6G Advanced Communication and Sensing: Essential Enabling Technologies, Issues, and Challenges

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Abstract

The impending sixth generation (6G) of wireless communication technology is set to transform the digital world by combining improved communication and sensor capabilities. It will allow for ultra-reliable, high-speed data transfers, huge networking, and seamless integration of intelligent devices and applications. This confluence will pave the way for future applications including holographic telepresence, extended reality (XR), autonomous systems, and digital twins. Terahertz (THz) communication, reconfigurable intelligent surfaces (RIS), integrated sensing and communication (ISAC), AI-driven networking, quantum communication, and edge computing are all critical 6G enablers. These technologies strive to meet the rapidly increasing demand for data throughput, dependability, and latency requirements while also providing extremely accurate and efficient sensing capabilities. Furthermore, breakthroughs in non-terrestrial networks (NTN), blockchain-based security frameworks, and novel antenna designs would be required for broad 6G implementation. Despite this promise, 6G development and implementation confront considerable obstacles. These include technological difficulties like as overcoming high route loss in THz bands, creating energy-efficient designs, and dealing with spectrum scarcity. With widespread data generation and networking, security and privacy problems grow in importance. In addition, there are governmental and societal difficulties, such as standardization, ethical concerns about data usage, and the potential digital gap caused by uneven access to 6G infrastructure. The purpose of this study is to investigate the essential technologies that will power 6G communication and sensing systems, identify the primary barriers to adoption, and describe the multifarious problems that must be overcome in order to achieve a robust, secure, and inclusive 6G ecosystem.

Keywords: Standards, Difficulties, Integrated Sensing and Communication (ISAC), 6G, and Key Enabling Technologies

Introduction

A move toward investigating new technologies that can support sixth generation (6G) wireless networks has been made possible by the continuous standardization and deployment of fifth generation (SG) wireless networks. A 6G terrestrial wireless network roadmap has been developed to provide users and machine-type devices with continuous connectivity. For instance, the new recommendation for the vision of international mobile telecommunications 2030 IMT-2030(6G) was successfully written by the International Telecommunications Union's (ITU-R) radio communication section. One of the primary use cases for IMAR - 2030/6G, according to the International Telecommunication Union’s (ITU-R) radio communication section, is integrated sensing and communication (Isac). It is anticipated that ISAc will be essential to the next wireless generation standard. We combine a number of critical standpoints in this work, such as academic and industrial advancement. This page specifically outlines 6G requirements and the Isac-enabled vision, covering integration issues, advantages of Isac coexistence, and different facets of 6G standardization. Furthermore, we introduce important enabling technologies, such as orthogonal time frequency space (OTFS) waveform design and interference management for ISAC, as well as intelligent meta surfaces- assisted ISAC. In order to open up a variety of research prospects and problems regarding ISAC technology toward 6G wireless communication, future aspects are finally covered. approved in the June 2023 summit in Geneva.Tthrough sophisticated surface sense that can be reconfigured and improved. Comprehend the transmission environment and the actual world. Given the significance and growth of ISAC in the next generation of wireless technology, we have highlighted a number of crucial and cutting-edge features of ISAC technology for the 6G standards domain [1-10]. In particular, this work can be concluded as follows: This article summarizes the needs for 6G and the goals of ISAC integration, discussing issues related to 6G standardization, the benefits of ISAC coexistence, and associated difficulties. b) It also highlights important enabling technologies, such as intelligent metasurface-: ISAC, and provides the OTFS waveform design for Is. c) In addition, the paper has examined potential future directions that could lead to other research directions for ISAC technology for 6G wireless communication.

As a key component of upcoming 6G networks, integrating sensing and communication (ISAC) is the subject of the paper Towards Integrated Sensing and Communication for 6G: Key Enabling Technologies, Standardization, and Challenges. It emphasizes how improved resource usage, reduced latency, and improved spectrum efficiency might result from the convergence of various technologies.

