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Integrated Sensing And Communications (ISAC); Use Cases and Deployment Scenarios

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) Integrated Sensing And Communications (ISAC).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Executive summary

The present document identifies 18 advanced use cases relying on Integrated Sensing And Communications (ISAC) and their technological benefits. Described use cases bring societal benefits in various fields such as healthcare, public safety, transportation, robotics, smart factories or smart cities.

Described use cases are analysed to highlight consolidated requirements and KPIs that future 6G communications systems need to ensure to support these advanced use cases. The present document formulates considerations on deployment scenarios, suitable frequency bands, sensing modes, and integration levels. The present document also gives an overview of challenges associated with the described use cases.

Finally, the present document draws conclusions and formulates recommendations in terms of needed future work on ISAC channel modelling, measurements, evaluation methodology, system and radio access network architectures, security, privacy, trustworthiness, and sustainability for ISAC.

Introduction

There is currently an increased interest for ISAC from the whole research ecosystem (including worldwide standardization bodies, industrial individual members and stakeholder associations, academia, strategic national and regional collaborative projects, etc.). In this context, the present document proposes new use cases to be potentially supported by future 6G systems.

1 Scope

The scope of the present document is to:

- Define 6G use cases for integrated sensing and communications.
- Identify and describe the corresponding deployment scenarios and the potentially suitable frequency bands.
- Define, characterize and evaluate the relevance of different sensing types and integration levels, and their mapping to the selected use cases/deployments.
- Identify requirements and define key performance/value indicators for the identified use cases.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

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3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	3rd Generation Partnership Project
6GS	6th Generation System
ADAS	Advanced Driver Assistance Systems
ADS-B	Automatic Dependent Surveillance-Broadcast
AGV	Automated Guided Vehicles
AI	Artificial Intelligence

AMR	Autonomous Mobile Robots
ANSP	Air Navigation Service Provider
AP	Antenna Pannel
API	Application Programming Interface
AV	Aerial Vehicles
AWGN	Additive White Gaussian Noise
BLE	Bluetooth® Low Energy
BPS	Body Proximity Sensor
BS	Base Station
BVLoS	Beyond Visual Line of Sight
CIS	Common Information Services
C-ITS	Cooperative Intelligent Transport Systems
CLSK	Commando Luchtstrijdkrachten
CN	Core Network
CPE	Customer Premises Equipment
CPR	Consolidated Potential functional Requirements
CPS	Cyber-Physical System
CR	Cooperative Robot
CRLB	Cramer-Rao lower bound
CSI	Channel State Information
CTR	Controlled Traffic Regions
DT	Digital Twin
DUT	Device Under Test
EIRP	Effective Isotropic Radiated Power
FCC	Federal Communications Commission
FWA	Fixed Wireless Access
GDPR	General Data Protection Regulation
gNB	3GPP Radio Access Point (gNodeB)
GNSS	Global navigation satellite system
GPU	Graphic processing unit
HAPS	High-Altitude Platform Station
HD	High Definition
I2O	Indoor to Ourdoor
IC	In Coverage
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IoT	Internet of Things
ISAC	Integrated Sensing And Communications
KPI	Key Performance Indicator
LAPS	Low-Altitude Platform Station
LIDAR	Light Detection and Ranging
LoS	Line of Sight
LVNL	Luchtverkeersleiding Nederland
MaaS	Mobility as a Service
ML	Machine Learning
MNO	Mobile Network Operator
MPE	Maximum Permissible Exposure
MPR	Maximum Power Reduction
NB-IoT	Narrow Band Internet of Things
NCR	Network Controlled Repeater
NL	Netherlands
NLoS	Non Line of Sight
NTN	Non-Terrestrial Networks
O2I	Outdoor to Indoor
OoC	Out of Coverage
OPEX	Operating Expenses
PD	Power Density
PR	Potential Requirement
PRS	Positioning Reference Signal
QoS	Quality of Service
RAN	Radio Access Network
R-CPS	Realtime Cyber-Physical System
RCS	Radar Cross-Section

RF	Radiofrequency
RGB	Red Green Blue
RIS	Reconfigurable Intelligent Surfaces
RMa	Rural Macro
SAR	Specific Absorption Rate
SBA	Service-Based Architecture
SDO	Standard Development Organization
SNR	Signal to Noise Ratio
STA	Station
TPU	Tensor Processing Unit
TR	Technical Report
TRP	Transmission Point
TS	Technical Specification
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UMa	Urban Macro
UMi	Urban Micro
USSP	UTM-Space Service Provider
UTM	Unmanned Aircraft System Traffic Management
UWB	Ultra-WideBand
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
VRU	Vulnerable Road User
WBPMP	Walking, (e-)Biking, Public transport, Mobility as a service and Private car
WG	Working Group
WI	Work Item
XR	eXtended Reality

4 Foundations of integrated sensing and communications

4.1 Sensing modes

The term "sensing mode" describes the topology consisting of one or more sensing nodes and their role. Sensing nodes may be User Equipment's (UEs) or Transmission Points (TRPs) that may act as a sensing transmitter and/or sensing receiver.

There are six unique sensing modes:

- TRP-TRP bistatic;
- TRP monostatic;
- TRP-UE bistatic;
- UE-TRP bistatic;
- UE-UE bistatic; and
- UE monostatic.

These basic modes may be extended to multi-static variants by adding additional UE(s) or TRP(s) to any of the six basic modes as sensing transmitter(s) and/or receiver(s).

4.2 Integration levels

The term "integration level" describes how communication and sensing functionalities are combined in one system. It is commonly categorized in multiple levels, reaching from loose integration to tight integration with variable granularity [i.41].

Loose integration refers to the case where the two functionalities are realized rather on a standalone basis with some level of coordination, e.g. on application level, or by combining dedicated sensors and communication hardware on a site.

Tight integration refers to a joint waveform or joint signal design that is suitable for both tasks.

Intermediate integration may refer to anything in between.

4.3 System terminology for sensing-enabled 6G systems

For the purposes of the present document, the following terms apply:

- **Sensing Signal** is a transmitted signal from a Sensing Transmitter for the purpose of sensing. The signal can be 6G or non-6G.
- A **Sensing Transmitter** is a 6G or non-6G entity that transmits a Sensing Signal.
- A **Sensing Receiver** is a 6G or non-6G entity that receives a Sensing Signal and produces Sensing Data. A Sensing Receiver can be co-located with a Sensing Transmitter.
- **Sensing Data** is the 6G or non-6G data produced for sensing purposes.
- A **Sensing Service** is a feature of the 6GS that is offered to service consumers. A Sensing Service provides Sensing Results based on communicated requirements and KPIs.
- A **Sensing Task** consists of activities to perform sensing, including the configuration of the required Sensing Transmitter(s) and Sensing Receiver(s) (if applicable), the collection of Sensing Data, the processing of the Sensing Data and the exposure of the Sensing Results. Each Sensing Task fulfils a Sensing Service request.
- A **Target Sensing Service Area** as defined in clause 3.1 of 3GPP TS 22.137 [i.2].
- The **Sensing Results** may include characteristics of objects (e.g. type, distance, velocity, trajectory, size, shape, material), or other contextual information (e.g. time of generation, environmental information) about objects in the Target Sensing Service Area.

NOTE: It is not precluded that the sensing result exposed to an entity within 6GS or to a third party may in some cases consist of the sensing data itself.

- **Fusion** refers to a process to join two or more streams of Sensing Data or Sensing Results together to form one or more Sensing Data or Sensing Result stream(s). Fusion can take place at the origin of the sensing data, along the system entities of a 6GS. The fusion of Sensing Results can also take place along all 6GS system entities. Fusion can also take place in non-6GS entities.

Figure 1 uses the terminology defined above and illustrates the described information flow.

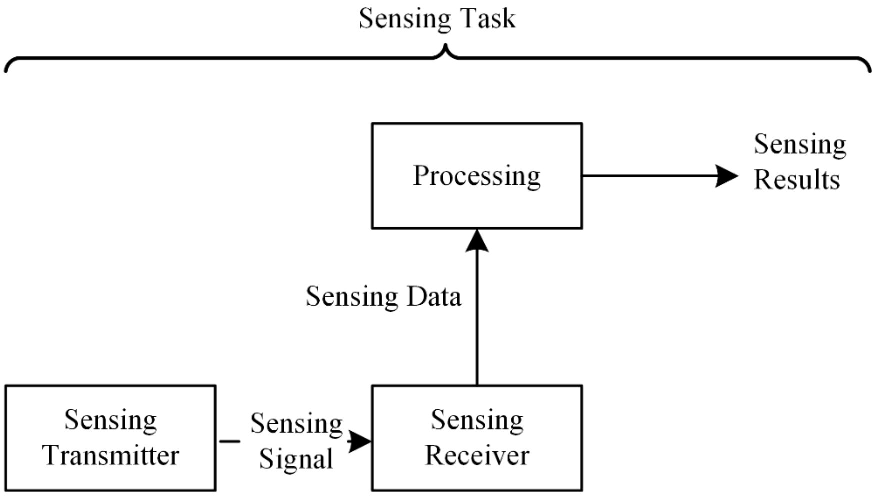


Figure 1: Workflow of Conducting Sensing Using Terminology Above

4.4 Overview of relevant existing use cases

4.4.1 Use cases and associated scenarios in 3GPP

In 3GPP Release 19, the Service and System Aspects group SA1 specified requirements related to a set of 5G-Advanced use case scenarios in 3GPP TS 22.137 [i.2]. The use case scenarios are:

- Object Detection and Tracking.
- Environmental Monitoring.
- Motion Monitoring.

These use case scenarios correspond to specific use cases that were captured in 3GPP TR 22.837 [i.1].

Table 1 captures the use case scenarios, the use cases in 3GPP TR 22.837 [i.1] and their corresponding object category and possible evaluation scenarios related to communications.

The functional requirements and performance of ISAC are further consolidated in 3GPP TS 22.137 [i.2]. Table 2 captures these requirements. In particular a few unique KPIs dedicated to ISAC were identified, for example accuracy of positioning, accuracy of velocity, sensing resolution, latency, missed detection and false alarm probability, etc. In general, accuracy of positioning and velocity estimate by ISAC represent the closeness of measured sensing results of the target object to its true value are typically around 1 ~ 10 m and 1 ~ 10 m/s respectively. KPI requirements for missed detection and false alarm probability, which describe the conditional probability of not detecting, or falsely detecting the presence of a target object/environment are also specified in 3GPP TS 22.137 [i.2], as shown in Table 2.

In addition to the 5G Advanced Sensing study, 3GPP SA1 has recently initiated a new study on 6G Use Cases and Service Requirements (3GPP TR 22.870 [i.69]) as part of the 3GPP Release 20 activities. This study explores new applications and services enabled by Integrated Sensing and Communication. Thirty-eight new use cases, along with their respective functional and performance requirements, that rely on sensing capabilities were proposed in SA1 in November 2024. As of December 2024, six of these use cases are included in 3GPP TR 22.870 [i.69]. In the coming months, it is anticipated that several new use cases that require sensing capabilities will be incorporated into 3GPP TR 22.870 [i.69].

