2025 International Conference on Advanced Mechatronics and Intelligent Energy Systems

Outlook and application of optical communication combined with 6G technology

AIPCP25-CF-AMIES2025-00040 | Article

PDF auto-generated using **ReView**
from
RIVER VALLEY
TECHNOLOGIES

Outlook and application of optical communication combined with 6G technology

Yuhao Hu

Faculty of Innovation Engineering, Macau University of Science and Technology, Macau, China

1230026709@student.must.edu.mo

Abstract. This paper focuses on the integration of optical communication and 6G technology. Since the application of 5G technology in 2020, 6G technology has become a hotspot for future research, and optical communication provides new ideas for the research of 6G technology with its own advantages. This paper describes the key technologies of the combination of optical communication and 6G technology, including high-speed transmission technology, bearer network optimization technology and pass-through integration technology, and introduces the current development status at home and abroad, such as the U6G large-scale MIMO technology of Southeast University, the study of pass-through integration algorithm of China Mobile, the research of the University of Southampton of the United Kingdom in the field of hollow optical fibre, and the IOWN1.0 technology of NTT Corporation of Japan, and so on. In the future, the integration of optical communication and 6G technology will greatly promote the progress of human society and have high application value in medical, aerospace, underwater and other fields.

INTRODUCTION

Since the introduction of 5G technology in 2020, the quality of human network life has been greatly improved, with the rapid development of Internet of Things, artificial intelligence, virtual reality and other emerging technologies, the communication system is facing higher requirements, and 6G technology for 2030 has become a hot topic of research at present.

The goal of 6G is to explore innovative communication mechanisms that go beyond the limitations imposed by current network paradigms and technologies. It integrates new concepts, architectures, protocols and solutions to fit existing and future application scenarios[1]. Compared with 5G technology, 6G not only has faster and more data transmission rate, but also has new technologies such as communication perception integration, etc. The research of 6G technology is of great significance to the progress of human society, which can promote the development of the digital economy, enhance national competitiveness and realize the global coverage of the network in the future. At present, the research of 6G technology is not always smooth, Terahertz (frequency range of 0.1 - 10 terahertz) technology is seen as a key enabler in the development of 6G communications due to its unique advantages. This technology is capable of realizing a considerable increase in communication capacity and significantly enhancing network connectivity, opening up broad prospects for the development of 6G communications. However, existing terahertz on-chip communication devices suffer from crosstalk, scattering losses, limited data speeds, and lack of tunability[2]. But at the same time, optical communication with its high bandwidth, low loss, anti-electromagnetic interference and other characteristics, to support the high-speed and stable transmission of massive data, become the core pillar of information and communication infrastructure, for the research of 6G technology to provide a new way of thinking.

The main content of this paper is about the combination and application of optical communication and 6G technology, summarizes the idea of technology combination, and discusses the development status at home and abroad, as well as future application scenarios.

CONVERGENCE OF OPTICAL COMMUNICATION AND 6G TECHNOLOGY

High-speed Transmission Technology

Lower transmission losses through the development of new optical fiber materials to meet the needs of 6G networks. Developing more advanced modulation technology that can achieve higher data rates with the same resources. Increase transmission capacity by constructing multiple parallel channels using multi-dimensional multiplexing technology and using multi-mode optical fibers and wavelength division multiplexing technology to transmit different signals at different wavelengths. One of the latest R&D results is the double-clad fibers (DCF) of Lab. WOCA, National Institute of Telecommunications (Inatel), Brazil. The DCF based radio frequency and power-over-fiber (RPoF) system can transmit data and power simultaneously using the core and inner cladding of the DCF to achieve simultaneous transmission of data and power over the same fiber link. Compared with single-mode fiber, the inner cladding of dual-cladding fiber can transmit high-power signals, avoiding the problem of nonlinear effect caused by the small core area and high power density of single-mode fiber; compared with multimode fiber, its single-mode core layer can ensure the quality of data transmission, overcoming the shortcomings of multimode fiber due to mode dispersion and crosstalk that leads to the limitation of the data rate, and realizing the high-efficiency transmission of data and power in the same fiber[3].