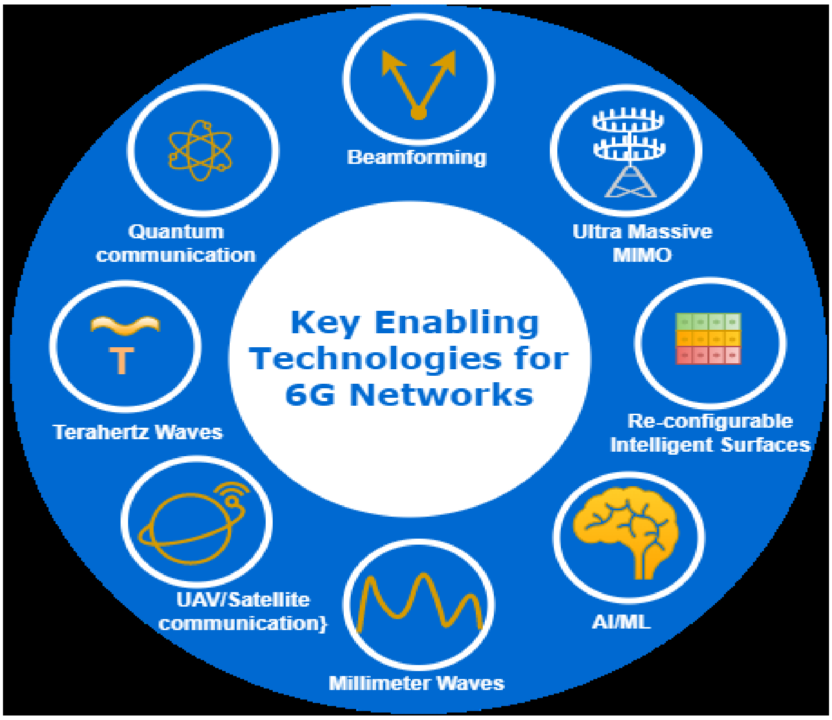


Figure 1. Key Enabling Technologies for 6G Networks

In order to enable ISAC capabilities, the authors talk about enabling technologies such as intelligent metasurfaces and Orthogonal Time Frequency Space (OTFS) waveforms. The difficulties in standardizing and incorporating ISAC into current and developing wireless communication frameworks are also covered in the article. Waveform design, interference control, and unifying disparate use cases under a single standard are major challenges. The study emphasizes how crucial interdisciplinary cooperation is to overcoming these obstacles and successfully advancing 6G technology.

1. ISAC and its significant impact on future generations.

Take integrated positioning and recognition, for instance. It is anticipated that imagination and reconstruction would offer complementary qualities that will be useful in intelligence. thriving social governance and industrial progress. Future wireless generations will be led by network-centric development of the wireless framework core. The development of current skills is made possible by the lessons learned from the preceding generation. 6G aims to outperform its predecessor and open up new possibilities by utilizing advancements in spectrum efficiency, network capacity, etc [11-15]. A higher order MIMO, for instance, is designed to use more antennas, allowing for improved performance.

1.1.Intelligent air interface

Unlike wireless generation, which uses advanced logistics and processing. Utilizing the smart air interface at the transceiver end will enable 6G technology by making it easy to adjust the wireless channel for better propagation conditions.[2]Help from RIS is one of the possible methods. THZ communication and holographic radio.Indeed, RIS support is a new feature of the 6G smart interface.

