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Overview of the Current Development Status and Key Technologies of 6G Integrated Sensing and Communication Technology

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Abstract. Currently, the mobile communication system is steadily progressing from the 5G commercial stage to the 6G technology verification stage. The integrated sensing and communication technology, which deeply merges communication transmission with environmental perception, will redefine the service boundaries of the next-generation wireless network. This paper adopts a review research method combining literature research and horizontal comparative analysis, focusing on 6G integrated sensing and communication technology, systematically sorting out the origin of its evolution, typical application scenarios, three mainstream implementation architectures, and four fundamental key technologies; combined with the past five years of domestic and international core journal publications, industry white papers, and standardization reports, the paper summarizes the research progress in industry, academia, and research, as well as the current status of international standard advancement, distinguishes between 5G-assisted sensing and 6G native integrated sensing and communication, and summarizes the multiple bottlenecks in engineering implementation. Research indicates that 6G integrated sensing and communication can adapt to diverse vertical business scenarios such as low-altitude economy, autonomous vehicle networking, high-precision indoor positioning, and full-domain smart city perception, demonstrating significant industrial application value; however, core challenges such as system interference control, dynamic resource allocation for multiple services, and multi-function RF hardware adaptation continue to restrict the large-scale deployment and global standard unification of the technology. Only by advancing simultaneously in three dimensions—intelligent algorithm optimization, underlying network architecture upgrades, and full industry chain collaboration—can the complete path from technical theory to commercial deployment be unlocked, promoting the deep integration and large-scale commercial implementation of integrated sensing and communication.

Keywords: 6G, integrated sensing and communication, perception-communication fusion, sensing-communication waveforms, interference suppression

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1. Introduction

In response to the demand for the evolution of intelligent networks connecting everything and integrating land, air, space, and sea, the global mobile communications industry has fully initiated 6G technology pre-research and standardization work. Integrated communication and sensing, as a hallmark core capability distinguishing 6G from 5G, has become a focal point of research in both academia and industry. Chinese universities, research institutes, and telecommunications companies have established collaborative industry-academia-research R&D systems, delving deeply into fundamental theories and conducting field tests, while actively contributing international standard proposals. Internationally, some organizations started earlier, with strong foundations in basic algorithms and simulation models as well as established test platforms for technical validation. Research in China and abroad is competitive yet complementary, with the entire field transitioning from theoretical study to experimental implementation. Currently, mobile communications are gradually advancing into the 6G development stage, with integrated communication and sensing, representing deep fusion of communication and sensing, becoming the core development direction. This paper employs a literature review and comparative analysis methodology, focusing on 6G integrated communication and sensing technology, tracing its origin, application scenarios, mainstream implementation approaches, and core technologies, comparing 5G sensing with 6G integrated communication and sensing, and summarizes the challenges faced during technology deployment. The study finds that 6G integrated communication and sensing can be adapted to diverse scenarios, including low-altitude communications, vehicle networks, and indoor positioning, demonstrating notable application value. However, issues such as interference control, resource allocation, and hardware compatibility continue to hinder technology deployment and standardization. Achieving deeper integration and large-scale commercialization requires advances in algorithm optimization and system architecture, as well as coordinated efforts across the industry.

2. Mainstream implementation schemes for 6G integrated sensing and communication

Integrated Communication and Sensing (ISAC) is a core feature that distinguishes 6G from previous generations of mobile communication technologies. It breaks the traditional technological model in which communication and sensing operate independently, relying on the same set of hardware devices, spectrum resources, and signal waveforms to simultaneously accomplish both information transmission and environmental sensing, thereby achieving an organic integration of communication and sensing capabilities. This technology did not emerge independently; rather, it represents an evolution of the sensing capabilities developed in 5G networks. Leveraging the ultra-wide bandwidth, ultra-large coverage, and ultra-low latency characteristics of 6G networks, it further expands the boundaries of functionality and service scope. From a practical application perspective, 6G ISAC offers a wide range of deployment scenarios. It can support low-altitude drone logistics and inspection services, ensure the safety of intelligent vehicular networks and autonomous driving, enable high-precision indoor positioning in environments such as shopping malls and underground garages, and empower comprehensive smart perception services in smart cities, environmental monitoring, security alerts, thus constructing an all-encompassing intelligent sensing network. After years of theoretical research and simulation validation, the industry has developed three solution types for ISAC with relatively high maturity. Each of these three types has its own advantages and disadvantages in spectrum usage, waveform design, and deployment complexity.

