ISAC - Integrated Sensing and Communication: Detailed Technical Analysis

3GPP Specifications | Releases 19-21 (5G Advanced / 6G Roadmap)

> *Document Status: Research analysis based on 3GPP TS 22.137 (Stage 1), TS 23.137 (Stage 2), and the Rel-20 system architecture overview. All normative citations are drawn directly from the 3GPP specification corpus.*

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1. Overview and Definition

Integrated Sensing and Communication (ISAC) is a paradigm that enables a cellular radio network to simultaneously perform traditional wireless communication *and* environmental radio-frequency sensing using shared hardware, spectrum, and waveforms. Rather than dedicating separate radar infrastructure for sensing, ISAC embeds sensing capability natively into the 3GPP radio access network (RAN) and 5G Core (5GC).

The 3GPP defines 5G wireless sensing service as:

> *"...capabilities for sensing one or more objects in the environment, monitoring environmental conditions, and human motion and gestures to enable more diversified applications." - TS 22.137 §5.1*

The service includes:

- **Collection** of 3GPP sensing data from sensing receivers
- **Secure delivery** of sensing data for processing
- **Controlled exposure** of sensing results to authorized third parties (Application Functions)

2. Standardization Roadmap

3GPP Release	Status	ISAC Role
Rel-18 (5G Advanced)	Frozen	Study item on sensing; TS 22.137 skeleton started (v0.0.0 May 2023)
Rel-19	Frozen	TS 22.137 Stage 1 service requirements stabilized (v19.x.x)

3GPP Release	Status	ISAC Role
Rel-20	**In progress**	**TS 23.137 Stage 2 architecture published; gNB-based sensing introduced**
Rel-21	Future (6G)	6G ISAC functional requirements and extended KPI categories added to TS 22.137

> *Note: 3GPP TS 22.137 change history shows the specification evolved from an initial skeleton (May 2023, v0.0.0) through multiple MCC cycles to v21.0.0 (September 2026), introducing advanced 6G ISAC functional requirements in Release 21.*

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3. Governing Specifications

Primary ISAC Specifications

Specification	Stage	Title	Key Content
TS 22.137	Stage 1	Integrated Sensing and Communication	Service requirements, use cases, KPIs
TS 23.137	Stage 2	Integrated Sensing and Communication	Architecture, NFs, procedures, protocols

Supporting Specifications (Referenced by ISAC)

Specification	Relevance
TS 23.501	5G System Architecture - base for SenF integration
TS 23.502	5GC Procedures - NRF registration used by SenF
TS 38.300	NR Overall Description - gNB as Sensing Entity
TS 38.xxx / 38.xxy	RAN-level sensing spec (TBD - pending RAN coordination)

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4. Use Cases and Service Categories

TS 22.137 §6.2 defines **7 sensing service categories** spanning a wide range of applications:

Category Overview

#	Category	Example Applications	Target Objects
1	Outdoor Object Detection & Tracking	UAV/drone airspace management, bird strike avoidance	UAVs (1.6x1.5x0.7 m), birds
2	Indoor Object Detection & Tracking	Smart building intruder detection, asset tracking	Humans (0.5x0.5x1.75 m)
3	Environmental Monitoring	Flood detection, infrastructure inspection	Water level, structures
4	Public Safety Sensing	Crowd monitoring, search & rescue	Humans, vehicles
5	Vehicle Detection & Tracking	Road traffic management, collision avoidance	Vehicles (7.5x2.5x3.5 m)
6	Motion Monitoring	Healthcare (sleep/respiration), sports analytics	Human body motions
7	Fine-Grained Sensing	Gesture recognition, industrial robotics, factory automation	Sub-metre targets

> *Category 7 has the most stringent KPI requirements (higher positioning accuracy, finer sensing resolution) and typically requires more radio resources - TS 22.137 §6.2 NOTE 6.*