Table 1: Use case scenarios and Use cases for ISAC in 3GPP 5G-Advanced

Scenario	Target Category	Use Case index (3GPP TR 22.837 [i.1])	Use Case Description (22.837)	Existing evaluation scenarios for communications
Object Detection and Tracking	UAV	5.10	Use case on UAV flight trajectory tracing	UAV (3GPP TR 36.777 [i.51])
		5.12	Use case on Network assisted sensing to avoid UAV collision	
		5.13.	Use case on sensing for UAV intrusion detection (level 1)	
		5.13	Use case on sensing for UAV intrusion detection (level 2)	
		5.22	Use case of UAVs/vehicles/pedestrians detection near Smart Grid equipment	
	Human Indoors and Outdoors	5.1	Use case of intruder detection in smart home	Indoor Office, UMi-street canyon, RMa, UMa (ETSI TR 138 901 [i.52])
		5.6	Use case on intruder detection in surroundings of smart home	
		5.22	Use case of UAVs/vehicles/pedestrians detection near Smart Grid equipment	
		5.25	Use Case on immersive experience based on sensing	
		5.27	Use case public safety search and rescue or apprehend	
	Automotive vehicles (at least outdoors)	5.2	Use case of Sensing for Parking Space Determination	V2X (3GPP TR 37.885 [i.53], 3GPP TR 38.802 [i.54])
		5.14.	Use case on sensing for tourist spot traffic management	
		5.22	Use case of UAVs/vehicles/pedestrians detection near Smart Grid equipment	
		5.30	Use case on sensing for automotive manoeuvring and navigation service when not served by RAN	
		5.28	Use case on Vehicles Sensing for Advanced Driving Assistance System (ADAS)	
	Automated guided vehicles (e.g. in indoor factories)	5.23	Use case on AMR collision avoidance in smart factories	Indoor Factory (ETSI TR 138 901 [i.52])
		5.32	Use case of integrated sensing and positioning in factory hall	
	Objects creating hazards on roads/railways, with a minimum size dependent on frequency	5.7	Use case on sensing for railway intrusion detection	High Speed Train (3GPP TR 38.802 [i.54])
		5.11	Use case on sensing at crossroads with/without obstacle	V2X (3GPP TR 37.885 [i.53], 3GPP TR 38.802 [i.54])
		5.2	Use case on pedestrian/animal intrusion detection on a highway	
Environment Monitoring		5.3	Use case on rainfall monitoring	Not specified
		5.4	Use Case on Transparent Sensing Use Case	
		5.5	Use case on sensing for flooding in smart cities	
Motion Monitoring		5.15	Use case on contactless sleep monitoring service	
		5.24	Use case on roaming for sensing service of sports monitoring	
		5.29	Use case on Coarse Gesture Recognition for Application Navigation and Immersive Interaction	

Table 2: KPIs for the 3GPP 5G-Advanced Use Case scenarios in Table 6.2-1 [i.2]

Scenario	Sensing service category	Confidence level [%]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency [ms]	Refreshing rate [s]	Missed detection [%]	False alarm [%]
			Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Object detection and tracking	1	95	10	10	N/A	N/A	10 [3]	5 [3]	1 000	1	5	2
	2	95	2	5	1	N/A	1	1	1 000	0,2	0,1 to 5	5
	3	95	1	1	1 [3], [4]	1	1 [3], [4]	1 x 1 [3]	100 [2], or 1 000 (note 3); 5 000 for detection in highway	0,05 to 1	2	2
	4	99 for public safety, otherwise, 95	0.5	0,5	1,5 for pedestrian, 15 for vehicle, otherwise, 0,1	1,5 for pedestrian	0,5	0,5 x 0,5 for factories	100 to 5 000	0,1	1	3
Environment monitoring	5	95	10	0,2 (note 4)	N/A	N/A	N/A	N/A	60 000	60 to 600	0,1 to 5	3
Motion monitoring	6	95	N/A	N/A	N/A	N/A	N/A	N/A	60 000	60	5	5
	7	95	0,2	0,2	0,1	0,1	0,375	0,3	5 to 50	0,1	5	5

NOTE 1: For sensing service categories to which UAV, human or vehicle is a sensing target, the typical size (Length x Width x Height) of UAV is 1,6 m x 1,5 m x 0,7 m, the typical size of human is 0,5 m x 0,5 m x 1,75 m, and the typical size of vehicle is 7,5 m x 2,5 m x 3,5 m.

NOTE 2: The safe distance between pedestrian/vehicle and power transmission station/line is 0,7 m/0,95 m.

NOTE 3: To realize 1m granularity tracking, when the velocity resolution is 1 m/s, the maximum corresponding sensing service latency is 1 s.

NOTE 4: This value is derived from the water level where people feel difficulty in walking.

NOTE 5: To achieve human motion monitoring, different accuracy KPI is needed to measure different human motions. E.g. respiration rate accuracy (2 times/min) is a KPI used to measure the accuracy of sleep monitoring, sit-up rate accuracy (3 times/min) is a KPI used to measure the accuracy of sports monitoring.

NOTE 6: Category 7 has more stringent requirements (e.g. for KPIs such as positioning accuracy and sensing resolution) compared to other categories and typically requires more radio resources.

4.4.2 Use cases in IEEE 802.11

The following use case classes were summarized in IEEE 802.11 [i.42]:

- Room Sensing use cases:
    - Room Sensing - presence detection/counting the number of people in the room, Smart meeting room - presence detection/counting the number of people in the room/ localization of active people, Human motion detection in a room, Home security - Intruder detection, Audio with user tracking, Store Sensing, Home Appliance Control.
- Gesture Recognition use cases:
    - Gesture recognition - short range (finger movement < 0,5 m), Gesture recognition - medium range (hand movement > 0,5 m), Gesture recognition - large range (full body movement > 2 m), Aliveliness detection, Face/Body Recognition, Proximity Detection, Home Appliance Control.
- Health Care:
    - Health care - Fall detection, Health case - remote diagnostics (breathing rate, heart rate, etc.), Surveillance/Monitoring of elder people and/or children, Sneeze sensing.
- 3-D vision:
    - Building a 3-D picture of an environment, using multiple stations (STA).
- In-car sensing:
    - Detection of humans in car, Driver sleepiness detection/detection aid.

Details of the different sensing classes and corresponding KPI's can be found in [i.42].

4.4.3 Use cases in Literature

There have been extensive studies of use cases in the literature including in [i.43] and [i.44]. Use cases discussed include the following:

- Sensing as a service:
    - Drone Monitoring and Management, Localization and Tracking in Cellular Networks, Area Imaging, Passive Sensing Network.
- Smart Home:
    - Intruder Detection, Location Aware Control, Human proximity detection.
- In-Cabin Sensing:
    - Passenger monitoring, Driver Attention Monitoring.
- Vehicle to Everything:
    - Vehicle Platooning, Simultaneous Localization and Mapping, High Precision Location.
- Smart Manufacturing and Industrial Internet of Things (IoT):
    - Automated Guided Vehicles, Digital Twin.
- Remote Sensing and Geoscience:
    - Drone Swarm Synthetic Aperture Radar Imaging, Satellite Imaging and Broadcasting.
- Environmental Monitoring:
    - Weather Prediction, Pollution Monitoring, Rain Monitoring.

- Human Computer Interaction:
    - Gesture Recognition, Keystroke Recognition, Head/Arm Activity Recognition.

4.4.4 ETSI ISG THz Use Cases and Sensing

In the ETSI Industry Specification Group (ISG) THz, a work item on use cases has been completed in January 2024 with use cases captured in ETSI GR THz 001 [i.23]. In ETSI GR THz 001 [i.23], sensing, imaging and positioning are identified as enabling technologies for some of the described 6G emerging use cases. These use cases related to ISAC include the following:

- Remote surgery.
- In-airplane or train cabin entertainment.
- Cooperative mobile robots.
- Hazardous material work.
- Remote education.
- Interactive immersive XR.
- Mission critical XR.
- Real time industrial control.
- Simultaneous imaging, mapping and localization.
- Commissioning of industrial plants.

4.4.5 ETSI ISG RIS Use Cases for ISAC

Reconfigurable Intelligent Surface (RIS) is a new type of network node that can be controlled and configured to improve communication performance, positioning, and sensing capabilities. As an example, a RIS can reconfigure the radio environment to sense human posture and detect someone falling, a useful application for elderly health care.

ETSI ISG RIS has studied several aspects related to RIS, including control mechanisms, deployment strategies, and performance evaluations. ETSI GR RIS 001 [i.45] identifies and defines relevant RIS use cases, with corresponding general KPIs. It also describes deployment scenarios as well as potential requirements for each identified use case, to enable interoperability with existing and upcoming wireless technologies and networks, including 6G ISAC.

RIS can be used in the 6G ISAC system to aid/support both communications and sensing capabilities. With respect to enhancing or enabling sensing services, both active and passive sensing with RIS may be considered. RIS, through establishing LoS, can provide sensing services for NLoS areas. RIS may also be used as a sensing anchor point to create additional ISAC links/angles for the sensing tasks. It is also possible to embed sensing capabilities at the RIS devices.

RIS use cases include Human Indoor/Smart Home, AGV/Smart Manufacturing, Environment Monitoring, Motion, Health Care, and Sensing Aided Communications.

4.4.6 Activities and vision of ISAC for automotive

An ISAC work item in 5GAA [i.3] aims at facilitating and enabling the applicability of ISAC to the existing automotive use cases [i.61], [i.62], [i.63] and to put ISAC in perspective with the existing roadmaps [i.64]. In addition, 5GAA also strives for providing automotive views and potential requirements of ISAC-capable systems to several other Standards Development Organizations (SDOs), such as 3GPP (e.g. [i.65]) and ETSI.

Table 3 provides an overview of the overall scope of ISAC in 5GAA [i.3].

Table 3: Scope and Mission of ISAC Study in 5GAA [i.3]

Common Understanding for Automotive	Survey the existing/relevant ISAC literature to identify key technology features, trends, as well as to develop the concept of Automotive ISAC. Harmonize related terminology and definitions.
Automotive Use Cases and Sensing Targets	Identification, revision/update of relevant use cases for connected mobility, where ISAC can provide enhanced support. Identification and characterization (e.g. radar cross section, dimensions, types, etc.) of sensing targets of interest according to the existing automotive use cases.
Metrics and Key Performance Indicators (KPIs)	To establish a framework for evaluation and assessment of ISAC-capable systems, and KPIs and requirements for the selected use cases.
Cooperation with other SDOs working on ISAC	Provide inputs, reports of progress, and make sure that automotive views and considerations are well-understood and taken into consideration.
Dissemination	Generate a group report with the findings and outcomes of the study.

The progress achieved so far, include, among others, the following aspects:

- Automotive use cases (considered and studied for ISAC, at the moment of writing) include Automated Valet Parking, Parking-Lot Management (focus: parking space determination), vehicle/UE sensing for advanced driver assistance system, Intersection Movement Assist, Hazard Information, and Road Event Collection for automated vehicles, Vulnerable Road Users.
- ISAC concept and key related technologies for automotive (e.g. sensing modes for car-based sensing and/or road-infrastructure-based sensing).
- Integration levels for automotive.
- Aspects for Vulnerable Road Users (VRUs) detection with ISAC technology.
- Physical characteristics of sensing targets for automotive.
- Initial discussions on potential next steps.

Main goal is generating a technical report outlining the main outcomes and achievements of the work item, expected to be released in the first quarter of 2025. The vision is to clarify and facilitate the possible adoption of ISAC technology, e.g. based on 3GPP technology, within the automotive industry.

4.4.7 ISAC Use Cases from one6G

The one6G association [i.66] established in March 2021, focuses on evolving, testing and promoting next generation cellular and wireless based communication solutions [i.66]. The association has as of November 2024, more than 160 affiliation members around the world, and current activities are focused on four Working Groups (WGs) with related Work Items (WIs) [i.67].

In particular one6G Work Item (WI) on "6G and e-health" has been focusing on identifying ISAC use case from e-Health perspective, with emphasis on deriving sensing- and communication-related requirements together with the required functional requirements. Other non-technical aspects related to medical device regulation, sustainability and ethics has also been considered.

During the course of discussions with various stakeholders from the medical domain, industry and academic researchers, One6G [i.22] has developed and published the white paper "6G & eHealth: Use Cases and Potential Service Requirements" [i.68]. On the basis of this publication [i.68], One6G has selected and adapted the following use cases with emphasis on the ISAC sensing functionality:

- Vital Sign Sensing in Medical Care Units.
- Medical Goods Logistics with Robotic Fleets.
- Safe Context Aware Mobile Robotic Platforms in Nursing Ward.

These use cases focus on the support of ISAC for:

1) human medical monitoring;

2) robot - medical environment interaction; and

3) robot - human interaction respectively.

4.4.8 Existing Use Case Summary

Table 4 summarizes the existing use cases giving a good overview of the use cases that have been addressed in exiting literature and standard development organizations.

Table 4: Summary of Relevant Use Cases

	3GPP 5G-A	IEEE 802.11	Literature	ETSI THz	ETSI RIS	5GAA [i.3]	one6G
UAV	x						
Human Indoor/Smart Home	x	x	x		x		x
V2X-core/ Automotive	x		x			x	
AGV/Smart Manufacturing/ Logistics	x		x	x	x		x
Environment Monitoring	x		x		x		
Motion	x	x			x		
Human Computer Interface		x	x				x
Health Care	x	x		x	x		x
In car/cabin Sensing		x	x	x		x	
Sensing as a service			x				
Remote Sensing			x				
3D vision/Interactive immersive XR/Mission Critical XR		x		x			
Sensing Aided Communications			x		x		
Remote education				x			
Simultaneous Imaging, Mapping and Localization				x			

5 6G use cases for integrated sensing and communications

5.1 Use case on human motion recognition

5.1.1 Description

This use case refers to comprehensive human motion classification and recognition for immersive interaction and sports monitoring. Motion is a kind of basic interface between human and natural world, and represents rich information of mental and physical statement. Motions/gestures/postures have different level of amplitude and duration, which raise different requirements for accuracy, update rate and latency to sensing equipment. Gesture recognition identifies motions and postures of human body parts, such as head, arms, legs, trunk, hands, fingers, feet, and other small body parts. The use case on comprehensive human gesture classification and recognition focuses on two levels of motions to ensure application of immersive (i.e. eXtended Reality (XR)) service, sports teaching, health monitoring and others.

