
# Integrated Sensing and Communication

Rev 2.0

Aug 2024

5GIF 6GCG

# PREFACE

The 5GIF 6G Cooperation Group (5GIF 6GCG) is created as a collaborative body for developing mindshare around 6G and creating positions around the prioritization of research and development, requirements, globally harmonized standards development and of market readiness in India.

The 5GIF 6GCG facilitates to advance and share the knowhow on technologies and trends; to further interests among stakeholders in India that will be driving the development of 6G and its applications over the next few years.

This whitepaper aggregates the expert opinions of the 6G Coordination Group (6GCG) members on ISAC, in the context of the IMT-2030 standards and its anticipated function within the emerging 6G Network/System. It provides an in-depth analysis of the "Sensing and Communication" paradigm as currently defined in 3GPP 5G standards and projects its evolution into the 6G landscape. The focus of the paper is on the unified application of communication and sensing technologies, emphasizing key areas of 6G development such as exploring new spectrum bands, crafting channel models sensitive to environmental nuances, leveraging AI/ML for collaborative use, and the potential advancements brought by a new Radio Interface Technology (RIT) for IMT-2030.

Additionally, the paper outlines the technical challenges and research opportunities associated with the implementation and standardization of ISAC. It serves as a strategic guide for ongoing and future research, as well as innovation in this emerging field.

1. Overview ... 3

2. Introduction ... 3

3. Forms of Integration ... 4

4. Potential application areas ... 5

5. Application Categories ... 6

A. High-accuracy Localization and Tracking ... 6

B. Simultaneous Imaging, Mapping, and Localization ... 6

C. Future application categories ... 7

6. ISAC Sensing Modes ... 8

7. ISAC status in 3GPP ... 9

A. ISAC Channel Modelling ... 9

8. Key observations from the on-going feasibility studies ... 10

9. Research opportunities in ISAC ... 10

10. Conclusion ... 11

Change Log ... 12

References ... 12

# 1. Overview

In Recommendation ITU-R M.2160 [1], the envisioned usage scenarios for IMT-2030 build upon the foundational scenarios established by IMT-2020—namely Enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low Latency Communications (URLLC), and massive Machine Type Communications (mMTC) as initially introduced in Recommendation ITU-R M.2083. IMT-2030 aims to support a wider range applications, requiring the development and integration of advanced and unprecedented capabilities. Beyond the augmentation of existing IMT-2020 scenarios, IMT-2030 is projected to facilitate *new usage scenarios*, propelled by emergent capabilities such as artificial intelligence and advanced sensing technologies—areas that were not the primary focus of previous IMT generations.

The Usage Scenario of Integrated Sensing and Communication (ISAC) is outlined, *ISAC, facilitates new applications and services that require sensing capabilities. It makes use of IMT-2030 to offer wide area multi-dimensional sensing that provides spatial information about unconnected objects as well as connected devices and their movements and surroundings. Typical use cases include IMT-2030 assisted navigation, activity detection and movement tracking (e.g., posture/gesture recognition, fall detection, vehicle/pedestrian detection), environmental monitoring (e.g., rain/pollution detection), and provision of sensing data/information on surroundings for AI, XR and digital twin applications. Along with the provided communication capabilities, this usage scenario requires the support of high-precision positioning and sensing-related capabilities, including range/velocity/angle estimation, object and presence detection, localization, imaging, and mapping.*

This report delves into the anticipated usage scenarios and the characteristic environments where the essential capabilities for applications that merge sensing and communications in forthcoming 6G systems will be cultivated. It offers a concise overview of the ongoing progress within the realm of 5G Advanced, highlighting developments that are poised to transition into the 6G era.

# 2. Introduction

The increasing demand for innovative sensing-based services across various sectors such as manufacturing, autonomous and assisted driving, 3D map reconstruction, smart cities, and healthcare has prompted the industry to evolve. The integration of sensing functionality within the communication network framework allows for the dual use of the communication spectrum and infrastructure for sensing purposes. A key objective is to harness the cooperative potential of numerous network nodes. The network's ability to "sense" not only augments network performance but also extends sensing capabilities, thereby facilitating the development of new and future services.

In the ITU-R IMT-2030 framework, ISAC emerges as a key feature for 6G networks. This integration facilitates the shared use of resources across time, frequency, and spatial domains, incorporating critical elements such as waveform, signal processing, and hardware. At its core, sensing involves detecting the presence, position, and movement of both connected and unconnected objects within the network. Additionally, the sensing of local environmental factors such as terrain, material properties, and weather conditions is under consideration. The sensing capability is envisioned as both a complementary and supplementary tool to the positioning of active objects, potentially being utilized to ascertain the velocity of objects within a given environment.