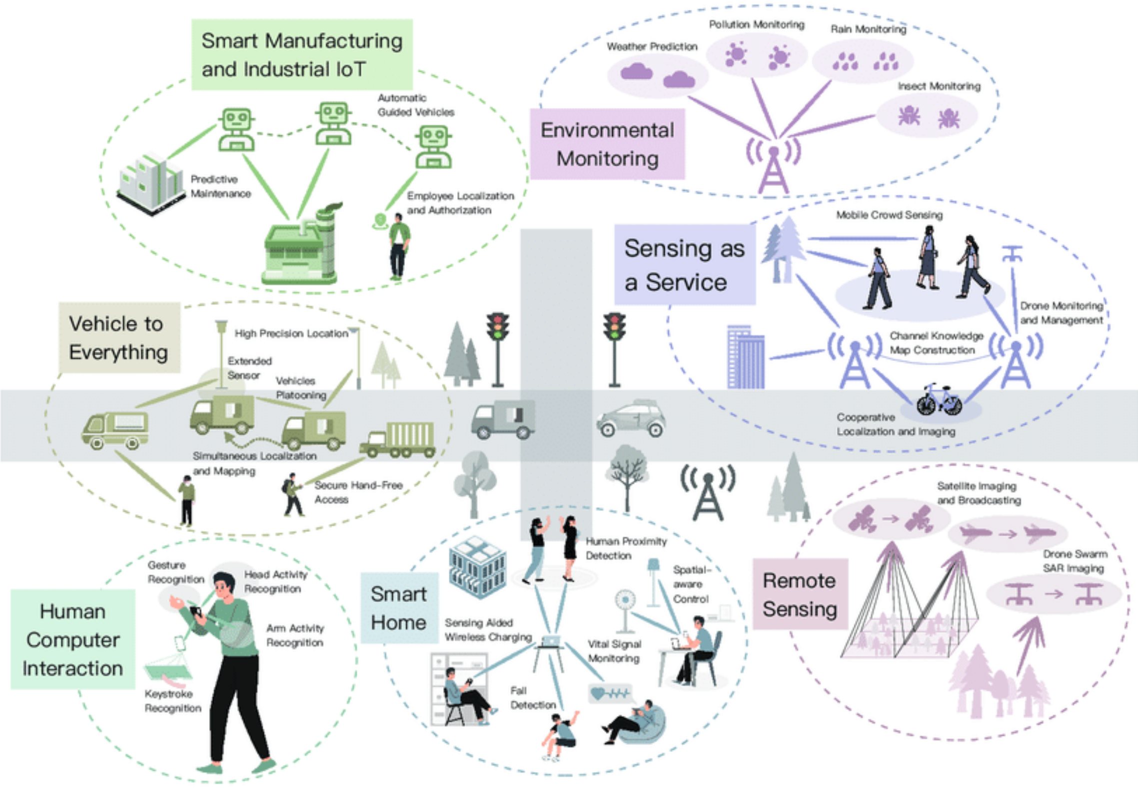


Figure 2 ISAC technology for future wireless networks

1.2.User-assisted improvements

The goal of 6G frontier is to leverage end users' computing capabilities without appreciably increasing the network system's total cost, size, or power consumption. Edge computing: by placing a typical computational load on the user's end, a number of advantages could be realized, such as: a) moving data storage and computation closer to the network edge,

b) lowering end-user latency, c) having real-time processing capabilities, and d) enabling context-aware services. 6G networks can support a wide variety of applications [16].

2. ISAC co-existence and 6G standardization

By creating a consistent platform for productive collaboration amongst developers, academics, and industries, standardization is essential to the advancement of ISAC. A thorough set of standards promotes scalability and interoperability and makes it easier to incorporate new technologies into already-existing ecosystems [17-21].

A. Initiatives and Establishments: Adopting standardization will enable ISAC to reach its full potential and open the door to a future that is sensor-driven, intelligent, and connected. *Project B: Third Generation Partnership (3GPP):* As the scope of 5G-Advanced expands following the initial phase of the 5G standard, interest in ISAC is steadily growing.

While the primary function of the traditional SG was to provide solely communication services, ISAC can play a significant role in its role by supporting new services that are aided by communication. Three main scenarios—object recognition and tracking, environment monitoring, and motion monitoring—are examined in order to find such new ISAC service possibilities.