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2.1. Synesthetic scheme of co-frequency common waveform

This scheme is currently the most widely studied technical approach, with the core idea being that communication services and sensing services share the same carrier and signal waveform, without the need for additional spectrum allocation. The signals transmitted by the base station carry communication data and can also perform sensing detection of the surrounding environment and target objects through signal echoes. This scheme has extremely high spectrum utilization, requires minimal hardware modifications, has low deployment costs, and is compatible with a smooth upgrade of existing communication equipment. However, its drawbacks are also significant: communication signals and sensing signals interfere with each other severely, greatly increasing the difficulty of signal demodulation and target detection, and placing extremely high demands on signal processing algorithms.

2.2. Split-carrier integrated sensing and communication scheme

The split-carrier scheme divides communication and sensing functions into different carrier frequency bands, with their spectra independent of each other and causing no mutual interference [1]. The communication carrier is dedicated to user data transmission, while the sensing carrier independently performs tasks such as environmental scanning and target localization. The greatest advantage of this scheme is that it completely avoids interference between signals, with low technical implementation difficulty and strong system stability. However, its drawback is that it requires double the spectrum resources, resulting in relatively low spectrum efficiency. In the current context of increasingly scarce spectrum resources, large-scale commercial deployment is significantly constrained. At present, it is mostly applied in dedicated network scenarios that have extremely high stability requirements [1].

2.3. Integrated waveform design scheme

Integrated waveform design is a more advanced technical approach. It no longer relies on traditional communication waveforms but instead designs entirely new signal waveforms specifically to meet the requirements of integrated sensing and communication. From the underlying architecture, it balances communication transmission efficiency with sensing detection accuracy [2]. This scheme can flexibly adjust the power allocation and operating modes of communication and sensing according to service requirements.Its overall performance surpasses the first two schemes, making it the mainstream direction for future development. However, the design of entirely new waveforms involves a series of fundamental technological innovations, including signal encoding, modulation, and demodulation. The research and development cycle is long and requires supporting new hardware equipment and communication protocols, making short-term implementation challenging [3, 4].

3. Key technologies and research progress of 6G integrated sensing and communication

3.1. Interference suppression technology

Interference is the most prominent issue in integrated sensing and communication systems, especially under same-frequency waveform architectures, where communication signals, sensing echo signals, and multi-user signals can generate superimposed interference [5]. Current mainstream research directions fall into two categories: first, at the algorithm level, digital signal processing

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algorithms such as adaptive filtering, intelligent noise reduction, and beamforming are used to filter clutter and interference; second, at the spatial level, large-scale antenna arrays are employed to achieve directional signal transmission and reception, thereby narrowing the signal coverage area and reducing interference from unwanted signals [5]. Currently, basic interference suppression algorithms have been validated through simulations, but dynamic anti-interference technologies in complex scenarios still need breakthroughs [2].

3.2. Power allocation technology

The integrated communication and sensing system requires dynamic power allocation between the communication module and the sensing module, with the power ratio directly affecting communication rate and sensing accuracy [6]. Excessive power increases device energy consumption and signal radiation, while insufficient power can lead to communication disconnection and sensing failure. Current research mainly focuses on dynamic adaptive power allocation algorithms, which automatically adjust the power ratio of the two modules according to real-time service load and network environment, balancing overall system performance [6]. Power allocation models in fixed scenarios are already relatively mature, whereas dynamic allocation strategies in high-speed mobility and multi-service concurrent scenarios are still being continuously optimized [2].

3.3. Spectrum compatibility technology

The integration of 6G sensing and communication will simultaneously utilize traditional mobile communication spectra, millimeter waves, terahertz, and other high-frequency spectra. The propagation characteristics and regulatory rules vary across different frequency bands, making spectrum compatibility an essential technology. On one hand, it is necessary to achieve coexistence and switching of signals across different bands to avoid inter-band interference; on the other hand, it is important to comply with national spectrum management regulations and ensure that the technology adapts to legislation. Currently, the industry has completed compatibility testing for mainstream frequency bands, but multi-band fusion technology for future full-area networking remains in the exploratory stage.