Large-scale motion: First level of motion is large-scale motion on the scale of meters related to macro-Doppler component of almost all parts of human body, such as walking, running, swimming and kinds of sports. Long duration time, large amplitude and large range of motion making it convenient to be recognized in terms of resource utilization and processing complexity. Large-scale motion related Key Performance Indicators (KPIs) have been defined in clause 5.22 of 3GPP TR 22.837 [i.1].

Small-scale motion: Second level of motion is small-scale motion or fine motion on the scale of centimetres or millimetres, typically related to micro-Doppler component of part of human body, such as swinging arms, kicking legs, turning head around, kinds of hand gestures, breath, heartbeat, blinking eyes, opening mouth and all kinds of fine motions. Small-scale motions have features of short duration time, small amplitude and range, requiring higher resolution, higher update rate and lower latency for recognition. Similar cases of small-scale motion and related KPIs have been listed in clauses 5.15, 5.17 and 5.29 of 3GPP TR 22.837 [i.1].

Even though use cases related to recognition of both motion levels have previously been investigated, some challenges are still unclear. From a physical layer perspective, recognition of different motion levels requires different sensing resources with different parameters, and different sensing procedures are triggered with different sensing resources. What's more, the procedures and related resources for small-scale motion recognition may differ at different states of large-scale motion (e.g. running and standing). Thus, one important capability and challenge of 6G sensing system is scheduling suitable sensing resources for recognition of both small- and large-scale motion and providing sensing results of those types of motions simultaneously (or in a specific time window).

Recognizing and tracking comprehensive human motions is a basic requirement for XR application to provide immersive experience. According to uncanny valley theory, only coarse large-scale motion detection and mapping in XR application will cause unpleasant feelings, which is a main problem to be solved in current metaverse applications. Precise recognition of both large-scale and small-scale motions should have a same priority, especially when humans want to interact with the virtual world without a sense of unreality.

For sports monitoring, detection of both large-scale and small-scale human body motion can provide richer information about human health state than ever before. Combining large-scale features about stride, frequency and step size, and small-scale features about heart-beat rate and depth of respiration, precise report can be provided to help analyse comprehensive health status and give professional exercise advice.

5.1.2 Pre-conditions

There are two roommates, Bob and Alice, both of whom subscribed to Mobile Network Operator (MNO) A, which has deployed Radio Access Network (RAN) entities (e.g. an indoor station and some outdoor stations around their house) supporting 6G-based sensing.

Bob and Alice are XR players, playing an open world game using an XR device that is connected to the indoor RAN entity. The XR device is equipped with 6G sensors and can provide sensing inputs e.g. sensing data (information about characteristics of hand gestures, eyes motions and body postures like walking, skipping and running). Using these sensing results, the virtual character can execute precise motions just like Bob himself.

Alice is also a sports fan. Every morning Alice goes out their house to run for an hour. Alice does not like any wearable sports monitoring device, and only carries her mobile phone with sensing capability.

5.1.3 Service Flows

Immersive interaction service with both large-scale and small-scale motion recognition

Step 1: Bob and Alice are playing indoors an open world game using two XR devices. In this game, they are executing a dragon hunting task. Bob wants to attack the dragon, so he gives a silent gesture by his left hand, points to the dragon by his right hand, and turns his head toward Alice, showing that Alice should attack from a far distance to help him. At the same time, Bob begins to run to get closer to the deer.

Step 2: RAN entity (the indoor station) is able to sense the Bob's large-scale motion of running, and the key features and parameters such as range and velocity of large-scale motion are estimated based on a sensing reference signal. Simultaneously, small-scale motion (turning head around) is recognized by the RAN entity with same sensing reference signal for large-scale motion. Due to block by Bob's body, the RAN entity failed to recognize Bob's hand gesture. However, Bob's XR device is able to recognize and classify Bob's hand gesture based on a different sensing reference signal at the same time.

Step 3: 6GS then processes the sensing data collected from XR device and RAN entity to detect Bob's comprehensive motion and provides the sensing result to a game server. The game server is able to show Alice a precise virtual posture of Bob on her XR device.

Sports monitoring service with both large-scale and small-scale motion recognition

Step 1: Alice wants to run outside for a while. She carries her mobile phone and begins running on the playground besides the house.

Step 2: Outdoor base station A begins to transmit sensing reference signal and outdoor base station B begins to receive the sensing reference signal. By receiving and processing the sensing reference signal, base station B is able to generate large-scale sensing data (including range and velocity of running) and part of small-scale sensing data (including Alice's arms and legs posture, stride frequency and step size). At the same time, Alice's mobile phone is able to estimate other part of small-scale sensing data including her heartbeat frequency, respiration rate and depth with sensing reference signal transmitted by itself. All sensing data is processed in 6GS and time aligned. Then 6GS exposes these sensing results to some health analysis application in an anonymous way.

Step 3: After running, Alice is able to check her detailed health report in the health analysis application. Alice is able to check her detailed sport report along a time axis. For example, Alice is able to check her heartbeat frequency, respiration rate and depth, stride frequency and step size with a specific position and velocity at any time. Based on these detailed sport reports, the health analysis application informs Alice that her arms posture is incorrect at the middle stage of running and that her heartbeat frequency is too high when her velocity exceeds 8 km/h. Then Alice can adjust her sport plan for health.

5.1.4 Post-conditions

Bob and Alice enjoy immersive games, and Alice is able to keep the habit of running, with help from the sensing service of 6G network.

5.1.5 Potential requirements

[PR 5.1-1] The 6G system should be able to simultaneously classify and recognize multiple types of motions, including large scale and small-scale motion (e.g. recognize multiple motions simultaneously including walking (one type of large-scale motion), breath rate, heart beat and gesture of left hand, right hand and legs (some types of small-scale motions)).

5.1.6 Enabling technologies and frequency bands

To enable recognition of both small- and large-scale motions, micro-Doppler features are recommended to be provided by the sensing system, which calls for deep research on channel modeling on micro-Doppler effect. Artificial Intelligence (AI) related technology and functionality has high correlation to the recognition of micro-Doppler pattern, thus research on combination of micro-Doppler and AI can be carried on. Both low frequency bands and high frequency bands are recommended to be used for motion recognition.

Main potential technologies related to comprehensive motion recognition and classification:

- AI based estimation of types of motion and associated parameters.
- Network structure and interaction procedure for recognition and classification both scales of motions simultaneously, and fusion of different kinds of sensing results.
- Channel model including at least micro-Doppler effect.

5.2 Use case on body proximity sensor

5.2.1 Description

Radio Frequency (RF) signal transmission, used in many broadcast and communication applications, is classified as non-ionizing radiation. Unlike ionizing radiation, such as x-rays, non-ionizing radiation does not have enough energy to remove electrons from atoms and molecules, so it does not pose the same immediate health risks. However, intense exposure to non-ionizing radiation can cause tissue damage through heat. Regulatory bodies like the Federal Communications Commission (FCC) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) set guidelines to limit exposure to protect against known thermal effects from electromagnetic fields. Two main metrics quantify RF exposure:

- Specific Absorption Rate (SAR); and
- Power Density (PD).

SAR measures the amount of RF energy absorbed by a unit mass of tissue, typically expressed in watts per kilogram (W/kg). This metric is crucial for sub-6 GHz frequencies, where RF signals can penetrate deeper into the body due to longer wavelengths. Power Density (PD) is used for millimetre-wave (mmWave) or higher frequencies, indicating energy incident on a surface area, usually measured in Watts per square meter (W/m²) or milliwatts per square centimetre (mW/cm²). SAR and PD are measured using phantoms with tissue-simulating materials. SAR is calculated based on the amount of RF power absorbed within a volume of 1 gram or 10 grams of tissue, while PD measures RF power on the phantom's surface. Both the FCC [i.39] and ICNIRP [i.38] have established upper limits for SAR and PD.

PD is generated by an Antenna Panel (AP) placed on one edge of the Device Under Test (DUT). Figure 2 illustrates that a 4 square-centimetre phantom is positioned directly in the path of the radiation beam at a specific distance as mandated by regulatory bodies [i.40]. The AP emits RF radiation onto the phantom, which contains tissue-simulating fluid. The electromagnetic fields generated by the RF radiation are measured using a probe that moves across the measurement area. The point of maximum radiation is identified, and the maximum PD is determined within a 4 square-centimetre patch. This measurement represents the Maximum Permissible Exposure (MPE) for the radiating beam, and it should remain within regulatory limits. Suppose the Effective Isotropic Radiated Power (EIRP) is above a certain threshold. In that case, the PD can exceed regulatory limits, especially when the distance between the phantom and the AP is small. To comply with the regulations, the transmit power might need to be reduced, a process known as Maximum Power Reduction (MPR). The MPR could be significant, particularly at higher duty cycles. However, when the distance between the phantom and the AP is increased, power density tends to stay within allowable limits even at higher EIRP levels. This indicates that there's a critical distance at which no power reduction is needed to maintain compliance.

In summary, to meet RF exposure limits, transmit power might need to be reduced based on the peak EIRP and the duty cycle. However, there is a distance threshold where the Power Density falls within acceptable levels, suggesting that no power reduction is necessary for regulatory compliance. A Body Proximity Sensor (BPS) can identify the human body's location and distance from the antenna panel. Various smartphone hand grip styles along with scenarios where a smartphone is lying on a table, can result in situations where human targets like hands and fingers are not directly in the path of a transmitting beam. To comply with RF exposure regulations, average transmit power can be limited over time. However, when human targets are detected to be near the transmitting beam, selective Maximum Power Reduction (MPR) can be applied to ensure compliance. This is particularly important for antenna panels that emit highly directional beams. Applying MPR only when necessary, allows for more efficient power management. This BPS enables the targeted application of MPR, reducing the need for broad power reduction and allowing for regulatory compliance without sacrificing performance. Many smartphone hand grip styles do not require MPR for RF exposure compliance. If BPS is used to detect human targets, MPR can be applied selectively. This targeted approach to MPR is also beneficial for other high-power devices, like Customer Premises Equipment (CPE) for Fixed Wireless Access (FWA) applications, ensuring they meet regulatory standards while maintaining optimal functionality.

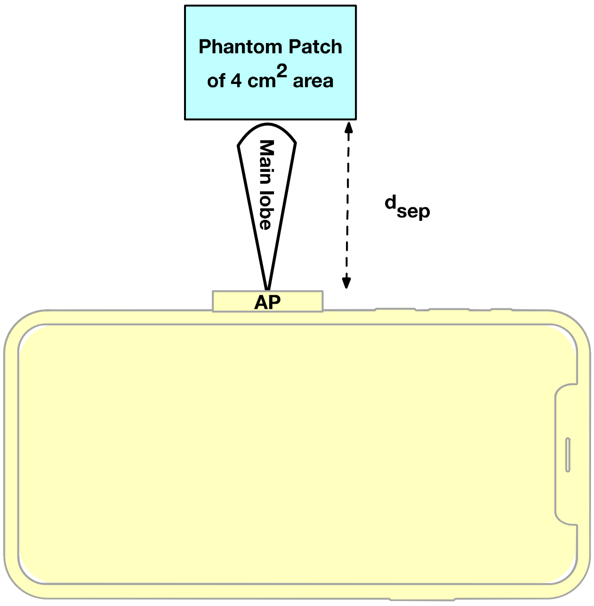


Figure 2: Experimental setup for power density determination of a given beam radiated out of the DUT's antenna panel

5.2.2 Pre-conditions

A wireless transceiver communicates with another wireless transceiver. Each wireless transceiver may be equipped with a Body Proximity Sensor (BPS). The wireless transceiver can detect the distance and the direction of a target, e.g. human body, from an antenna panel through the sensor.

5.2.3 Service Flows

Step 1: The wireless transceiver, comprising a sensing transmitter and a sensing receiver, transmits and receives a sensing signal and tries to detect a human target nearby.

Step 2: The wireless transceiver determines a beam for packet transmission.

Step 3: If the wireless transceiver detects the distance and direction of the human target, the wireless transceiver adjusts a transmission parameter (e.g. power) based on the distance, the direction and the beam.

5.2.4 Post-conditions

If BPS detects human targets, MPR can be applied selectively.

5.2.5 Potential requirements

- [PR 5.2-1] The 6GS should be able to transmit and receive a sensing signal to measure the distance and the direction between a 6G wireless transceiver's antenna panels and a human body.
- [PR 5.2-2] The 6GS should distinguish a human body and a non-human object based on the received sensing signal at the 6G wireless transceiver.
- [PR 5.2-3] The 6GS should be able to adjust the transmission parameter (e.g. power) of the 6G wireless transceiver, based on the sensing results (i.e. the distance and the direction), within the regulatory limits.