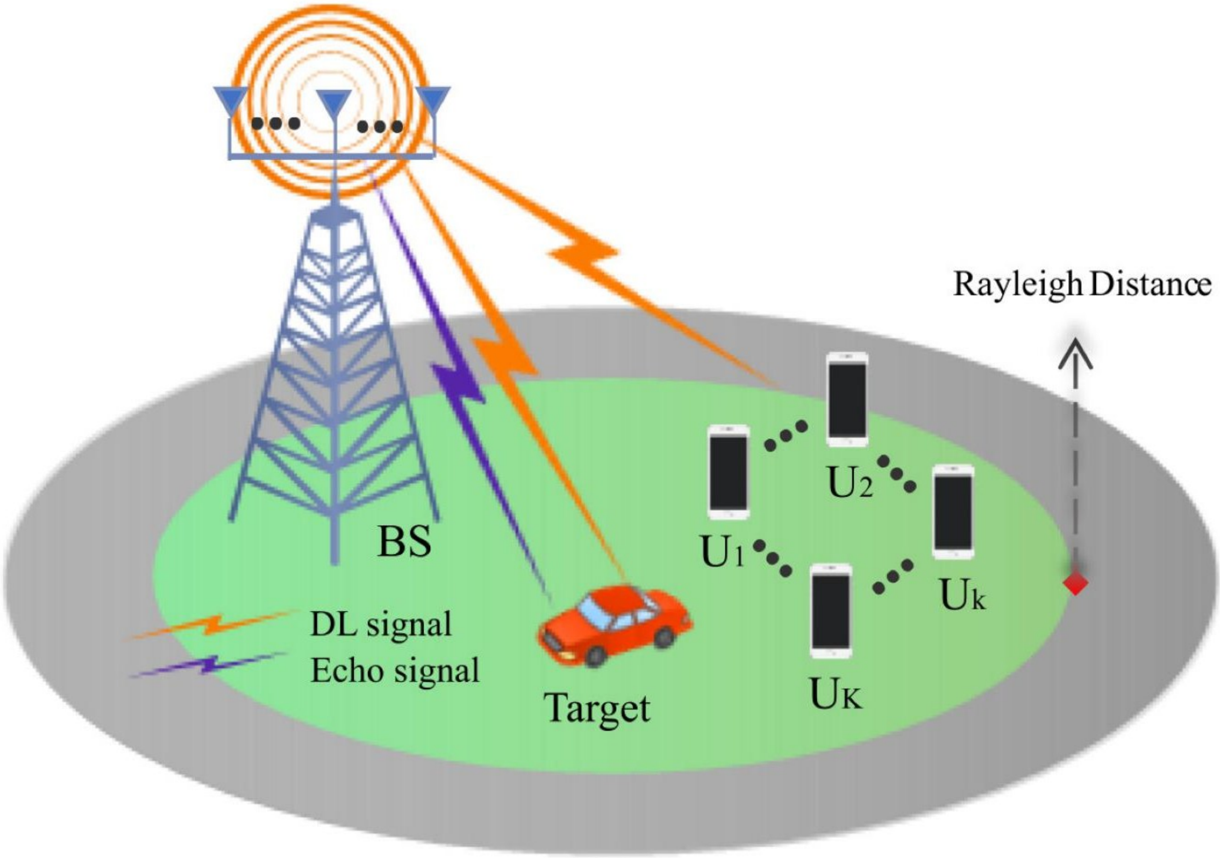


Figure 3. System model of DL NOMA empowered ISAC.