Carrier network Optimization Techniques

The evolution of mobile network architectures has evolved from a three-tier architecture in 2G to a two-tier architecture in 5G, with increasing network performance. 2G adopted the BTS, BSC, and CN architectures, 3G was similar to 2G with only partial replacements, 4G adopted an all-IP network architecture, and 5G introduced features such as a serviced architecture, forwarding and control separation, and network slicing[4]. With 5G struggling to meet emerging technology and application demands, 6G networks are being introduced and the accompanying 6G network architecture is being studied. The core of the 6G network architecture is Space-Air-Ground Integrated Network (SAGIN), which integrates space-based, air-based, and ground-based network resources, and is dedicated to creating a global, efficient, and intelligent communication network with global coverage and high efficiency and intelligence. The SAGIN architecture is of great significance in the development process of 6G communications, providing key support to meet emerging applications and technological needs. This architecture integrates the core network (CN) and the access network (RAN) into a single network consisting of a serviced control plane (SBCP), a serviced user plane (SBUP), and a radio unit (RU).The SBCP integrates the control plane functions of the CN and the RAN, and is used for mobility management, session management, etc., while the SBUP integrates the data plane functions of the two and is responsible for user data routing, QoS flow management, etc. The SAGIN architecture also integrates the control plane functions of the CN and the RAN. SBCP integrates the control plane functions of CN and RAN for mobility management, session management, etc.; SBUP integrates the data plane functions of both, responsible for user data routing and QoS flow management; and RU consists of part of the functions of AAU, and the remaining AAU functions are merged with DU. Through this integration, the network structure is simplified and the transmission delay of data forwarding and control signaling is reduced. At the same time, the data transmission path in the SAGIN architecture can also introduce green energy-saving concepts in aspects such as the physical level of optoelectronics, and optimize the energy management of optical transmission equipment, which can reduce the energy consumption of network operation.

Sensory Integration Technology

With the development of cellular networks to high frequency bands, the fusion of communication and radar spectrum generates interference, and integrated sensing and communication (ISAC) has become an inevitable trend in the development of 6G networks.

The integrated sensing and communication for optical communication can achieve 6G technology that integrates communication and sensing, using the scattering effect of optical fiber to achieve both spatial and temporal distributed sensing along the entire optical fiber and also to provide environmental sensing for 6G networks. ISAC realizes function integration through hardware and software resource sharing, which is divided into three levels: one is function integration but resource independence, relying on information sharing to reach function synergy; the second is resource integration but function independence, sharing spectrum and hardware resources; and the third is the deep fusion of function and resource, using the same resource to realize sensing and communication functions at the same time, which is also the key characteristic of 6G network[5].

CURRENT STATUS OF DEVELOPMENT AT NATIONAL AND INTERNATIONAL LEVEL

Southeast University in June 2024 proposed the use of large-scale MIMO technology in the U6G band to increase the transmission rate, and at the same time to give 6G perception and localization capabilities, the idea is to increase the number of antennas through the order of magnitude, so that mobile users are always in the antenna surroundings, to provide seamless high speed and high quality communication services for mobile users[6]. Currently in the theoretical stage of this technology in reality has a huge cost challenge, due to the order of magnitude increase in the number of antennas at the same time the cost of construction, training and feedback, model and computational complexity of the overhead is too large, the future also requires the introduction of new technologies to realize the theoretical ideas. Table1 shows the experimental data of many terahertz communication MIMO transmission experiments at home and abroad.

TABLE 1. Experimental data in recent years.

Year	System Type	Modulation Method	Carrier Frequency/GHz	Limited Distance/km	Wireless Distance/m	Transmission Rate/(Gbit/s)
2018	Photon - assisted	4×4 MIMO - PDM - PS - 64QAM	140	10	3.1	27%OH SD - FEC@BER 4×10^{-2}
2019	Photon - assisted	2×2 MIMO - PDM - PS - 64QAM	450	20	1.8	27%OH SD - FEC@BER 4×10^{-2}
2022	Fiber - terahertz - fibe	2×2 MIMO - DP - QPSK	360 - 430	20 + 20	1	206.25
2023	Photon - assisted	2×2 MIMO - PS - 64QAM	330 - 500	10	10	1048.8
2024	Photon - assisted	2×2 MIMO - PS - 64QAM	319	20	3	616

China Mobile Communications Group proposed an algorithmic study on the integration of 6G communication sensing, based on the existing cellular network OFDM waveforms for the integration of communication sensing design, to achieve the perception of the target object, is one of the technical routes of the current research on the integration of communication sensing, which can minimize the impact on the design of the communication system and the hardware, and has a better industrial realizability. They introduced three multi-target perception algorithms, 2D-DFT, rotationally invariant subspace method and multiple signal classification algorithm. After experiments, it was concluded that 2D-DFT has the advantage of lowest converged SINR and low complexity, but its range or speed accuracy is limited, while ESPRIT and MUSIC can achieve the desired range and speed accuracy requirements at higher SINR, but at the cost of higher computational complexity[7].