5.2.6 Enabling technologies and frequency bands

To enable BPS, sensing signal transmission and reception capability are needed and high-frequency bands (e.g. mmWave) are recommended for BPS operation.

5.3 Use case on airborne-based sensing for environmental reconstruction

5.3.1 Description

Sensing from airborne vehicles based on Unmanned Aerial Vehicle (UAV), Low-Altitude Platform Station (LAPS) and High-Altitude Platform Station (HAPS) has always been associated with navigation systems. The ability of airborne vehicles to sense the environment has motivated rapid development of radar technology aimed for detection of other airborne vehicles, the ground, the weather, and any other factor that might impact the flight conditions.

As airborne vehicles are currently increasingly connected to the (e.g. 3GPP-based) 6GS, it is expected that these vehicles support further sensing applications in 6G. These devices are referred to as on-board User Equipment (UE), to distinguish them from other auxiliar sensors mounted on these vehicles. These on-board UEs have the potential to provide accurate radiofrequency (RF) mapping of the environment.

In this use case illustrated in Figure 3, cellular communications and sensing capabilities are available in airborne vehicles such as UAVs, LAPS and HAPS. UAVs (e.g. drones) typically operate at around 100 m altitude; LAPS can fly at heights up to a few kilometres; and HAPS typically operate at 20 km altitude. The 6GS service area also covers the surroundings of the vehicle flight area both on the ground and in space. Thanks to the new on-board UE sensing capability and the high visibility the airborne vehicles have for the environment, accurate sensing of the environment from the air becomes possible without impacting or requiring other specialized navigation systems.

Airborne vehicles equipped with one or more onboard UEs are able to scan the environment in addition to providing communication services with the 6GS (e.g. to provide real-time video, offload surveillance data, progress data traffic, etc.). The sensing data collected by the onboard UE(s) is sent to the 6GS for further processing and/or exposure to third-party applications. The onboard UE(s) may receive configuration and assistance from the 6GS to perform dedicated sensing tasks, e.g. tracking a given object on the ground, performing RF mapping of part of the environment, etc. The collected sensing data may also be leveraged by the 6GS to better provide communication services, e.g. through precise beamforming and beam management that avoids obstacles, improved Base Station (BS) selection during initial access, seamless handovers, identification and tracking of mobile hotspots (e.g. a bus, a train, etc.), etc.

Given that different airborne vehicles may traverse similar areas during part of their flight, their respective sensing results may exhibit commonalities that can be fused by the 6GS to improve the level of detail of the sensed environment. Airborne-based sensing thus exhibits some of the characteristics of a distributed sensing network whose results can be further combined and exposed for better RF mapping of the environment.

The flying nature of the sensing transmitters brings the added complexity of the potential overlap between the sensing areas seen by the vehicles. It also allows direct sharing of sensing data and/or results between onboard devices (either directly or via the 6GS), in order to further process or combine the results before exposing them to a third-party application that requested the service. A high degree of coordination is therefore expected between devices, and between them and the 6GS, to ensure the consistency of the sensing results.

The high-speed channel conditions experienced by fast-moving onboard UEs may demand 6G ISAC capabilities in at least two respects: sensing latency to minimize channel ageing between consecutive sensing occasions; and Doppler impact which may be especially harmful in bistatic or multistatic sensing scenarios where BSs process the reflected signals after significant obstruction and Non-Line of Sight (NLoS) effects.

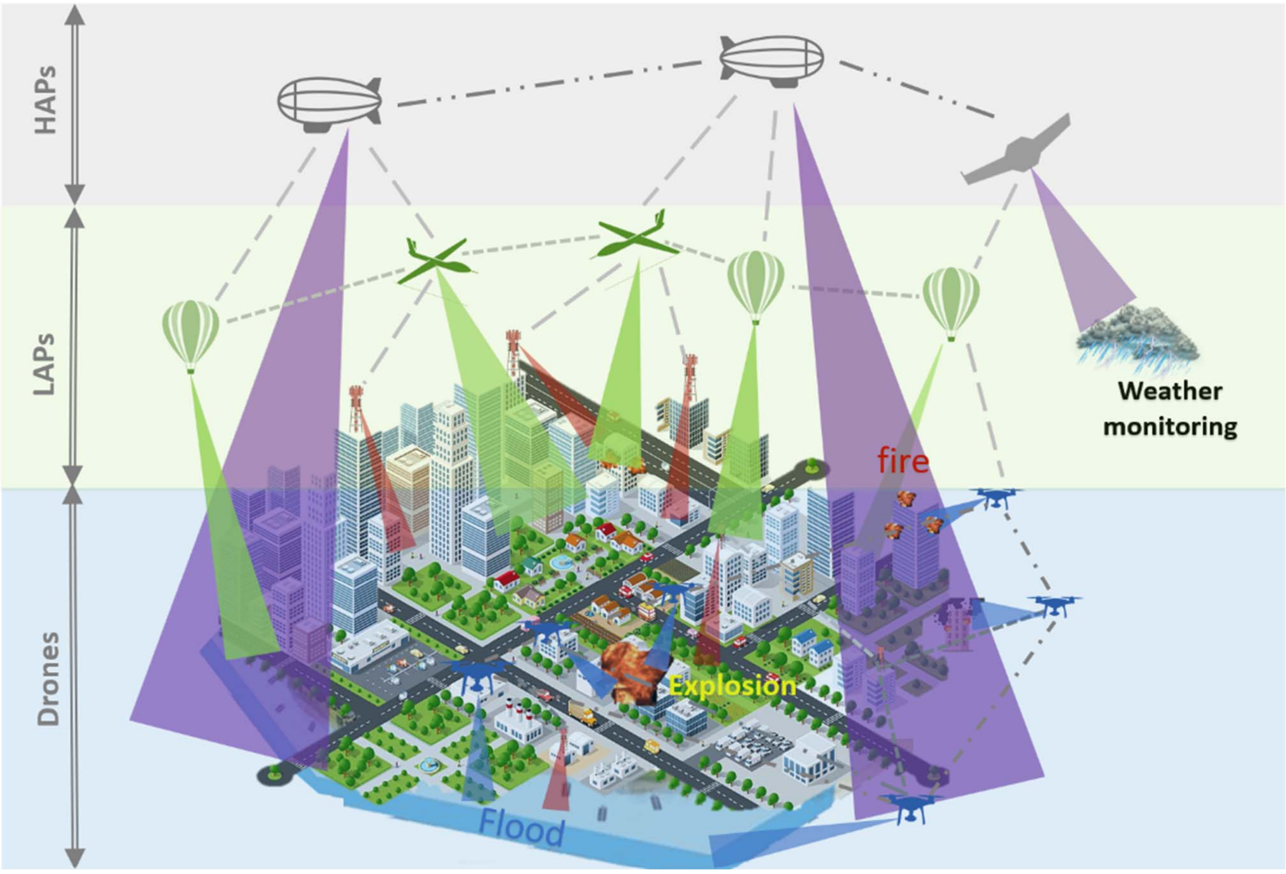


Figure 3: Illustrative scenario in airborne-based sensing for environment reconstruction use case

5.3.2 Pre-conditions

A MNO offers high-speed wireless cellular services to its customers with the help of suitable terrestrial Base Stations (BSs) deployed in a given service area. The services provided include sensing services in addition to communication services, e.g. by exposing the sensing results obtained from wirelessly scanning the radio-frequency environment.

Within the coverage area, one or more airborne vehicles subscribed to the MNO are equipped with onboard UEs which are wirelessly connected to the BSs. The onboard UEs can perform monostatic sensing, bistatic sensing, or both sensing modes depending on the UE capabilities and the type of sensing service requested, and further report to the 6GS the sensing data and/or the (post-processed) sensing results.

A third-party sensing application requests specific sensing tasks to the MNO as part of the offered cellular services. The 6GS, in addition to configuring the onboard UEs to perform sensing tasks, is capable of gathering the sensing data and either fuse them or process them and expose the resulting sensing result to the sensing application.

5.3.3 Service flows

Step 1: A third-party sensing application is registered to the MNO that provides cellular services in a given area. At some point in time, the application requests a sensing task to be performed by airborne vehicles equipped with onboard UEs that are subscribed to perform it and may be flying in the coverage area of the MNO. The number of UEs to be involved in the sensing task may be all or a subset of the onboard UEs of the airborne vehicles that are flying in the coverage area.

Step 2: The onboard UEs perform the sensing task and collect sensing data that are further reported to the 6GS.

Step 3: The 6GS k collects the sensing data from the onboard UEs and either exposes them to the sensing application or fuse them prior to exposing the results.

Step 4: The 6GS leverages the sensing result as an additional input to the communication functions, e.g. to optimize the behaviour of RAN or Core Network (CN) functions that may benefit from them.

5.3.4 Post-conditions

Thanks to the sensing tasks performed by the airborne vehicles, the sensing application receives the sensing results that provide a useful representation of the RF environment surrounding the flight area of the vehicles. These sensing results can be used to reconstruct the environment and provide geo-located information that can be useful, e.g. for emergency services, rescue operations, road traffic control, hazard prevention, etc. In addition, the 6GS can benefit from the insight obtained by incorporating the sensing results as inputs to some of the RAN and CN functions, e.g. for beamforming, initial access, handover control, etc.

5.3.5 Potential requirements

Functional requirements in this use case are:

- [PR 5.3-1] Based on operator policy and sensing configuration, the 6GS can offer sensing services via onboard UEs to third-party applications that are registered in a MNO.
- [PR 5.3-2] The onboard UEs subscribed in a MNO can register as sensing transmitters/receivers for environment reconstruction upon request from the 6GS.
- [PR 5.3-3] The onboard UEs that are registered in a MNO as sensing transmitters/receivers can send sensing data to the 6GS, in addition to communication data, for further processing and/or exposure of the sensing results to third-party applications.
- [PR 5.3-4] The onboard UEs can send sensing data to other onboard UEs for further processing or delivery of sensing data and/or result to the 6GS.
- [PR 5.3-5] The 6GS should be able to collect the sensing data individually reported by the onboard UEs and expose sensing results to a third-party application that requested a sensing service.

- [PR 5.3-6] The 6GS should be able to fuse the individual sensing data prior to exposing the sensing results to a third-party application that requested a sensing service.

Some of the new KPI-related requirements in this use case are given in Table 5. Values were sourced from 3GPP TR 22.837 [i.1] for the use case on public safety search and rescue or apprehend (Pedestrians) with some modifications explained in the notes.

Table 5: Performance requirements of sensing results for airborne-based sensing for environment reconstruction

Scenario	Sensing service area	Confidence level [%]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency	Refreshing rate	Missed detection [%]	False alarm [%]
			Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Airborne-based sensing for environment reconstruction	Outdoor	N/A	0,5 - 1 see note	1,0 see note	1,5 see note	1,5 see note	3	5 m/s	≤ 1 s	≥ 10 Hz	≤ 3	≤ 3

NOTE: Actual values could change depending on the type of airborne vehicle.

5.4 Use case for high-resolution topographical maps

5.4.1 Description

Existing sensing use cases in 3GPP TR 22.837 [i.1] (e.g. 5.4, 5.8, 5.19, 5.26) capture the use of 6GS sensing data for services such as topographical and environmental maps, through the exposure of the sensing results to an application server connected to the 6GS. The application server may fuse this sensing data with other non-6GS sensing data e.g. LiDAR, camera data, and/or with other non-sensing data e.g. localization, synchronization data. This in turn may be used to improve the detail of the application server output by enhancing the sensing accuracy beyond that obtainable from the 6GS sensing data alone.

Enhancements in 6GS sensing will provide for enhanced sensing performance for example in terms of measurement accuracy, measurement latency, measurement confidence level and measurement efficiency through enhanced wave form design, enhanced integration of 6GS access node connectivity and coordinated resource utilization across triggered sensing transmitters.

6GS sensing in the RAN will be provided by sensing transmitters and receivers which may be capable of enhanced sensing operation e.g. with greater resolution, additional configuration options, improved timing coordination, etc.

This use case is distinguished from previous use cases in 3GPP TR 22.837 [i.1] not only by the 6GS sensing using more advanced capabilities and reliable sensing data but also due to enhanced capability sensing transmitters, and due to receivers being able to provide enhanced sensing results with higher QoS and performing to higher KPIs that enable the application server to provide enhanced or higher-resolution topographical and environmental maps.

5.4.2 Pre-conditions

An application server connected to the 6GS is capable of producing high resolution topological and environmental maps from 6GS sensing results and other non-6GS sensing results.