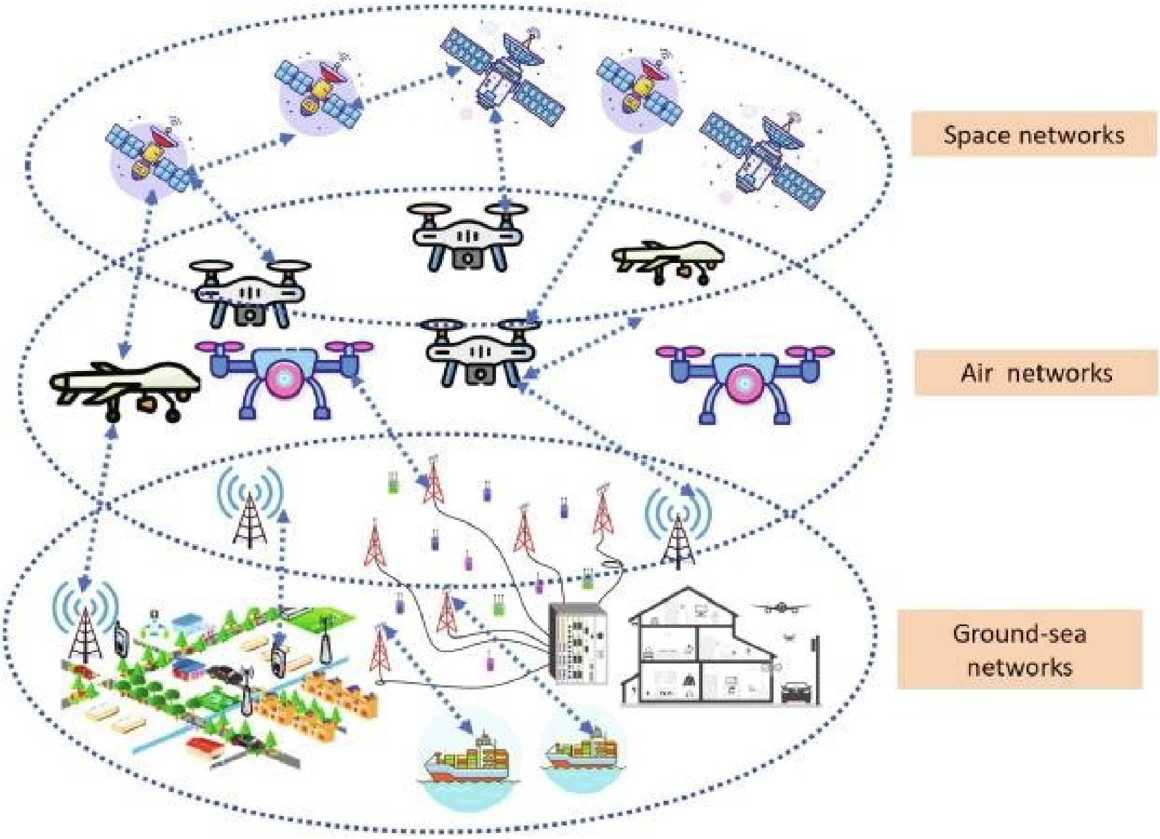
3. Previous publications

• *Literature review overview:* give a thorough analysis of the body of knowledge about ISAC in 6G, emphasizing studies that were published in 2022–2024 [22-26].

Categorization by theme: Important enabling technologies: talk about the function of edge computing, reconfigurable intelligent surfaces (RIS), terahertz (THz) communication, artificial intelligence (AI), and machine learning.

• Standardization initiatives: examine the contributions made by organizations like as IEEE, 3Gpp, and ITU in purchasing the 6G standard, especially for ISAC.

• *Difficulties:* emphasize studies tackling issues including interoperability, latency security, and spectrum allocation.



Figur.4 The integrated ground-sea-air-space 6G expected network.

4. Content and technique

Methodology: describe the methodical process used to collect and examine study data [27- 31].

Data sources: enumerate the databases, journals, and conference proceedings (such as IEE xplore and AÇMA digital library science direct) that were used to compile pertinent literature [32].

Theoretical framework: if any, describe any simulations or model frameworks that are used to examine how sensing and communication are integrated in 6G [33].

Evaluation criteria: describe the standards by which the enabling technologies, standardization procedures, and difficulties are judged.

5. Results and discussion

• Talk about how AI and machine learning improve 6G network security, efficiency, and adaptability.

• Examine how Examine Rix can enhance connection and optimize signal propagation with reconfigurable intelligent surfaces (RIS) [34][35].

• Cutting-edge computing Examine how edge computing and latency reduction can support real-time applications in 6G [36] [37].

• Standardization initiatives: • 3GPP and IEEE contribution: describe the state of 6G standardization at the moment, with an emphasis on ISAC.

• Standardization with an emphasis on ISAC

The role of international cooperation in creating unified 6 GB standards was explored.

Conclusion

Towards Integrated Sensing and Communication for 6G: Essential Facilitating Technologies, Standardization, and Difficulties concluding highlights how important integrated sensing and communication (ISAC) will be in forming wireless technology for the sixth generation (6G). The authors emphasize how ISAC can improve overall system efficiency, save infrastructure costs, and maximize spectrum utilization. Notwithstanding its potential, ISAC's effective implementation depends on resolving a number of technical and standardization challenges, such as the creation of uniform international standards, sophisticated waveform designs, and interference control. In order to fully exploit the potential of ISAC technologies and to clear the path for reliable 6G implementations that meet a variety of use cases and criteria, the study urges ongoing multidisciplinary research and cooperation among academia, industry, and standardization bodies.

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