Hollow fibre is a new fibre optic technology, has shown great potential for application in communication, sensing and medical fields in recent years. The University of Southampton in the UK is an important force in hollow-core fibre research. 2018 - 2020, the hollow-core fibre group in its ORC centre developed a 6-unit nested-tube NANF-6 fibre with loss reduced to 0.28dB/km. 2022, the group optimized and obtained a 5-unit dual-layer nested-tube hollow-core fibre (DNANF-5) with a minimum loss of 0.174dB/km and further achieved a 5-unit hollow-core fibre with Microsoft in 2024 with a minimum loss of 0.08±0.03dB/km, and in 2024, it further achieved a 5-unit hollow-core fibre with Microsoft. In 2024, the group further realized DNANF-5 with a minimum loss of 0.08±0.03dB/km with Microsoft, which represents the international advanced level of hollow fibre loss control. The joint team of Jinan University, Leader Fibre Technology and China Mobile has adopted a 4-unit truncated double-layer nested tube structure to realize the anti-resonance hollow fibre with partial band loss ⩽0.1dB/km, and the lowest loss is close to 0.06dB/km. In addition, Beijing Institute of Technology and other universities have also carried out researches in the field of hollow fibres, for example, Fibre home Communication has jointly used the nested anti-resonance hollow fibres with single-bridge structural characteristics for ultra-large-capacity hollow fibres with Beijing Institute of Technology, and has used them in the field of ultra-large capacity hollow fibres. For example, Fibre home Communication and Beijing University of Technology have used nested anti-resonance hollow fibre with single bridge structure characteristics for real-time data transceiver transmission test of ultra-high-capacity hollow fibre system, and achieved a transmission capacity of 1.2Tbit/s and a transmission distance of 1.5km in a specific high-speed data transmission scenario. The XLIM Institute at the University of Limoges, France, has succeeded in reducing the core surface roughness of hollow-core photonic crystal fibres (HCPCFs) by using an innovative fabrication technique that uses reverse airflow to increase shear, achieving ultra-low loss in the short wavelength range[8]. Both fibre losses are below the silica Rayleigh scattering limit, table2 recording low loss values in the short wavelength range.

TABLE 2. Loss values for different fibres.

Fibres	Wavelength(nm)	Dilapidation(dB/km)
Fibre A	290	50.0
Fibre A	369	9.7
Fibre A	480	5.0
Fibre B	558	0.9
Fibre B	719	1.8

Reducing network energy consumption has become crucial in the pursuit of a sustainable social development process. However, the energy cost of network infrastructure is expected to increase 12 times by 2050 compared to 2007[9]. NTT Japan launched IOWN (Innovative Optical and Wireless Network) 1.0 technology in 2023, which provides ultra-low latency network services through APNs, as well as compact, energy-efficient devices for use in the network. APNs (All-Photonic Networks) offer unprecedentedly low latency, with latency of only 1/ APNs (All-Photonic Networks) offer unprecedented low latency, with latency times as low as 1/100th of existing services, without latency jitter and visual latency tuning, enabling use cases such as remote entertainment experiences, telesurgery, and GPU-as-a-Service. In order to better realize IOWN technology, NTT uses InP devices, which are electronic or optoelectronic devices based on indium phosphide with high-speed electronic performance and good optical characteristics. The high electron mobility of InP devices makes them suitable for high-speed electronics, which can satisfy the needs of IOWN for high-speed data transmission. InP can be used to fabricate optoelectronic devices such as lasers, photodiodes, and optical signal modulators, and the synergistic operation of these optoelectronic devices enables IOWN to optimize network architecture, improve communication efficiency, and reduce transmission loss. The high-speed performance and low power consumption of InP devices can be utilized to provide powerful computing and data processing capabilities for Digital Twin Computing (DTC) and Cognitive Foundation (CF) technologies in IOWN[10].

