, M. A. M., and Gnawali, O. 2019. Visible Light Communication: Concepts, Applications and Challenges. IEEE Communications Surveys & Tutorials, vol 21(4), pp 3204–3237.

[10] Elamassie, M., Miramirkhani, F., and Uysal, M. 2019. Performance Characterization of Underwater Visible Light Communication. IEEE Transactions on Communications, vol 67(1), pp 543–552.

[11] Cui, M., Zhang, G., and Zhang, R. 2019. Secure Wireless Communication via Intelligent Reflecting Surface. IEEE Wireless Communications Letters, vol 8(5), pp 1410–1414.

[12] Pinchera, D., Migliore, M. D., and Schettino, F. 2021b. Optimizing Antenna Arrays for Spatial Multiplexing: Towards 6G Systems. IEEE Access, vol 9, pp 53276–53291.

[13] Ni, S., Zhao, J., Yang, H. H., and Gong, Y. 2019. Enhancing Downlink Transmission in MIMO HetNet With Wireless Backhaul. IEEE Transactions on Vehicular Technology, vol 68(7), pp 6817–6832.