The 6GS supports the application server through the acquisition of sensing data from its connected 6G capable sensing receivers, through the authorization of the application server and the identification of suitable sensing transmitters and receivers capable of supporting the application servers request for high accuracy sensing result. The application server request may include an indication of a required sensing result accuracy e.g. through indicated QoS for requested sensing result, in order to ensure production of high-resolution topological and environmental maps.

5.4.3 Service Flows

An application server used for the production of topographical and environmental maps, activates a service request for 6GS to provide sensing result of an enhanced QoS, in accordance with the required sensing accuracy, to support the production of high-resolution topological or environmental map for a specific area.

The 6GS receives the server request and identifies for a specified area the authorized and authenticated 6GS sensing transmitters and receivers capable of providing 6G sensing data to support the enhanced sensing result with QoS in accordance with the application server service request.

The 6GS configures the identified 6G sensing transmitters and receivers for the enhanced sensing result and the sensing mode e.g. monostatic, bi-static, multi-static, etc. in order to obtain the sensing result in accordance with the requested service enhanced QoS. The 6G sensing data is collected, processed and the sensing result is exposed via the 6GS to the application server, for the production of high-resolution maps for the specific area and target applications and for a time period if specified.

5.4.4 Post-conditions

The application server processes the 6GS sensing data produced from the selected 6GS sensing transmitters and receivers, to produce high resolution topological or environmental map(s).

In one use of the high resolution environmental map, the map is made available or forwarded to vehicles with high levels of autonomous driving capability e.g. L3-L5 autonomy [i.48], where higher levels of map accuracy are required.

Production of high resolution topographical and environmental maps can be used for many other services e.g. civil engineering, for outdoor pursuits, assist emergency services, road traffic control, hazard prevention, etc.

5.4.5 Potential requirements

Existing features partly or fully covering the use case functionality include several aspects. Fusing non-6GS generated HD sensing results with 6GS results, e.g. use case 5.28 from 3GPP TR 22.837 [i.1], may provide some limited ability to produce topological maps. However, the resolution, repeatability and complexity in achieving and maintaining such a solution is unreliable. In particular the proposed enhancement addresses challenges with the reliability and repeatability in configuring, synchronizing and processing both the 6GS sensing results together with non-6GS sensing results from other disparately connected HD sensors of varying sensing types, in order to produce reliable results whilst minimizing impacts on service quality and latency.

New functional requirements for this use case are:

- [PR 5.4-1] The 6GS, based on operator policies, should support and be able to identify and configure sensing transmitters and receivers with enhanced capabilities that may satisfy the service request for a high resolution topological or environmental map.

- [PR 5.4-2] The 6GS sensing task should be able to support the KPIs in Table 6.

Table 6: High resolution topographical maps KPIs

Scenario	Sensing service area	Confidence level [%]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency [ms]	Refreshing rate [s]	Missed detection [%]	False alarm [%]
			Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal / vertical) [m/s x m/s]				
High topology mapping	Outdoor	N/A	0,10	0,10	[-]	[-]	[0,4]	[-]	[50]	[-]	[≤ 10]	[< 1]
NOTE: KPIs in [] brackets adapted from 3GPP TR 22.837 [i.1] use case 5.28.												

5.5 Use case on vision aided smart traffic management

5.5.1 Description

Sensing solely based on Radio Frequency (RF) signals used in Integrated Sensing and Communication (ISAC) systems provides limited information about objects, such as presence, location, and relative speed, particularly when considering long-range applications [i.59]. Cameras have the capability to capture visual information (sensing data) that allows computer vision algorithms to identify objects, classify them, and extract details like size, shape, and colour. However, cameras alone present challenges such as sensitivity to lighting and rough weather such as rain and fog. Combining ISAC with computer vision can leverage both technologies' strengths to provide not only a much richer understanding of the environment and the capability to differentiate between similar objects but also a more robust and reliable solution. Achieving this requires accurate temporal and spatial alignment of distributed sensors to create a cohesive understanding of the environment, as having the same reference is a key factor for reliable and accurate data fusion.

A relevant use case for vision-aided sensing would be a smart traffic management system, as traditionally, these rely on sensors like loop detectors embedded in roads, imposing limitations on capturing real-time traffic density, vehicle types, and the presence of pedestrians. A sensing system can detect and roughly locate vehicles and pedestrians on the road while cameras mounted on traffic lights or poles can provide additional information. Furthermore, computer vision algorithms can analyse the camera streams to identify cars, trucks, motorcycles, and pedestrians providing real-time traffic density data and performing congestion analysis [i.60]. The benefit attained from visual information is twofold as it can be used as a source of ground truth to train machine learning algorithms that perform ISAC and can also be fused with 6G sensing in runtime for more robust detection.

5.5.2 Pre-conditions

- **Existing infrastructure:** a key prerequisite for vision-aided sensing is the deployment of a robust communications network with high bandwidth and low latency to enable real-time transmission of one or more video streams to central processing units. To reduce the bandwidth usage, edge computing devices may be used for real-time video processing and basic analysis locally, hence avoiding the need to send the video streams to the cloud. Either way, a secure and scalable data management system is needed to store and analyse the large amount of data collected from cameras and ISAC.

- **Non-6GS sensors:** ensuring that the system is equipped with at least a single source of sensors, such as cameras, lidars, radars, etc. Diversifying the sources of sensors allows for a higher degree of freedom in the fused sensing data.

- **Computer-vision:** computer vision algorithms trained on large datasets of traffic scenes are required and should be able to identify, classify and track objects to extract relevant information.

- **Data fusion:** the development of data fusion techniques that effectively fuse data from cameras with radio sensing to create a comprehensive picture of traffic conditions. Also, privacy considerations should be taken into account and strategies for anonymizing camera footage need to be implemented.

- **Traffic management unit:** Towards a successful integration with existing traffic control infrastructure, standardization efforts on data formats, communication protocols, and cybersecurity measures are crucial. This is important not only to ensure interoperability between different components of the system, but also to provide safety guarantees that are very important in a critical application such as the one considered here.

5.5.3 Service Flows

Step1: Data Acquisition: A high-resolution camera captures real-time video feeds of the traffic scene.

Step2: Edge Processing: Edge computing devices collect and process the raw video data received from one or more devices using computer vision algorithms.

Step3: Data Transmission: The edge processing unit extracts structured data (object type, count, location, etc.) and transmits them to 6GS using the available 6GS communications capabilities.

Step4: Data Fusion and Analysis: 6GS fuses structured non-6GS sensing data from multiple edge processing units and fuses it with 6GS sensing data extracted from 6G sensing receivers to create a comprehensive view of traffic conditions.

Step5: Traffic Flow Analysis: 6GS analyses the fused sensing data from both non-6G (vision) and 6G RF sources to identify congestion points, vehicle speed patterns, and pedestrian activity.

Step6: Dynamic Traffic Management: Based on the analysis, 6GS exposes the extracted traffic information (sensing result) with a third-party, namely the traffic management system, and the traffic management system dynamically adjusts traffic light timings, displays real-time traffic information on variable message signs, and potentially activates emergency response measures.

5.5.4 Post-conditions

Combining ISAC which is capable of providing a broader picture of the environment with computer vision that offers a more information-rich view, allows a system to leverage both their strengths to enable real-time traffic flow analysis and dynamic adjustments. This translates to more efficient and safer traffic with benefits for the end user including reduced congestion, and improved safety for pedestrians and drivers. In the long term, a solution such as this one can even promote lower levels of pollution in cities due to lower emissions of smooth-flowing traffic.

5.5.5 Potential requirements

Functional requirements in this use case are given below:

- [PR 5.5.5-1] 6GS should allow data collection from non-6G sensing receivers in a structured form to insure interoperability.
- [PR 5.5.5-2] 6GS should provide methods for sensing data collection from different resources and fuse them into fused sensing results for traffic management systems.
- [PR 5.5.5-3] 6GS should provide the necessary infrastructure and capabilities to enable dynamic traffic management by leveraging fused sensing data extracted from multiple sources. A potential subscriber can benefit from this service, e.g. to determine the best route.
- [PR 5.5.5-4] 6GS should provide a reliable, low-latency communication link between edge processing units and centralized processing systems.
- [PR 5.5.5-5] 6GS should allow storing and processing large volumes of heterogeneous sensing data (e.g. 6GS and non-6GS) to enable extracting meaningful traffic information.
- [PR 5.5.5-6] 6GS can receive non-6GS sensing data from trusted third-party sources, that are in full compliance with privacy regulations. Responsibility for obtaining public consent may lie with these third-party providers.
- [PR 5.5.5-7] 6GS should allow procedures for protection against unauthorized access to sensing data and sensing results.
- [PR 5.5.5-8] 6GS should provide high-precision timing and localization support to assist ISAC applications requiring common spatial references across distributed sensors. This capability should aim to reduce the need for frequent recalibration by maintaining spatial alignment with sub-centimetre-level localization accuracy and sub-millisecond timing synchronization, thereby supporting robust vision-aided ISAC operation under changing physical conditions.

Some of the new KPI-related requirements in this use case are given in Table 7.

Table 7: Performance requirements of sensing results for vision-aided smart traffic management

Scenario	Sensing service area	Confidence level [%]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency[s]	Refreshing rate [s]	Missed detection [%]	False alarm [%]
			Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Smart traffic management	outdoor	95	0,5 - 1 note 1	1 - 5 note 3	0,5 note 2	1 notes 2 and 3	0,5 note 2	1 x 1 note 2	< 1	<0,03 note 2	< 5	< 5

NOTE 1: Width of vehicles roughly varies between 1 - 2 m as reference.
NOTE 2: Actual values may change due to the environment being observed, as the dynamics of urban, rural and highway scenes are very different.
NOTE 3: Vertical movement is not critical in traffic scenarios.

5.5.6 Enabling technologies

- **Edge computing device:** The edge computing device allows for an initial processing of vision-based sensing data using a reduced capability processing.
- **Smart traffic management:** This unit uses the fused structured and unstructured sensing data to identify congestion points, vehicle speed patterns, and pedestrian activity.
- **Reconfigurable Intelligent Surfaces (RIS):** RIS allows sensing in obstructed areas, enabling integration with vision-based sensing data even in those blocked regions.
- **Artificial Intelligence (AI):** Utilize AI algorithms for sophisticated sensing data analysis, predicting potential traffic issues and relevant information, such as the estimated congestion duration, based on the real-time fused data.

5.6 Use case on real-time monitoring of health hazard and disaster risk

5.6.1 Description

Disaster prevention, prediction, mitigation, and relief is a major concern for public authorities and first responder services all over the world, to protect and rescue population in case of environmental catastrophes such as flooding, earthquakes, landslide, fire, etc. In some cases, events such as heat waves may put at risk specific population categories. More generally, it can be considered as a disaster any unusual public health event that overwhelms the coping capacity of the affected community [i.4]. Disaster prevention and prediction is the first step allowing to minimize the number of victims. If disaster cannot be anticipated/prevented, first responder teams are often themselves subject to the unfolding disaster. Having an accurate real-time hazard map update in disaster site, and knowledge about the high-priority evacuees is of utmost importance for reducing the intervention times and saving human lives.

The goal of the current use case is threefold:

- Hazard monitoring.
- Disaster area prediction.
- Disaster control.

ISAC may play various roles in the different steps of disaster management. Using massively existing communication infrastructure and terminals sensing capabilities can complement, or limit the need for manufacturing and deploying, dedicated sensing infrastructures and contributes to improve the health and safety of the population.

Concerning health risk prevention, each individual can benefit at a personal level from applications monitoring and predicting a personal risk based on personal vital signs monitoring enabled by ISAC. Variations of temperature, humidity, pressure, can affect differently people depending on their age, physical activity, medical condition or previous personal antecedents. Personalized health hazard monitoring and prediction can be achieved for example by combining accurate weather monitoring/forecast and personal vital data monitoring performed by wireless sensing, offering a real-time complete solution going beyond in-household monitoring (e.g. use case 5.15 on contactless sleep monitoring service, use case 5.17 on health monitoring at home or use case 5.18 on service continuity of unobtrusive health monitoring) described in 3GPP TR 22.837 [i.1], or use cases related to outdoor healthcare monitoring as in clause 5.8. In this type of scenario, specific care should be taken to protect the confidentiality of personal and medical data that cannot be exposed to any third party without specific consent from the individual.

Non-personalized sensing data collection may be performed by using UAV and/or automated driving offroad vehicle. Wireless sensing data, possibly fused with data from other sensing sources allows to predict disaster areas and to build and update in real time the hazard map in an unfolding disaster site.

Anonymized and/or non-personalized sensing data potentially fused with high resolution time/location weather data and ground deviation data is especially helpful in both predicting health hazard or hazard areas and responding to an unfolding disaster situation. As opposed to simple hazard detection as in the use case 5.5 on sensing for flooding in smart cities described in 3GPP TR 22.837 [i.1], this allows to assess the number, location, and degree of emergency for high-priority evacuees and build a real time hazard map, which improves the first responder intervention.