Furthermore, ISAC is set to synergize with emerging 6G technologies like Reconfigurable Intelligent Surfaces (RIS), potentially enhancing its capabilities through RIS-assisted ISAC [2]. Its integration into future networks is expected to open a wide range of opportunities, leading to smarter cities, more efficient manufacturing, safer autonomous driving, and more. ISAC embodies the innovation of the 6G era, paving the way for a future where communication and sensing are integrated to meet the demands of an increasingly connected society.

## 3. Forms of Integration

The integration of sensing functionality within communication networks is anticipated to occur at multiple levels, each strategically designed to balance the incremental costs against the potential benefits. This integration typically begins with the sharing of network infrastructure and the repurposing of existing hardware and spectrum resources. Such foundational integration helps in reducing the overhead costs while maintaining the functionality of both sensing and communication operations.

Advancing further, a more sophisticated level of integration involves the repurposing of communication waveforms and network signals for sensing tasks. This approach not only optimizes resource utilization but also enhances the system's overall efficiency. However, it necessitates a thorough evaluation of the propagation environments, network and device density, activity factors, and their potential impacts on communication links, which are critical for maintaining system integrity and performance.

The effectiveness of sensing integration also varies significantly with the frequency bands used in communication links. For instance, integrating sensing with low and mid-band communication links could facilitate broad area coverage but might suffer from limited range resolution due to the narrower bandwidths of these bands. On the other hand, higher frequency bands, such as mmWave, offer superior resolution for ranging and angle estimation due to their wider bandwidths and higher antenna gains. Yet, the use of these higher bands might be restricted to localized areas owing to their limited deployment and challenging propagation conditions.

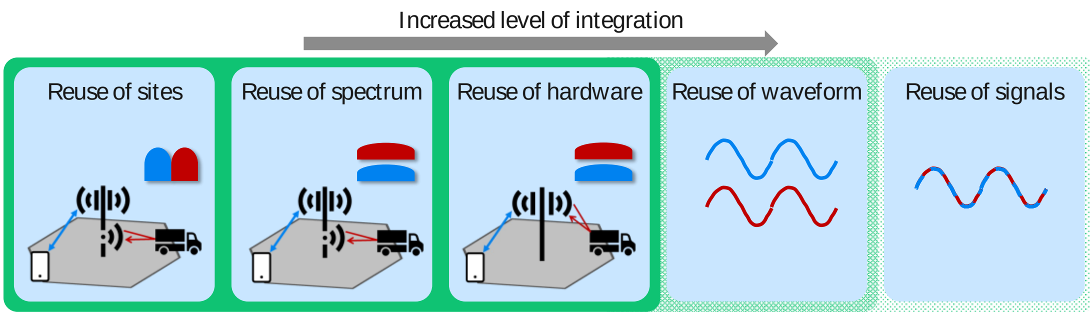


Figure 1: Levels of integration in an ISAC system

To enable new applications and services based on ISAC, it is also important to expose the network sensing functionality for *service exposure*, control, and management of sensing tasks, to process the "*sensed information*(s)" in a meaningful format for end-user applications. The data/signal processing functionalities also need to consider authorization, privacy preservation, data retention as well as data predictability and validity duration before exposing the data to applications/services.

# 4. Potential application areas

ISAC technology heralds a new era of services and applications characterized by high-precision localization, advanced imaging, and detailed environmental reconstruction. Its influence spans across multiple sectors, offering enhancements in performance, safety, and operational efficiency.

## A. Wide Area applications:

- Monitoring crossroads, parking space determination, automotive maneuvering and navigation, detecting objects on rails.
- Flight trajectory tracking, collision avoidance, intrusion detection, especially for UAVs
- Search and rescue, flood detection in smart cities.
- Sensing for improving communication network/infrastructure (for e.g., detection of interference for spectrum sharing).

 

### B. Localized Area applications

- AGV detection and tracking, integrated sensing and positioning, geo fencing, localization and tracking of large passive objects, AGV and human collision avoidance.
- Health sensing using wireless signals, contactless sleep monitoring.

Sensing technology acts as a vital bridge between the physical and digital worlds, powering the creation and operation of "digital twins". These virtual representations of physical entities or systems enable real-time monitoring and simulation, leading to enhanced decision-making and operational efficiency.

Furthermore, the ability of ISAC to simultaneously sense the environment and communicate data can also revolutionize the network performance enhancement and eventually also improve user experience in addition to provide new end-user applications. This dual utility positions ISAC as a cornerstone technology driving the evolution of connected and intelligent systems.