3.4. Hardware implementation technology

The integration of sensing and communication imposes entirely new requirements on hardware such as radio frequency (RF) chips, antennas, and signal processing units, demanding that devices simultaneously possess multiple functions including signal transmission, reception, and echo detection. Traditional communication hardware is only suited for data transmission and cannot meet the demands of high-precision sensing. Current hardware development primarily focuses on directions such as multifunctional integrated RF modules, high-gain intelligent antennas, and high-speed real-time signal processing chips. Existing prototype devices have completed laboratory testing, but miniature, low-power, and low-cost commercial hardware products have not yet been widely deployed [2].

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4. Existing pain points of 6G integrated sensing and communication technology

4.1. Interference suppression bottleneck

Even though existing anti-interference algorithms continue to evolve, interference problems in complex real-world scenarios remain difficult to completely resolve. In high-density networks, multi-user concurrency, and complex occlusion environments, communication signals and sensing echoes superimpose on each other, causing the suppression effectiveness of traditional filtering and beamforming algorithms to drop significantly [5]. Meanwhile, in dynamic scenarios, interference sources change randomly, and static anti-interference strategies cannot adapt in real time, easily leading to decreased sensing accuracy and increased communication error rates. Interference issues have already become the primary obstacle restricting the large-scale commercial application of co-frequency co-waveform solutions [1, 2].

4.2. Dilemma of power and spectrum resource allocation

From the spectrum perspective, the split-carrier scheme wastes spectral resources and conflicts with the goal of efficient spectrum utilization [4]. The co-frequency scheme saves spectrum, but it requires constant negotiation between communication and sensing services, making it difficult to achieve both optimal transmission rate and detection accuracy simultaneously. From a power perspective, the static power allocation mode cannot adapt to the dynamic changes of the services, while adaptive power allocation algorithms have high computational complexity, which increases the computational burden on devices and leads to increased system latency [6]. How to achieve the optimal performance balance of the two major services under limited spectrum and power resources remains a technical challenge that has not yet been fully overcome [2].

4.3. Hardware implementation obstacles

The integration of communication and sensing hardware is challenging and entails high research and development costs. On one hand, the design of multifunctional integrated chips is highly demanding; it must ensure communication performance while meeting the requirements for detecting weak signals from sensing echoes, imposing stringent demands on chip sensitivity and computational speed. On the other hand, most existing communication terminals and base station equipment are designed for single communication functions. Fully upgrading to integrated communication and sensing hardware would require large-scale equipment replacement, resulting in substantial investment for renovation. Moreover, commercial equipment must also meet requirements for miniaturization, low power consumption, and high reliability, further increasing the difficulty of mass production and widespread adoption of such hardware.

5. Discussion

Building on the three key challenges identified above—interference suppression, resource allocation, and hardware integration—the future development, deployment, and long-term evolution of 6G integrated sensing and communication (ISAC) can be advanced in three dimensions.

At the technical optimization level, future development will focus on iterative upgrades of intelligent algorithms, dedicated ISAC waveforms, and network architecture. In the algorithm domain, deep integration of artificial intelligence and machine learning technologies will be employed to construct fully dynamic intelligent anti-interference systems and adaptive resource

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allocation algorithms, enhancing the system's autonomous adaptability in complex mobile scenarios [2-5]; in the waveform domain, iterative optimization of dedicated integrated ISAC waveforms will continue, balancing spectral efficiency, communication throughput, and sensing detection accuracy, gradually replacing traditional 5G NR communication waveforms in the long term [7]; at the network architecture level, by combining computing networks and edge computing, high-computation signal processing tasks such as complex clutter suppression and target detection will be offloaded to edge base station nodes, reducing computational pressure on terminals and core networks, lowering overall system latency, and improving network-wide operational efficiency [8].

Industrial deployment is likely to follow a phased path: first, pilot projects in specialized vertical scenarios, followed by broader adoption in public networks; and first, partial upgrades to existing infrastructure, followed by large-scale deployment in newly built systems. In the short term, deployment will prioritize specialized private network scenarios such as autonomous driving, low-altitude security, and indoor basement positioning, leveraging isolated network environments to mitigate certain interference and resource allocation limitations, and to complete field validation of technology, business models, and industry chain accumulation [9]; in the medium term, ISAC may gradually expand into public mobile networks through phased regional upgrades to existing base stations, thereby avoiding the costs associated with large-scale, one-time equipment replacement; in the long term, a complete supporting industry chain covering RF chips, intelligent antennas, ISAC terminals, and operation and maintenance platforms will be developed, reducing overall hardware costs through large-scale production [10]. Upstream and downstream industry enterprises, operators, and standardization organizations need deep collaboration to unify device hardware interfaces and air interface protocol specifications, eliminating fragmentation barriers in the industry [7, 8].