Key Target Object Dimensions (from TS 22.137 §6.2 NOTE 1)

Object	Length (m)	Width (m)	Height (m)
UAV	1.6	1.5	0.7
Human	0.5	0.5	1.75
Vehicle	7.5	2.5	3.5

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5. Functional Requirements (Stage 1 - TS 22.137)

5.1 Core Sensing Capabilities

Per **TS 22.137 §5.2.1**, the 5G system shall:

1. **Detect and/or track** one or more objects (e.g., UAVs, birds) and the environment around them
2. **Collect 3GPP sensing data** from sensing receivers based on operator policies
3. **Provide sensing services** in a defined Target Sensing Service Area using coordinated sensing transmitters and receivers
4. **Activate, configure, and deactivate** sensing based on location and network load (subject to regulation)
5. **Support sensing continuity** for moving objects
6. **Support roaming scenarios** for sensing services (subject to operator policy)
7. **Prioritize** sensing services among themselves and relative to communication services

5.2 Non-3GPP Sensing Data Integration

The 5G system may augment its 3GPP sensing data with data from non-3GPP sensors:

> *"Subject to user consent, regulation, and operator's policy, the 5G system shall be able to collect non-3GPP sensing data from authorized non-3GPP sensors and securely provide it to 5G network... the 5G system should support the joint processing of the 3GPP sensing data and non-3GPP sensing data to derive a combined sensing result." - TS 22.137 §5.2.1*

5.3 Unlicensed Spectrum and V2X Sensing

- UEs **without 5G RAN coverage** may use unlicensed spectrum to provide sensing service (subject to local regulation)
- UEs supporting **V2X applications** may perform 5G wireless sensing outside RAN coverage using ITS or unlicensed spectrum

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6. System Architecture (Stage 2 - TS 23.137)

6.1 Architectural Principles

The 5G sensing architecture is defined in **TS 23.137 §4.1** as an extension of the 5GS architecture (TS 23.501). Key design principles:

- Sensing capability is **additive** to the existing 5GC - a new NF (SenF) is introduced
- **gNB** nodes act as Sensing Entities (SenE), performing radio-based sensing alongside communication
- Only **gNB-based sensing** is supported in Rel-20; UE-based sensing is future work
- The **Application Function (AF)** initiates sensing service requests, either via NEF (external) or directly (trusted domain)

6.2 New Network Function: Sensing Function (SenF)

The **SenF** is the central new core-network function introduced for ISAC. Per **TS 23.137 §4.5.2**:

```
SenF
  |-- Sensing Control Functionality (SenF-C)
  |-- Sensing Processing Functionality (SenF-P)
```

> *There is no standardized interface between SenF-C and SenF-P in Rel-20.*

SenF Responsibilities (TS 23.137 §5.5):

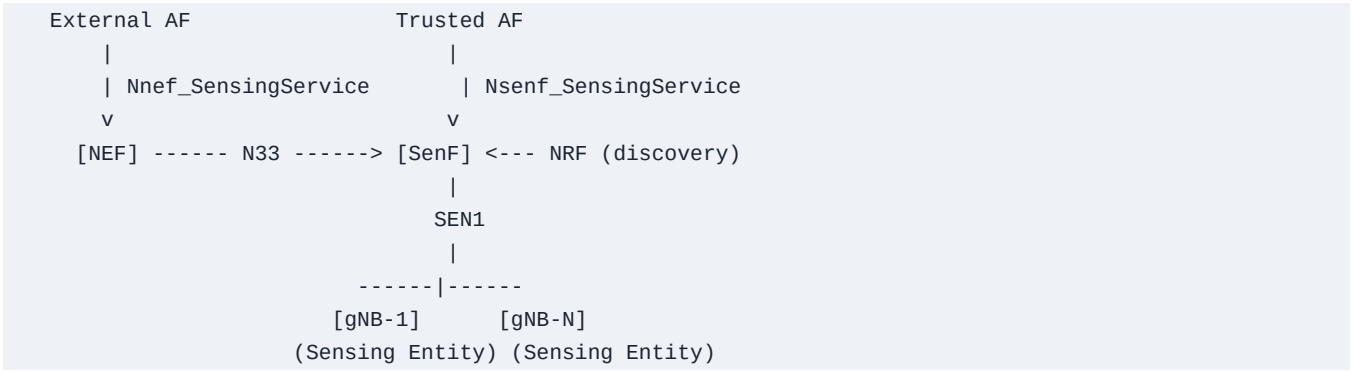
- Receive Sensing Service requests from AF (via NEF or directly)
- **Authorize** sensing service consumers and requests
- **Discover and select** appropriate gNBs as Sensing Entities