## 5. Application Categories

### A. High-accuracy Localization and Tracking

ISAC in 6G leverages wireless networks for high-precision localization, functioning seamlessly indoors and outdoors under diverse conditions. Building on the meter-level accuracy achieved by 4G and 5G, 6G aims for even finer precision, down to sub-centimeter and sub-millimeter levels, to meet the demands of advanced manufacturing and robotics. This enhanced localization is vital for autonomous systems, offering cost-effective and reliable alternatives to traditional tracking technologies like cameras, LIDAR, and RADAR. The adoption of ISAC in 6G promises to boost the capabilities of industrial and urban applications significantly. It can detect intruders or UAVs in smart homes and industries, prevent railway collisions by identifying humans or animals on tracks, and improve personal safety through precise individual tracking and threat detection. The performance of localization and tracking is measured by KPIs including positioning and velocity accuracy, miss-detection and false-alarm rates, sensing resolution, and latency, ensuring compliance with the high standards required for these critical applications.

### B. Simultaneous Imaging, Mapping, and Localization

Simultaneous Imaging, Mapping, and Localization (SIML) enables robots and machines with human-like perception, enabling them to pinpoint a person's location relative to room furnishings. This capability stems from device-free sensing combined with AI, facilitating route planning and target delivery. Leveraging AI and channel multipath information, SIML creates detailed 2D and 3D models for precise positioning. Unlike traditional localization that relies on physical transceivers as reference points, SIML uses virtual transmitters, such as stable landmarks, as virtual anchors to boost precision. Beyond indoor applications, SIML is instrumental in city mapping, high-speed vehicle and UAV localization, environmental imaging, augmented human senses, and recognizing gestures and activities. The integration of SIML with 6G technology is set to transform 3D imaging and mapping capabilities, even when direct line-of-sight is obstructed. The performance of SIML is measured by KPIs including accuracy of reconstruction, miss-detection and false-alarm rates, resolution, and latency, ensuring it meets the stringent demands of these sophisticated applications.

## C. Future application categories

### i. Augmented Human Sense

RF sensing in 6G networks promises high-resolution imaging and detection for a range of applications, from remote surgery to detecting product and infrastructure flaws, leveraging tens of GHz bandwidth and thousands of antennas for superior resolution. This technology offers consistent, all-day performance due to radio wave propagation advantages. With 6G, devices such as smartphones and medical implants will enhance human sensing in diverse environments. In healthcare, 6G sensing will be crucial for diagnosing and treating chronic diseases, while higher frequencies will allow for material identification through electromagnetic characteristics, revealing insights into their composition. The effectiveness of RF sensing is assessed by KPIs such as positioning and reconstruction accuracy, miss-detection and false-alarm rates, resolution, and latency, to meet the high requirements of these advanced applications.

### ii. Gesture and Activity Recognition

The higher frequencies in 6G enhance resolution for detailed activity and gesture recognition. Integrated with AI and advanced computing, this paves the way for intelligent, device-free recognition systems in complex indoor settings. Cellular transmission points will serve as dual-purpose sensors, boosting performance for applications in smart hospitals, including gesture and vital sign monitoring, fall and intrusion detection. These systems will also supervise patient rehabilitation exercises, enhancing recovery. For ultra-precise tasks like playing a virtual piano, the expected accuracy is around 3 mm with a recognition probability above 99%, ensuring seamless functionality. The success of these recognition systems is measured by KPIs including positioning accuracy, miss-detection and false-alarm rates, and latency, ensuring they fulfill the stringent demands of such advanced applications.

## 6. ISAC Sensing Modes

**Mono-static Sensing:** This mode involves a single entity (usually a gNB) acting both as the transmitter and receiver of signals. In mono-static sensing, the signal is transmitted from the gNB, reflects off the target, and is received back by the same gNB. This mode is particularly effective for direct path measurements and is simpler to implement since it requires synchronization and processing at a single point.

**Bi-static Sensing:** Unlike mono-static sensing, bi-static sensing involves separate entities for transmitting and receiving signals. In this mode, one gNB may transmit the signal, which then bounces off the object and is received by a different gNB or UE. Bi-static sensing can provide more comprehensive spatial information and improve the detection of objects in cluttered environments. However, it requires more complex coordination and data fusion from multiple points to achieve accurate sensing.