Figure 4 depicts the concept of real-time monitoring and guidance of disaster risk and high-priority evacuees, in an example where personalized data can be collected. Figure 5 depicts an example of non-personal data collection in a specific example where the terrestrial network is unavailable due to unfolding disaster, and sensing data collection from external sensors relies on mobile direct 6G NTN communication. In the generic case sensing can equally be performed by the 6GS and fused with data from other sensing sources.

Deployment scenarios relative to this use case correspond to mixed indoor/outdoor settings, typically with limited pedestrian mobility.

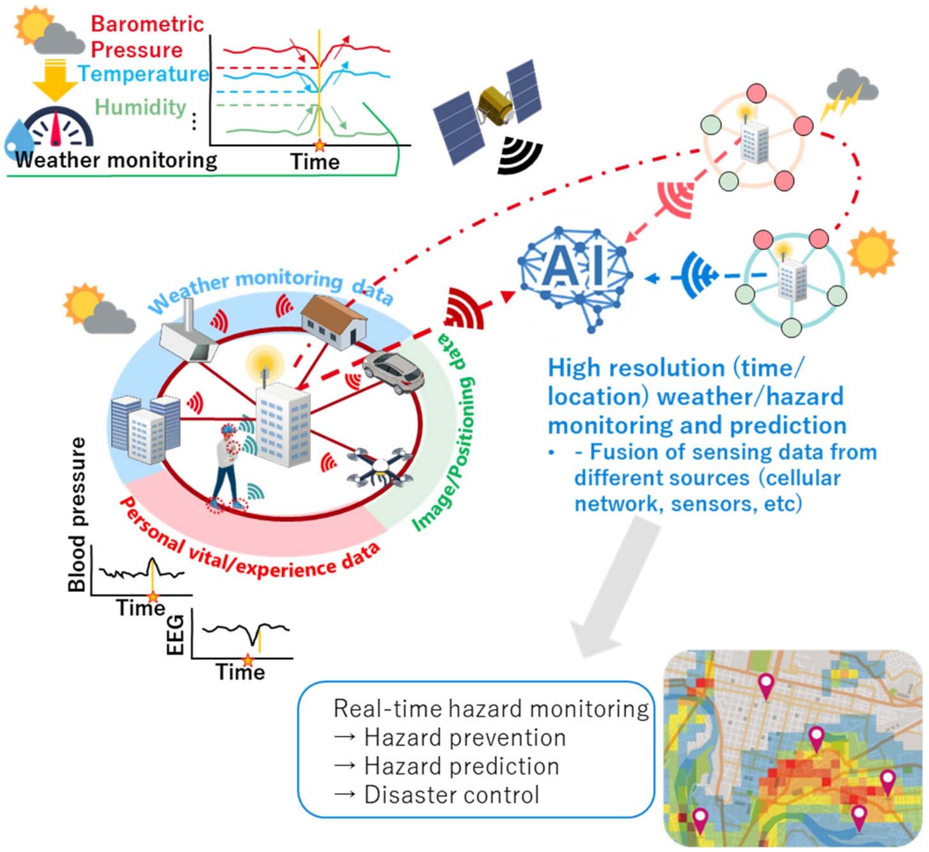


Figure 4: Real-time monitoring and guidance of disaster risk and high-priority evacuees

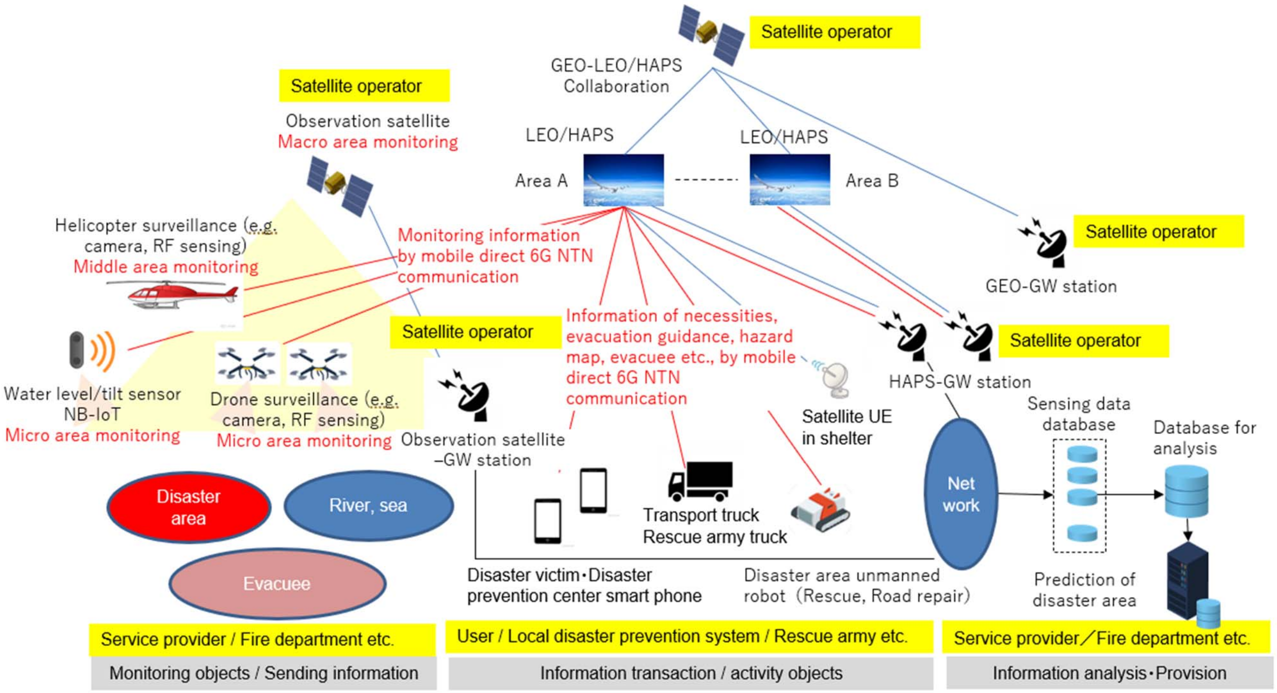


Figure 5: Example of sensing data collection in the case of disaster relief relying on 6G NTN

5.6.2 Pre-conditions

There is a service agreement between one or several MNO(s) and the health and safety service provider. A MNO can also be health and safety service provider, although this is not mandatory.

5.6.3 Service Flows

Step 1: Sensing data is collected and processed by a sensing function that can be deployed in the 6GS or provided by an external application or a combination thereof. The exact separation of functionalities between those entities is not further explored in the framework of this use case. Fusion of sensing data from different sources is possible.

Step 2: Sensing data that is collected in a sensing database for further processing and/or fusion with data from multiple sensing sources (e.g. high-resolution weather forecast, imaging, positioning, etc.).

Step 3: The health and safety service provider uses the sensing database to monitor health and hazard risks, and build a real time hazard map and predicted disaster area It may request the MNO to adapt the frequency of RF sensing when the MNO is performing RF sensing, and/or to ensure appropriate QoS for conveying sensing data from external sources, depending on the identified/predicted hazard risk (e.g. NB-IoT, camera surveillance, UAV, offroad vehicles, etc.).

Step 4: When a health or safety hazard is determined, appropriate measures are triggered (e.g. inform population, emergency or first responder services, evacuate an area, etc.).

Furthermore, individuals may choose to use their personal medical data for advanced personalized health hazard monitoring for being informed when they are at risk (e.g. demanding physical exercise for a person with heart condition under high humidity and dropping pressure conditions).

5.6.4 Post-conditions

Based on accurate sensing data, public health hazard can be predicted or is determined to be unfolding. The health and safety service provider provides alerts, real-time hazard maps, predicted disaster areas and high-priority evacuee information to first responder and public safety services. It may further receive accurate personal sensing data about individuals having subscribed a personalized service and can generate alerts if an adverse event happens to them.

5.6.5 Potential requirements

To support this use case, the 6G system is potentially required to:

- [PR 5.6-1] Coordinate wireless sensing among a set of RAN entities and UEs, and potentially fuse 6GS and non-6GS sensing data.
- [PR 5.6-2] Support a mechanism for 6G entities to take part in the wireless sensing, whereby the authorization and the sensing accuracy target may be provided based on location and/or request from a third-party (e.g. unfolding disaster, high disaster risk).
- [PR 5.6-3] Support a mechanism for 6G to derive and expose sensing results to a trusted third-party, whereby the amount of exposed data may depend on the sensing area and/or request from a third-party (e.g. increased amount of sensing data in areas identified by the 6GS or by a third party as having and unfolding disaster or a high disaster risk).

5.6.6 Enabling technologies and frequency bands

This use case may highly benefit from enabling technologies such as AI/ML (machine learning) and data fusion.

5.7 Use case on emergency search and rescue

5.7.1 Description

Environmental catastrophes such as earthquakes, floods and avalanches are a major fear of many people around the globe. Such tragedies are a serious threat to the life of affected people that require quick and proactive rescue operations. Yet, these rescue teams are often affected by the tragedy as well and their help is needed in numerous cases such that they can not address all of them in a timely fashion. This is a major problem since fast response is critical and the probability of survival is reduced with every minute a victim is buried by snow or rubble.

Radar-based sensing is an established method to localize people buried under rubble or snow by exploiting variations in the signal reflections caused by micro-movements due to heartbeat and breathing. ISAC offers the possibility to include such functionality into mobile devices, allowing quick identification and localization of victims to increase their chances of survival.

5.7.2 Pre-conditions

- User A and User B have UEs that are subscribed to a network operator with a subscription that includes sensing services.
- There is a sensing pre-configuration that allows UEs to perform sensing if they are out of coverage, e.g. due to failure of the cellular system during an emergency.

5.7.3 Service Flows

Due to a catastrophe, e.g. an earthquake or an avalanche, User B was buried under rubble, snow, or something similar. User A who was lucky not to be affected by the catastrophe knows about the situation of User B and wants to help locate User B as quickly as possible as time is critical. User A immediately calls for help and wants to utilize the 6G sensing services to locate User B while waiting for the rescue team.

He follows the procedure below:

Step 1: User A opens an application that can request a sensing service.

Step 2: The application evaluates the available sensing services, offered by the UE, other 6GS nodes and other potential non-6GS sensors and sensing services based on technologies such as Wi-Fi®, BLE and UWB.

Step 3: Based on coverage, User A's UE requests configurations for monostatic sensing. In case the network is down due to the catastrophe or User A's UE is out of coverage; it falls back to a pre-configuration that was potentially received before or that is specific for emergencies.

Step 4: User A's UE activates sensing and User A follows the instructions provided by the sensing application to obtain accurate and reliable sensing results.

Step 5: User A's UE may further utilize the non-6GS sensing services and/or positioning services to obtain a holistic view of the situation.

Step 6: User A's UE gathers sensing data and/or sensing results using these services and fuses them.

Step 7: Using such services, User A is able to determine whether User B is still alive and to locate User B.

5.7.4 Post-conditions

With the help of the 6G ISAC, User A was able to localize User B such that the rescue team was able to rescue User B quickly. He was brought to a hospital and survived the incident without permanent damages.

5.7.5 Potential requirements

- [PR 5.7-11] The 6GS should enable monostatic sensing and bistatic sensing at the UE.
- [PR 5.7-2] The 6GS should allow local processing of sensing data and usage of the sensing results at the UE.
- [PR 5.7-3] The 6GS should enable collection and fusion of sensing data of 6GS and non-6GS sensors at the UE.
- [PR 5.7-4] The 6GS should enable monostatic sensing and bistatic sensing at the UE in case the UE is not connected to a network/ out of coverage.
- [PR 5.75] The 6GS should enable sensing services at the UE with KPIs that allow to detect humans and their motions through rubble, snow, or other material with a distance resolution of 0,5 m for distances up to 20 m, and their motions with a velocity resolution of 0,1 m/s.

5.7.6 Enabling technologies and frequency bands

To perform sensing through rubble, snow or other material, distinctive characteristics are required. These include that a device located close to the incident is able to control, perform, and evaluate monostatic/bi-static sensing. The carrier frequency may need to be as low as possible to be able to penetrate through snow and rubble.