- **Derive sensing parameters** from AF requirements (target area, duration, report type)
- **Distribute parameters** to selected gNB(s)
- **Collect sensing data** from gNB(s) and generate Sensing Results
- **Deliver sensing results** to AF (via NEF or directly)
- **Dynamically update** sensing parameters based on real-time results

6.3 Reference Points

Reference Point	Between	Purpose
SEN1	gNB <-> SenF	Sensing control signalling and data transfer
SEN2	SenF <-> NEF	Sensing service exposure to external AFs
SEN3	SenF <-> NRF	SenF NF profile registration and discovery
N33	NEF <-> AF	Existing 5GC reference point reused for sensing service exposure

6.4 Architecture Diagrams



Reference point representation - TS 23.137 §4.2 (Figure 4.2-1)

6.5 Protocol Stacks

Two protocol stacks are defined (TS 23.137 §4.6):

Stack	Interface	Purpose
Sensing Control Signalling	SEN1 control plane	Parameters/configuration from SenF to gNB
Sensing Data Transfer	SEN1 user plane	Raw or processed sensing data from gNB to SenF

7. Key Performance Requirements (KPIs)

Per **TS 22.137 §6.1 and §6.2**, the performance framework encompasses the following metrics:

7.1 KPI Definitions

KPI	Definition
Positioning Accuracy (Horizontal)	Error between measured and true 2D position of target
Positioning Accuracy (Vertical)	Error on the altitude/vertical axis
Velocity Accuracy (Horizontal)	Error between measured and true horizontal velocity
Velocity Accuracy (Vertical)	Error between measured and true vertical velocity
Confidence Level (%)	Percentage of measurements that include the true value within the stated accuracy
Sensing Resolution	Minimum detectable difference in range or velocity between two objects
Range Resolution (m)	Minimum range difference to distinguish two separate targets
Velocity Resolution (m/s x m/s)	Min horizontal/vertical velocity difference to distinguish targets
Max Sensing Service Latency (ms)	Time from sensing trigger to result availability at the interface
Refreshing Rate (s)	Rate at which sensing results are regenerated

KPI	Definition
Missed Detection Probability (%)	**P(not detecting target**
False Alarm Probability (%)	P(detecting target

7.2 Quantitative Requirements (Selected Highlights from Table 6.2-1)

Metric	Representative Value
Range Resolution	0.2 m (Category 7 / factory environments)
Velocity Resolution	0.5 x 0.5 m/s (horizontal/vertical, for factories)
Sensing Latency	0.05 ms to 1 ms (Category 1 - stringent tracking)
Refresh Rate	1.5 s (pedestrian), 15 s (vehicle), 0.1 s (other)
Missed Detection	<= 1%
False Alarm	<= 1%
Confidence Level	Up to 99% (Category 4 - public safety)

> *NOTE 3 (TS 22.137 §6.2): To realize 1 m granularity tracking, when the velocity resolution is 1 m/s, the maximum corresponding sensing service latency is 1 s.*

> *NOTE 5 (TS 22.137 §6.2): Human motion monitoring requires application-specific KPIs - e.g., respiration rate accuracy of 2 times/min for sleep monitoring; sit-up rate accuracy of 3 times/min for sports monitoring.*