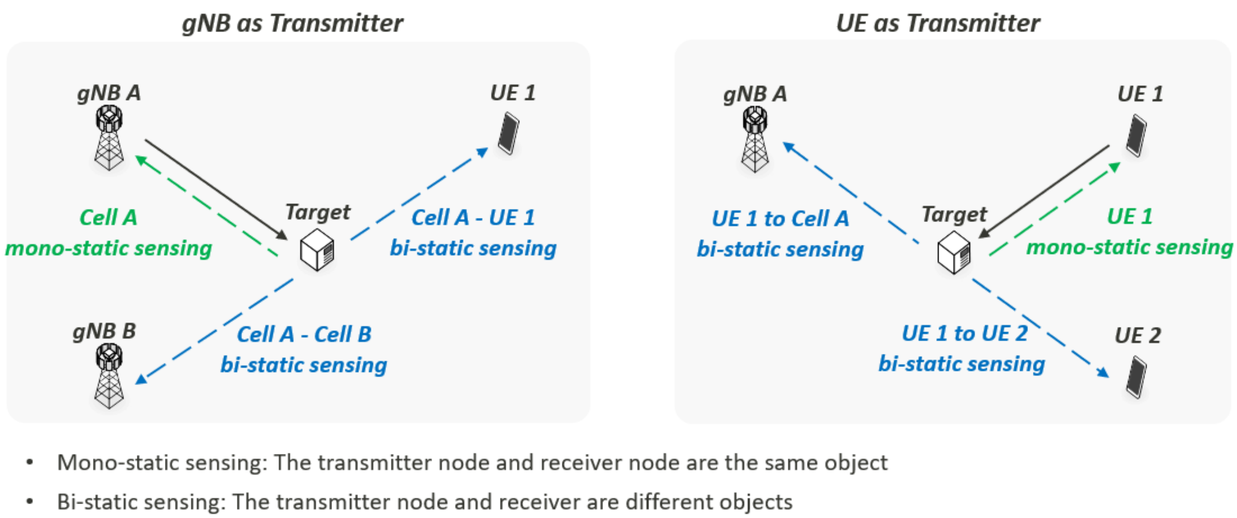


Figure 2: Different modes of sensing

Both mono-static and bi-static sensing modes leverage the advanced capabilities of gNBs and UEs in 6G networks to achieve high-precision localization and tracking. These components and modes form the backbone of ISAC technology, enabling a wide array of applications from enhanced mobile broadband to ultra-reliable low-latency communications and massive machine-type communications.

# 7. ISAC status in 3GPP

The development of ISAC within the 3GPP framework has progressed with the initiation of a new study item, "Feasibility study on ISAC" [3], by the 3GPP SA. This study focuses on NR-based sensing utilizing existing data such as cell/UE measurements and location updates. The primary aim of TR 22.837 is to explore use cases and potential enhancements for the 5G system to provide sensing services across various applications including autonomous/assisted driving, V2X, UAVs, 3D map reconstruction, and sectors like smart cities, homes, factories, healthcare, and maritime. Following this, the "Service requirements for ISAC" [4] was introduced in 2023, detailing the functional and performance requirements for 5G wireless sensing services.

## A. ISAC Channel Modelling

Channel modelling is a cornerstone of ISAC research, receiving considerable focus from both the 3GPP and the wider research communities like IMT2020 (5G) Promotion Group [5]. In ISAC systems, the sensing mechanism relies on the detection of targets by capturing signals reflected off them. This necessitates the construction of bidirectional multipath channels suitable for ISAC, encompassing both the transmitter-to-target and target-to-receiver links. To adapt existing communication channel models for ISAC, elements such as the Radar Cross Section (RCS) are integrated, enabling these models to cater to a variety of ISAC scenarios, including highways, UAV operations, and more.

The 3GPP RAN1 is actively engaged in channel modelling for ISAC [6], aiming to enhance object detection and tracking scenarios. The objective is to develop a channel modelling framework that aligns with use cases in TS 22.137 specifications, capable of accurately identifying and tracking objects such as UAVs, humans (both indoor and outdoor), automotive vehicles (outdoor), automated guided vehicles (indoor), and hazardous objects on roads/railways. This framework, covering frequencies from 0.5 to 52.6 GHz and scalable to 100 GHz, will consider all six sensing modes involving TRPs and UEs in both bistatic and monostatic configurations.

Key tasks include defining deployment scenarios for these use cases and developing channel modelling specifics based on 3GPP TR 38.901 [7]. This involves modelling sensing targets and the environment, considering factors like radar cross-section (RCS), mobility, clutter, and ensuring spatial consistency. ISAC channel modelling distinguishes itself from traditional communication modelling by requiring a deterministic approach to precisely define the signal's propagation path, including the known positions of sensing targets. The ultimate objective is to create a comprehensive and adaptable channel modelling methodology that satisfies the intricate demands of ISAC applications, thereby enhancing the capabilities of future communication and sensing networks.