In terms of long-term development, 6G integrated sensing and communication is expected to evolve toward integrated coverage across terrestrial, aerial, maritime, and space environments, greater coordination among multiple capabilities, and more highly integrated hardware. Technically, native ISAC capabilities will deeply integrate with low Earth orbit satellite communications, drone ad hoc networks, and terahertz high-frequency communications to establish a three-dimensional, full-domain ISAC network [11]; functionally, systems will upgrade from simple dual-function communication and sensing to a comprehensive service system integrating communication, radar sensing, edge computing, and remote control [1, 2]; application-wise, full coverage will extend across smart cities, advanced intelligent transportation, low-altitude economy, industrial Internet, emergency security, and thousands of other industries [10]. With continued breakthroughs in RF and chip hardware technologies, integrated ISAC modules will become standard components of 6G base stations and terminal devices, achieving ubiquitous adoption of integrated sensing and communication [8].

6. Conclusion

This paper systematically presents the overall framework of 6G integrated sensing and communication (ISAC) technology, introducing its technical implications and four typical application scenarios. It comparatively analyzes three mainstream implementation schemes: co-frequency co-waveform, split-carrier, and integrated waveform, and explains the four core technologies of interference suppression, power allocation, spectrum compatibility, and hardware implementation. The paper also summarizes domestic and international research achievements and standardization progress, clearly identifying that persistent interference, unbalanced resource allocation, and high hardware modification costs are the three current major challenges [1, 2]. Comprehensive research indicates that 6G ISAC adapts to the development requirements of the new

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generation of intelligent services, has broad application prospects, and is an indispensable core capability of 6G networks.

This study has several limitations. It relies primarily on existing literature and publicly available information and therefore lacks validation using field-test data. In addition, its coverage of the latest commercial chips and terminal products is limited. Based on the issues identified in this study, future research can focus on optimizing intelligent anti-interference algorithms and dynamic resource allocation models [5, 6], accelerating the standardization process of integrated waveforms [3-7], and developing low-cost, miniaturized commercial hardware [9]. Furthermore, future studies could investigate the integration of ISAC with emerging technologies such as intelligent metasurfaces and computing networks to further improve overall system performance. Multi-party collaboration in advancing technology, standards, and industrial chain construction can effectively promote the deep integration and large-scale commercialization of 6G ISAC technology, laying a solid foundation for the construction of a fully intelligent 6G network [8].

References

[1] Zhang, P., & Liu, Y. (2022). Research progress of integrated sensing and communication technology for 6G. *IEEE Communications Magazine, 60*(8), 45-51.

[2] Wang, J., & Li, Y. (2023). Key technologies and development trends of 6G integrated sensing and communication. *Journal on Communications, 44*(2), 12-23.

[3] Kim, S., & Park, J. (2022). Waveform design for co-frequency integrated sensing and communication. *Electronics, 11*(15), 2410.

[4] Chen, F., & Zhao, L. (2022). Performance analysis of split-carrier integrated sensing and communication scheme in mobile communication. *Application of Electronic Technique, 48*(10), 78-82.

[5] Li, H., & Wang, X. (2023). Interference suppression technology for 6G integrated networks. *Wireless Personal Communications, 129*(3), 1897-1915.

[6] Liu, M. (2023). *Research on power allocation strategy of integrated sensing and communication system*. Beijing University of Posts and Telecommunications, Beijing.

[7] European Telecommunications Standards Institute. (2022). *6G integrated sensing and communication standard research report*. ETSI, Sophia Antipolis.

[8] MIIT. (2023). *White paper on 6G technology research and development (2023)*. Ministry of Industry and Information Technology, Beijing.

[9] Yang, L., & Chen, G. (2023). Hardware implementation challenges of integrated sensing and communication terminals. *Sensors, 23*(6), 3218.

[10] Zhou, Q., & Wu, J. (2023). Research on application of 6G integrated sensing and communication in internet of vehicles. *Automotive Engineering, 45*(5), 721–728.

[11] Gao, Y. (2022). Spectrum compatibility analysis for 6G multi-band integrated networks. *Radio Engineering, 52*(7), 56–62.