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8. End-to-End Sensing Procedures

8.1 Sensing Establishment Procedure (TS 23.137 §6.2.1)



Pre-requisites:

- gNB(s) must have established signalling connections with SenF (TS 38.xxx - pending)
- SenF NF profile must be registered/updated in NRF

Report types supported:

- One-time sensing report
- Periodic sensing report
- Event-triggered sensing report

8.2 Sensing Service Modification Procedure (TS 23.137 §6.2.2)

- **AF-triggered:** AF invokes `Nnef_SensingService` modification APIs -> NEF -> SenF -> gNB(s)
- **SenF-triggered:** SenF autonomously updates sensing parameters based on real-time results

8.3 Sensing Service Un-Subscription Procedure (TS 23.137 §6.2.3)

AF invokes `Nnef_SensingService_Unsubscribe` -> SenF releases gNB sensing resources -> service terminated.

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9. Network Function Services

9.1 NEF Services (TS 23.137 §7.2.2)

Operation	Direction	Purpose
Nnef_SensingService_Subscribe	AF -> NEF	Request new sensing service subscription
Nnef_SensingService_Unsubscribe	AF -> NEF	Cancel sensing subscription
Nnef_SensingService_Notify	NEF -> AF	Deliver sensing results or status updates

9.2 SenF Services (TS 23.137 §7.3.2)

Operation	Direction	Purpose
Nsenf_SensingService_Subscribe	NEF/AF -> SenF	Core network-level sensing subscription
Nsenf_SensingService_Unsubscribe	NEF/AF -> SenF	Core network-level unsubscription
Nsenf_SensingService_Notify	SenF -> NEF/AF	Deliver sensing results and operation status

9.3 SenF Discovery and Selection (TS 23.137 §5.2.1)

- SenF registers its NF profile with the NRF
- NEF or trusted AF discovers the SenF using standard NRF service discovery
- SenF can be configured by OAM or via NRF registration

9.4 Sensing Parameters Provided to gNB (TS 23.137 §5.5)

Parameter Category	Examples
Sensing operational info	Target Sensing Service Area, Sensing Service Duration
Report configuration	Type of sensing data reporting (one-time / periodic)

> *Note: The full list of parameters requires further coordination with RAN WG3.*

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10. Security, Privacy and Authorization

10.1 Authorization Framework (TS 23.137 §5.1)

A **two-tier authorization** model is defined:

1. **Sensing Service Consumer Authorization:** The SenF (or NEF on its behalf) verifies the AF is authorized to consume sensing services at all.
2. **Sensing Service Request Authorization:** Per-request authorization checks that the specific sensing parameters (area, targets, duration) are permitted.

If authorization fails at either stage, the request is rejected with an appropriate cause code and no sensing resources are allocated.

10.2 Privacy and Data Integrity (TS 22.137 §5.1)

The specification explicitly calls out new considerations when sensing is introduced as a system capability:

> *"New considerations on authorization for service access and operation access, data confidentiality, data integrity, and user privacy are needed, to ensure that these aspects are taken into account when deriving service requirements."*

Key privacy dimensions:

- **User consent** required before using non-3GPP sensor data

- **Regulatory compliance** required before activating sensing in geographic areas
- **Data confidentiality** for sensing data in transit and at rest

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11. Energy Efficiency Considerations

Per **TS 22.137 §5.1**, energy-efficient sensing is a first-class design requirement:

- **Temporarily disabling** sensing transmitters/receivers not involved in active operations
- **Adjusting sensing operation parameters** (e.g., sensing frequency) to minimize energy usage
- **Coordinating sensing transmitters and receivers** for interference management
- Sensing operations are activated/deactivated dynamically based on **network load and location**

conditions (TS 22.137 §5.2.1)

This aligns ISAC with 3GPP's broader sustainability agenda (energy efficiency in Rel-18/19 RAN).