5.8 Use case for outdoor healthcare sensing and monitoring

5.8.1 Description

ISAC has emerged as a critical enabler in the advancement of 6G use cases, offering the ability to sense and monitor targets without physical contact. Radio Frequency (RF) sensing is known for its omnipresence, non-intrusive nature, and commitment to privacy. Its application in human sensing using wireless signals is drawing considerable attention in healthcare monitoring section. ISAC can help healthcare monitoring by leveraging real-time sensing data, enabling a more responsive and precise healthcare control. By capturing and analysing environmental variations, a more comprehensive picture of health determinants can be drawn leading to improved patient outcomes and a new frontier in medical care. The contribution aims to redefine healthcare sensing by transitioning from predominantly indoor environment given in the 3GPP TR 22.837 [i.1] and 3GPP TS 22.137 [i.2] to a comprehensive outdoor framework. Outdoor environments introduce unique challenges and opportunities that differ significantly from indoor settings, such as variable weather conditions, mobility patterns, and broader spatial coverage. This shift not only expands the scope of monitoring but also introduces new services and dynamics in how healthcare data is captured and utilized, offering more natural, unobtrusive, and real-time health management solutions. In the ETSI ISAC ISG, several use cases such as the use case on human motion recognition in clause 5.1 or the use case on real-time monitoring of health hazard and disaster risks in clause 5.6 address outdoor sensing challenges with main focus on human sensing that may complement the challenges and requirements of this use case.

ISAC can offer seamless, dual-purpose sensing and communication capabilities for health monitoring. The appeal of ISAC usage scenario lies in their widespread, non-contact nature and their support for privacy. Consequently, the application of wireless signal-based human sensing has received significant attention within the research community [i.35].

Imagine walking through a city, where advanced 6G base stations continuously monitor your health. These stations detect subtle physiological changes like heart rate and breathing patterns by analysing disruptions in 6G signals caused by bodily movements. If an anomaly such as a sudden fall or a potential medical issue is detected, the system instantly processes this data to assess the situation and, if necessary, alerts emergency services with your exact location and condition. This seamless and contactless monitoring offers enhanced safety and peace of mind, ensuring quick responses to health emergencies directly from your urban environment.

Beyond individual emergencies, this technology significantly benefits various population groups. For instance, elderly individuals who often face risks such as falls can feel safer knowing they are monitored continuously. Parents of children with conditions like asthma appreciate the reassurance that any sudden onset of symptoms is immediately noticed and addressed, even when the child is playing outside. Similarly, athletes training in open environments benefit as the system can monitor physiological stress and fatigue levels, providing alerts before conditions like heatstroke develop. Tourists unfamiliar with local medical services find comfort in the knowledge that in any health emergency, local healthcare providers are promptly informed and guided to their exact location.

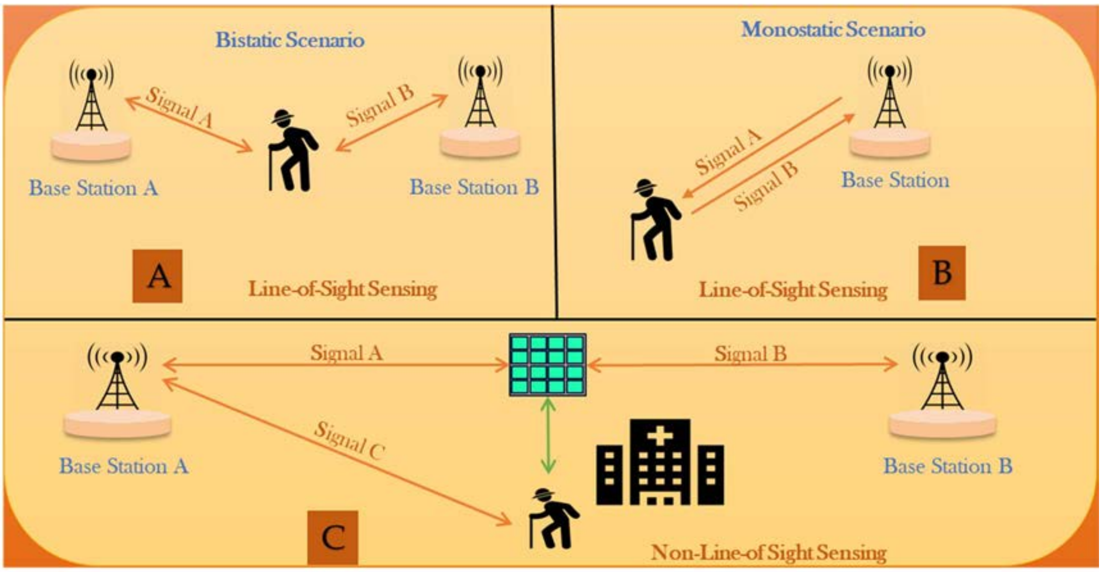


Figure 6: Illustration of an outdoor ISAC based health monitoring scenario

Figure 6 illustrates various outdoor sensing scenarios utilizing base stations designed to monitor vital signs. In Scenario A, two base stations cooperate to perform Line of Sight sensing, extracting vital health data directly when the individual is visible to both stations. Scenario B demonstrates a monostatic sensing setup, where a single base station independently handles the sensing task. Conversely, Scenario C showcases a non-Line of Sight approach, where Reconfigurable Intelligent Surfaces (RIS) are employed to assist in capturing vital signs when direct visibility is obstructed.

5.8.2 Pre-conditions

- **Existing Infrastructure:** The deployment capitalizes on the widespread existing network of a mobile network operator stations across urban and suburban locales. The 6G base stations are already configured with the requisite capabilities in a given service area to support sensing and communication services.

- **Regulatory Compliance and Data Privacy:** The 6G system operates within stringent data protection frameworks to ensure that all personal and health-related sensing data captured through 6G sensing signals are processed and stored in compliance with global privacy standards. This compliance is crucial to maintaining public trust and legal integrity of the monitoring services.

- **Technological Compatibility:** Ensuring that the existing 6G base stations are equipped with advanced sensing and data analytics capabilities necessary for detailed health monitoring tasks. This includes software upgrades to enable sophisticated sensing data processing like pattern recognition, anomaly detection, and health event prediction.
- **Collaboration with Healthcare Providers:** Established partnerships with local healthcare providers and emergency services to ensure that data and alerts generated by the monitoring system are effectively used to provide timely medical interventions. This collaboration ensures that the 6G system not only monitors but also acts by integrating seamlessly with existing health response frameworks.

5.8.3 Service Flows

Step 1: A third-party sensing application is registered with the MNO that offers cellular services in a specific region. At a certain point, the application initiates a sensing task to begin an **outdoor monitoring** service for a designated User Equipment (UE) or a sensing service area, such as sports and/or health monitoring. This service is intended for subscribers who have opted for outdoor monitoring for a group of UEs.

Step 2: The sensing receiver performs the sensing task by accurately measuring critical health metrics such as heart rate, respiration rate, and unusual movement patterns, including pace and gait frequently over a specified period. It then reports the sensing data to the network in a periodic, event basis, etc.

Step 3: The 6GS gathers the sensing data, conducts preliminary processing, and performs real-time analysis to identify potential health risks such as falls or sudden immobility. These risks are then communicated to the sensing application, which may take significant measures and provide advice to mitigate the risks (e.g. stop running, lay down, hydrate, etc.).

Step 4: If an emergency is detected, the 6GS shares the sensing results with a third party for further evaluation and promptly notifies emergency services, providing the UE's location and personal profile, which may include personal health conditions, blood type, etc., that already agreed to be shared upon registration. Additionally, the 6GS informs the sensing application of the estimated response time and the next steps.

Step 5: The 6GS continues to provide updates on the aforementioned steps until the emergency system issues a termination request, indicating that the case has been addressed.

Step 6: The 6GS shares the report associated with the application profile to a health monitoring entity to register the case in the log file for the record and future usage.

5.8.4 Post-conditions

- **Health Monitoring Enhancement:** The implementation of this system will significantly enhance health monitoring capabilities in urban environments. This improvement will bolster public health responses and increase individual safety, enabling a variety of health monitoring services.
- **Data-Driven Urban Health Management:** Continuous sensing data collection provides valuable insights for public health management and policymaking. Furthermore, it will facilitate real-time data collection and analysis, leading to more informed decision-making.

5.8.5 Potential requirements

Functional requirements in this use case are given below.

- [PR 5.8-1] The 6GS supports advanced signal processing algorithms to differentiate between noise and critical health signals due to the dynamic nature of outdoor settings and accurately interpret signals affected by physiological changes like heart and respiration rates in complex outdoor environments.
- [PR 5.8-2] The 6G base stations are able to dynamically adjust sensing ranges and resolution based on crowd density and individual mobility.
- [PR 5.8-3] The 6GS has well-established and clear protocols for user consent and continuous engagement regarding sensing data collection and usage.

- [PR 5.8-4] The 6GS supports protocols for the exposure of sensing results to the third parties within the healthcare sector enabling integration with existing healthcare systems and electronic health records.
- Some of the new KPI-related requirements in this use case are given in Table 8. Values were sourced from [i.36], [i.37] for the use case with some modifications explained in the notes.

Table 8: Performance requirements of sensing results for healthcare sensing monitoring

Scenario	Sensing service area	Confidence level [%]	Human motion rate accuracy [Hz]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing resolution		Max sensing service latency[ms]	Refreshing rate [s]	Missed detection [%]	False alarm [%]
				Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range resolution [m]	Velocity resolution (horizontal/ vertical) [m/s x m/s]				
Healthcare monitoring	outdoor	95	0,05 Notes 1 and 2	0,5 - 1 Note 3	0,5 - 1 Note 3	1,5 Note 3	1,5 Note 3	< 0,5 Note 3	2 - 3 Note 3	< 2 000	< 1 Notes 3 and 4	< 10 note 3	< 2

NOTE 1: Sit-up rate = 30 times/min as reference, 0,05 Hz corresponds to 3 times/min.
NOTE 2: Push-up rate = 40 times/min as reference, 1/15 Hz corresponds to 4 times/min.
NOTE 3: Actual values could change due to outdoor activities like walking, running, cycling.
NOTE 4: Actual values could change due to sensing tasks, e.g. macro activity or micro activity sensing.

5.8.6 Enabling Technologies

- Edge computing.
- Data Collection: The 6GS collects health and movement data, which is transmitted to local edge computing devices for initial processing.
- Data Analysis entity: Edge devices perform real-time analysis to detect anomalies or health risks, utilizing AI algorithms trained for diverse outdoor scenarios.
- Reconfigurable Intelligent Surfaces (RIS): RIS enables the reach and reliability of signals across complex urban topographies specifically in the non-line-of sight.
- Network-Controlled Repeaters (NCRs): Improve signal strength and quality, ensuring uninterrupted service even in densely built areas.
- Artificial Intelligence (AI): Utilize AI algorithms for sophisticated data analysis, predicting potential health issues based on real-time data.

5.9 Use case on remotely controlled robots for senior citizen monitoring and care

5.9.1 Description

Many countries in the world are facing the challenges of severely increasing population ageing. Senior citizens are more and more often living far away from close family members and are facing health issues and social isolation. Elderly care robots have been envisioned for senior citizens still autonomous but in need of companionship and/or medical monitoring and support. The psychological human perception of the human-robot interaction and the control and safety of such interactions are major challenges in the success of the robot elderly care scenario.

Figure 7 depicts the concept of remotely controlled robots for senior citizen monitoring and care. An elderly care remotely controlled robot is present in the household of the senior citizen and acts as an avatar of a remotely located family member. The robot is capable of acquiring information beyond ability of human senses and provides information of the health state of the senior citizen. The robot is equally capable of reproducing human sensory and behavioural characteristics such as posture, poise, facial expressions, thus providing a familiar and comforting presence during the interaction with the senior citizen. The family members and the senior citizen can interact through the bias of the avatar robot that can faithfully convey the personality, mood, and emotions of the family members. Given the personal nature of the sensing data, collection, transfer and processing of associated sensing should be done with appropriate user consent and adherence to regional and national regulations.

Tight synchronization between remote and at local scene is required for both sensing and movements to ensure safe interaction.

Deployment scenarios relative to this use case correspond to indoor (in-household) settings, with limited pedestrian mobility.