## 8. Key observations from the on-going feasibility studies

The choice between mono-static and bi-static sensing is a critical decision in the field of ISAC, influenced by various factors including sensing frequency, quality, and accuracy. Ongoing feasibility studies [8] have yielded key observations that inform this decision. The gNB mono-static configuration, while limited in coverage, provides high accuracy within its sensing range, making it suitable for applications where precision is critical. Conversely, configurations involving gNB-to-UE or UE-to-gNB offer extensive coverage but suffer from comparatively lower accuracy, primarily due to uncertainties in timing and the variable locations of User Equipment (UE). However, integrating bi-static with gNB mono-static modes can harness the strengths of both setups: the extensive coverage of bi-static configurations and the high accuracy of mono-static setups. This complementary approach allows for a more versatile and effective ISAC system, capable of meeting diverse operational demands with greater efficiency.

## 9. Research opportunities in ISAC

The field of ISAC presents a wealth of research opportunities that are as broad as the spectrum of its potential applications. As the exploration of new use-cases for ISAC continues to unfold, the need for innovative solutions in network architecture and waveform design becomes increasingly evident. The strategic implementation of network slicing is one such solution, offering a pathway to a more adaptable and capable network infrastructure that can support the diverse requirements of ISAC services.

The adaptation of existing communication waveforms for sensing purposes is a key area of research, necessitating a thorough investigation into their dual-use potential and the trade-offs that may be involved. The development of new waveforms and sensing reference signals is equally critical, aiming to deliver high-precision sensing without compromising the integrity of communication functions. Protocol development is another crucial aspect, focusing on the efficient handling and integration of sensing data within the network's existing operational framework.

Furthermore, the formulation of resource management strategies is essential to balance the simultaneous demands of communication and sensing, ensuring that the quality of service for both is maintained. These research domains collectively contribute to the advancement of ISAC technology, paving the way for its integration into future networks and the realization of its full potential. As ISAC technology evolves, it promises to play a pivotal role in shaping the next generation of networked communication and sensing.

In summary, ISAC research encompasses a multitude of topics, including the integration of sensing functions into existing communication infrastructure, the potential reuse or creation of new waveforms for ISAC, channel modelling considerations, and the choice of sensing methods (mono-static vs bi-static). Alongside these technical aspects, research must also establish well-defined Key Performance Indicators (KPIs) to evaluate the efficacy of ISAC systems prior to their commercial deployment.

## 10. Conclusion

The advent of ISAC within the 6G framework marks the onset of a transformative phase in connectivity and environmental perception. This paper has underscored the boundless innovative prospects that ISAC brings to the table, with its integration poised to significantly enhance the fabric of our increasingly interconnected world. The potential applications of ISAC span a multitude of domains, from the enhancement of urban infrastructure and healthcare systems to the transformation of industrial operations and the augmentation of personal devices.

As this paper concludes, it is evident that the journey towards realizing the full potential of ISAC is just beginning. The collective efforts of the research community in addressing the challenges and seizing the opportunities presented by ISAC will undoubtedly pave the way for a future where the fusion of sensing and communication technologies creates new paradigms for innovation and service delivery in the 6G era and beyond.

## Change Log

| Revision/Date | Short remark | Meeting/Reference |
|---|---|---|
| 0.1 | Content added from MediaTek | |
| 0.2 | Objective and Scope added Ericsson/Sendil | |
| 0.3 | Update of section editor notes | 6GCG Call, 18th March 2024 |
| 1.0 | Stable release with inputs from MediaTek and editorial corrections | Online 6th June 2024 |
| 2.0 | Proof reading and formatting – Co-Chairs | 16th July and 14th Aug |

## References


[1] Recommendation ITU-R M.2160-0, "Framework and overall objectives of the future development of IMT for 2030 and beyond"

[2] Whitepaper V9.0B 2023.03, "System Architecture and Key Technologies of Integrated Sensing and Communication", Global 6G Conference

[3] 3GPP TR 22.837, "Feasibility Study on Integrated Sensing and Communication"

[4] 3GPP TS 22.137, "Service requirements for Integrated Sensing and Communication"

[5] Channel Modelling Methods of 5G-Advanced Integrated Sensing and Communication, IMT-2020 (5G) Promotion Group, 5G-Advanced Sensing Task Group

[6] RP-234069, "New SID: Study on channel modelling for Integrated Sensing and Communication (ISAC) for NR"

[7] 3GPP TR 38.901, "Study on channel model for frequencies from 0.5 to 100 GHz

[8] RWS-230055, "Study Item on NR Sensing in Rel-19", vivo, 3GPP TSG RAN Rel-19 workshop