CONCLUSION

This paper summarizes the methods suitable for the combination of optical communication and 6G technology and the current development status at home and abroad. Following the implementation of 5G technology in 2020, 6G technology has emerged as a prominent research focus, with the objective of overcoming the prevailing network paradigm and technological constraints. This development is of paramount importance to the advancement of human society. However, the process is encountering challenges, and the field of optical communication, characterized by its high bandwidth and low loss properties, is offering novel approaches for the investigation of 6G technology. The convergence of these two fields is driven by several key technologies, including high-speed transmission technology (e.g., double-clad fiber technology), bearer network optimization technology (development of new fiber materials, evolution of network architecture, and SAGIN architecture for 6G to simplify the structure, reduce latency, and lower energy consumption), and perception convergence technology (ISAC for optical communication utilizes the fiber scattering effect to realize the convergence of 6G communication and perception and achieve function integration by sharing resources of hardware and software at different levels). The ISAC for optical communication employs the fiber optic scattering effect to achieve 6G communication and perception integration, thereby realizing function integration through hardware and software sharing at different levels. Regarding the domestic and international context of its development, Southeast University in China has proposed the implementation of large-scale MIMO technology within the U6G frequency band. In addition, China Mobile has undertaken research endeavours focused on perception fusion algorithms for 6G communication. On the global stage, noteworthy achievements have been made in the field of hollow-core optical fiber research by the University of Southampton in the United Kingdom. Furthermore, the XLIM Research Institute in France has successfully mitigated the loss of hollow-core photonic crystal fibers. Japan's NTT has introduced IOWN 1.0 technology, with the aim of enhancing communication efficiency. In conclusion, the development of new fiber materials, the optimization of bearer networks and the study of convergence technology are the keys to the convergence of optical communication and 6G technology, and the future convergence of the two will promote the progress of the global society, with high application value in many fields, and optical communication will become a highly efficient way of communication in the information age.

REFERENCES

1. Pengfei Li, Jiaxin Fan, Jianhong Wu, Exploring the Key Technologies and Applications of 6G Wireless Communication Network,iScience,2025,112281,ISSN 2589-0042.
2. Kumar, A., Gupta, M., Pitchappa, P. et al. Phototunable chip-scale topological photonics: 160 Gbps waveguide and demultiplexer for THz 6G communication. Nat Commun 13, 5404 (2022).
3. Souza, L.C.d., Pinto, F.B.F., Andrade, T.P.V. et al. Power and data simultaneous transmission using double-clad fibers towards 6G. Sci Rep 15, 4486 (2025).
4. H. Cui et al., " Space-air-ground integrated network (SAGIN) for 6G: Requirements, architecture and challenges, " in China Communications, vol. 19, no. 2, pp. 90-108, Feb. 2022.
5. L. Ma, C. Pan, Q. Wang, M. Lou, Y. Wang and T. Jiang, " A Downlink Pilot Based Signal Processing Method for Integrated Sensing and Communication Towards 6G, " 2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring), Helsinki, Finland, 2022, pp. 1-5,
6. Zhang Bing, Yu Jianjun. Research and prospect of photonic-assisted terahertz MIMO-based systems[J]. Mobile Communication,2024,48(12):21-30.
7. Wang Xiaoyun,Zhang Xiaozhou,Ma Liang,et al. Research and optimization of sensing algorithm for 6G communication sensing integrated network[J]. Journal of Communications,2023,44(2):219-230.
8. Osório, J.H., Amrani, F., Delahaye, F. et al. Hollow-core fibres with reduced surface roughness and ultralow loss in the short-wavelength range. Nat Commun 14, 1146 (2023).
9. A. Shimada, " IOWN1.0—Start of IOWN Service " , NTT Technical Review, vol. 21, no. 3, pp. 16-20, Mar.2023.
10. T. Tsutsumi, " Cutting-edge THz Devices as Essential Parts of IOWN - Innovative Optical and Wireless Network, " *2023 IEEE International Meeting for Future of Electron Devices, Kansai (IMFEDK)*, Kyoto, Japan, 2023, pp. 1-4.