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12. ISAC in the 6G Context (Rel-20/21)

12.1 Rel-20 Overview

According to the 3GPP Release overview:

> *"Rel-20 study areas include: Sub-THz spectrum exploration (100 GHz - 300 GHz), AI-native network design, Integrated Sensing and Communication (ISAC), extreme positioning, sustainable/energy-efficient RAN and core, digital twin networks."*

Rel-20 represents the **first normative deployment phase** of ISAC with:

- TS 23.137 Stage 2 architecture published
- gNB-based sensing operational framework defined
- Aerial object (UAV/drone) detection and tracking as the first supported use case
- SenF as a new standardized 5GC NF

12.2 Rel-21 Extensions (6G Era)

TS 22.137 v21.0.0 introduces advanced 6G ISAC capabilities, expanding beyond Rel-20:

- Additional sensing service categories (7 categories defined)
- Extended KPIs for human motion monitoring (respiration, gesture recognition)
- 6G ISAC functional requirements formalized
- V2X sensing integration (using ITS/unlicensed spectrum outside RAN coverage)
- UE-based and sidelink-based sensing (anticipated in future RAN specifications)

12.3 Convergence with Other 6G Technologies

6G Technology	ISAC Interaction
Sub-THz (100-300 GHz)	Higher frequencies -> finer range/velocity resolution; enables mm-scale sensing
AI-Native Networks	AI/ML for sensing data processing, intelligent SenF resource selection
Digital Twin Networks	ISAC provides real-world sensing data to feed digital twin models
Extreme Positioning	Sensing and positioning share waveforms and infrastructure
Ambient IoT	Passive sensing targets enabled by bistatic configurations

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13. Open Issues and Future Work

The following items are explicitly noted as requiring further specification work (as of Rel-20 TS 23.137):

Area	Status

Area	Status
RAN-level sensing specification	**TS 38.xxx / TS 38.xxy numbers TBD - pending RAN WG coordination**
Step 9 procedure details (SenF <-> gNB interaction during active sensing)	Requires coordination with RAN WG3
Full parameter list for gNB (sensing parameters from SenF)	Partially defined; further discussion needed
SenF-C / SenF-P standardized interface	Not standardized in Rel-20
UE-based sensing	Not supported in Rel-20; planned for future releases
Multi-gNB sensing result fusion	Implementation-specific in Rel-20; no normative algorithm defined
UE sensing on unlicensed/ITS spectrum	Subject to regulatory study
Non-3GPP sensor fusion algorithms	Implementation-specific; no normative standard

14. Abbreviations

Abbreviation	Expansion
AF	Application Function
ISAC	Integrated Sensing and Communication
NF	Network Function
NEF	Network Exposure Function
NRF	Network Repository Function
RAN	Radio Access Network
SenE	Sensing Entity (= gNB acting in sensing role)
SenF	Sensing Function (new 5GC NF)
SenF-C	Sensing Control Functionality
SenF-P	Sensing Processing Functionality
UAV	Unmanned Aerial Vehicle
V2X	Vehicle-to-Everything
5GC	5G Core Network
5GS	5G System
gNB	Next Generation Node B (5G base station)
KPI	Key Performance Indicator
ITS	Intelligent Transportation System

15. References

Reference	Document	Notes
[1]	3GPP TS 22.137 v19.0.0 / v20.0.0 / v21.0.0	Service Requirements for ISAC (Stage 1)
[2]	3GPP TS 23.137 v20.0.0	ISAC Stage 2 Architecture and Procedures
[3]	3GPP TS 23.501	System Architecture for the 5G System (5GS)
[4]	3GPP TS 23.502	Procedures for the 5G System (5GS)
[5]	3GPP TS 38.300	NR; NR and NG-RAN Overall Description
[6]	3GPP Release 20 Overview	Study areas including ISAC