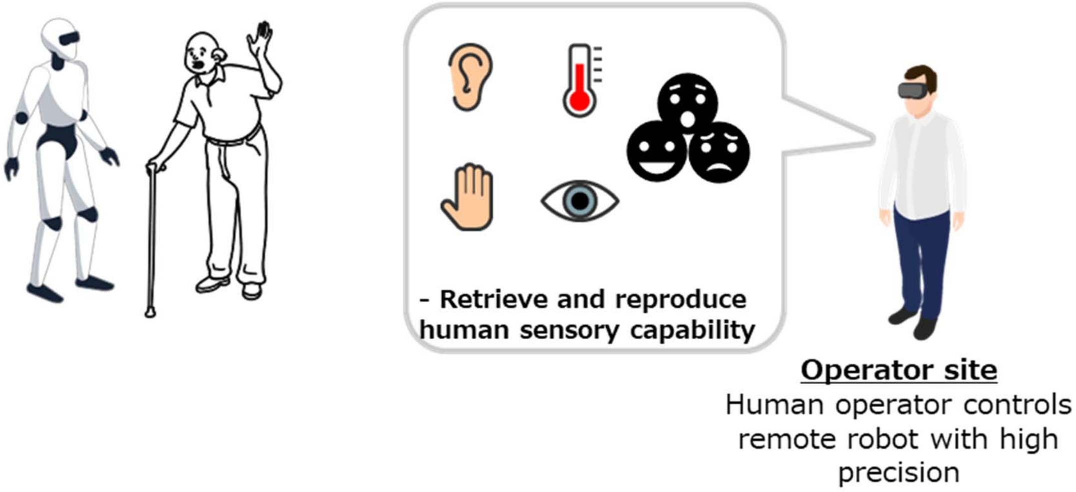


Figure 7: Remotely controlled robots for senior citizen monitoring and care

5.9.2 Pre-conditions

Avatar robots are equipped with sensing and communication capabilities and are also able of reproducing human sensory and behavioural characteristics collected on the human operator (remote family member) side. Both the remote family member and the senior citizen sites are under the coverage of a network providing throughput and latency compatible with remotely controlled human-robot interaction.

5.9.3 Service Flows

Step 1: At the senior citizen premises, the remotely controlled avatar robot collects sensing data beyond human capability.

Step 2: At the operator site, the remote family member is equipped with both sensing and sensing reproduction devices. The human operator controls the remote robot via closed-loop feedback.

Step 3: At the senior citizen premises, the remotely controlled avatar robot reproduces sensory information collected at the operator (remote family member) site.

Step 4: Sensing data is transferred via a network that guarantees very high throughput, very low latency, and bounded delay.

Step 5: Sensing data is processed. Time synchronization is preserved among streams corresponding to different sensors, and among sensing data from different sources. Time synchronization is equally ensured for sensing collection/reproduction between the operator and the remote sites.

Step 6: Protection of personal data is equally ensured during collection, transfer and processing.

5.9.4 Post-conditions

Avatar robots remotely controlled by family members provide companionship, health monitoring and care for isolated senior citizens. The mental and physical condition of elderly isolated people can be monitored and improved.

5.9.5 Potential requirements

To support this use case, the 6G system is potentially required to support latency/jitter/throughput/sensing synchronization between local and remote site, with values compatible with human/robot remotely controlled interaction. Although with 5G/5G-Advanced applications such as XR also have requirements related to simultaneous needs in terms of high throughput and low latency and tactile/audio/video streams alignment, XR services typically require the radio access network to guarantee tens of Mbps with a latency in the order of 10 ms measured at transport/application layer and less than 20 ms delay between the motion and the video stream to avoid motion-sickness [i.24]. These requirements are insufficient for the needs of the current use case.

For personalized healthcare robots emulating human behaviours, the need for synchronized multi-modal communication and control is recognized as a differentiating element with respect to 5G [i.17]. Identified 6G key drivers include bi-directional haptic teleoperation [i.17], [i.21], [i.22], synchronized multi-modal information [i.17], [i.22] and new human-machine interfaces [i.18], [i.19], [i.20]. The associated requirements in terms of bitrate, latency, reliability, security may highly vary, but single-digit ms values for the end-to-end latency are often cited [i.20], [i.21], [i.22]. The nominal communication delay of 1 ms for tactile and multimodal remote operation is reported in [i.22] to be translated to a physical-layer delay of less than 0,1 ms. Not only extremely high data rates but also tight synchronization between the different streams of multi-modal information, and between the information at remote/local sites are also needed.

Appropriate user awareness, user consent and adherence to regional and national regulations need to be ensured for the sensing data.

Therefore, the following potential requirements are considered:

- [PR 5.9-1] 6GS should ensure tight synchronization between the different streams of multi-modal data and the sensing data, and between the information at remote/local sites.
- [PR 5.9-2] Appropriate user awareness, user consent and adherence to regional and national regulations need to be ensured for the sensing data.

5.10 Use case on collaborative robots based on digital twinning

5.10.1 Description

Over recent years, Digital Twinning became significantly more important in complex scenarios where a digital representation of the physical world, in combination with processes to be automated in that physical world, allows to organize the sheer amount of data. Such capabilities eventually enable closed-loop automations where the Digital Twin (DT) takes full control of the actions in the physical world without human interactions. The present use case focuses on such scenario where robots and assembly lines collaboratively aim to solve a joint task, e.g. finding and transporting an object/person to a different location, investigate an area of interest or delivery of goods, which is conducted in an autonomous and closed-loop manner [i.32]. While existing autonomous robots have a range of built-in sensors, e.g. video, light detection and ranging (LIDAR), radar, it is assumed in this use case that sensing based on signals from the 6GS is mainly used to expose sensing results to the DT for precise mapping of the environment to coordinate movements and actions of all robots on the ground. It is assumed that all robots act as a traditional User Equipment (UE) and that they can reach the DT over the mobile network.

Figure 8 illustrates the envisaged scenario where a DT controls three robots on the ground, UE_1, UE_2 and UE_3, by receiving sensing data from their built-in sensors as well as the sensing results from the 6GS. The 6GS obtains the sensing results by performing a range of sensing tasks using monostatic, bi-static and multi-static capabilities among the 6G UEs and Base Stations (BSs) deployed. The goal is for the two robots (UE_1 and UE_2) to lift up a large steel bar from the ground and allow the third robot (UE_3) to drill a hole in the wall through existing carved out holes in the steel bar. Upon completion, UE_1 pushes bolts into the hole and tightens the bar with nuts. All the described actions are fully coordinated by a DT with the robots only executing action commands sent by the DT.

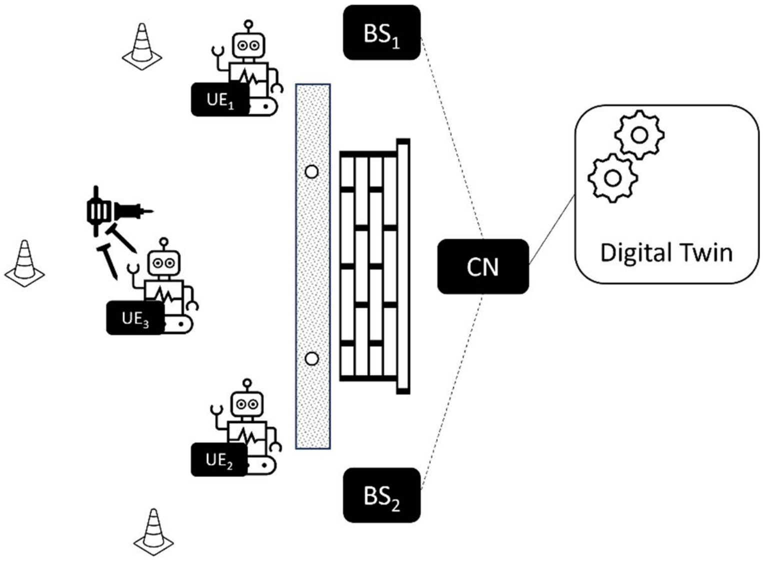


Figure 8: Illustration of Collaborative Robots Based on Digital Twinning Use Case

In modern flexible factories, the assembly line frequently changes to accommodate the production of various products (e.g. different car parts, different car models) [i.33] and [i.34]. Therefore, it is crucial for the Digital Twin (DT) to be aware of these changes. While mobile system-based sensing can help acquire this information, the sensing required for robot control differs from that needed to detect changes in the assembly lines. The former may necessitate *precision sensing* capable of pinpointing the location of robots and the objects they handle, whereas the latter may require *holistic sensing* capable of detecting large-scale changes in the assembly line and the factory floor. Interactions and synchronization between these two processes, each with distinct KPIs, are crucial for achieving a flexible factory. For instance, depending on the sensing results of the *holistic sensing*, the DT may need to update the parameters of the *precision sensing*.

5.10.2 Pre-conditions

The DT can communicate with the 6GS and has been granted access to the exposure service for sensing results from the 6GS.

Furthermore, the following pre-conditions exist:

- Each robot is equipped with a wireless communication device (acting as a UE) and has the appropriate identification to attach to the network.
- Both 6G BSs are connected to the 6G Core Network (CN).
- All 6G UEs have successfully registered against the network.
- UE_1 and UE_3 are attached via BS_1 and UE_2 via BS_2.
- 6G UEs and BSs provide sensing capabilities and can operate in monostatic, bi-static or multi-static sensing modes in all UE/BS combinations.
- Any non-public information in this use case is removed before sensing results are exposed to the DT.

5.10.3 Service flows

The DT requires a range of sensing results to control the collaborative task accurately. This includes:

a) the information about the environment where the robots will perform their collaborative task;

b) location and orientation of the robots within the environment; and

c) the location and orientation of the target object, i.e. the steel bar.

To achieve this, it is foreseen that the DT requests separate sensing services from the 6GS for a), b) and c). Each sensing service request goes to the 6GS where the sensing tasks (identified by the UEs and BSs involved in it, their sensing processes, sensing mode as well as KPI requirements) are coordinated and executed. It is foreseen that the sensing data from UEs/BSs is processed in the CN to produce the sensing results expected by the DT. This includes the identification of objects, their categorization as well as any high-layer abstraction of sensing data, e.g. 6 Degrees of Freedom (position and orientation).

5.10.4 Post-conditions

Based on the sensing results exposed from the 6GS the DT was successfully able to coordinate the robots to lift up the steel bar, drill the holes in the wall and mount the steel bar securely against the wall.

5.10.5 Potential requirements

Potential requirements needed to support the use case are described hereinafter.

Functional requirements in this use case are:

- [PR 5.10-1] Coordination of sensing tasks between multiple BSs and UEs, supporting all sensing modes (monostatic, bi-static, multi-static).
- [PR 5.10-2] Ability to switch between sensing modes and BSs and UEs involved based radio and environmental conditions throughout the execution of a sensing task requested by the DT.

Additionally, there are new KPI-related requirements that can be derived from the use case presented above. Clause 7.2 in 3GPP TR 22.837 [i.1] as well as the technical specification on sensing 3GPP TS 22.137 [i.2], clause 6.2 consolidates all use cases and their KPIs into a single table by creating sensing service categorizing to cluster use cases. The relevant categories related the use case described above is Sensing Service Category 4 "Factory and public safety, indoor/outdoor" [i.1] with the following KPIs:

- Confidence level: 95 %.
- Accuracy of positioning estimate by sensing of 0,5 m (horizontal/vertical).
- Accuracy of velocity estimate by sensing between 0,1 (other), 15 m/s (vehicle) and 1,5 m/s (pedestrian) depending on the potential speed of the sensed object.
- Sensing resolution: 0,5 m (range), 0,5 m/s (horizontal/vertical velocity).
- Maximum sensing service latency between 100 and ~5 000 ms.
- Refreshing rate: 0,1 s.
- Missed detection: 1 %.
- False alarm: 3 %.

3GPP TS 22.137 [i.2] covers the related use cases as "Object detection and tracking", Sensing Service Category 4 with identical similar KPIs compared to the feasibility study [i.2]:

- Confidence level: 95 %.
- Accuracy of positioning by sensing: 0,5 m (horizontal/vertical).
- Accuracy of velocity by sensing: 1,5 m (pedestrian), 15 m (vehicle), 0,1 m (other).
- Sensing resolution: 0,5 m (range), 0,5 m/s (horizontal/vertical velocity) for factories.
- Maximum sensing latency: 100 - 5 000 ms.
- Refreshing rate: 0,1 s.
- Missed detection: 1 %.

- False alarm: 3 %.

Based on the use case above where sensing results are required to identify an existing hole in the steel bar in order to drill a hole and then pushing a bolt into it, more stringent KPIs can be derived, clearly differentiating the collaborative robots based on DT from any already studied use cases in [i.1]. For this precision sensing approach the following KPIs are envisioned:

- [PR 5.10-3] Sensing accuracy KPIs for collaborative robots:
  - Linear motion path accuracy as x-y-z positioning:
    - Accuracy: ≤ 1 cm.
    - Level of confidence: 95 %. Derived from [i.3], section 5.1.2.3, for V2X scenarios.
    - As no existing work can be identified that provides experimental- or simulation-driven data to support the sensing KPIs, the studies are required to provide precise numbers.
  - Orientation accuracy along the x-y-z coordinates:
    - Accuracy: This should be studied in field trials and depends on the collaborative task the robots are supposed to complete.
    - Level of confidence: This should be studied in field trials and depends on the collaborative task the robots are supposed to complete.
  - Latency to generate sensing results from when something was actually sensed:
    - As the sensing results are consumed by the DT to control the robots' actions (i.e. a machine instead of a human), the maximum acceptable latency is based on the ability of the DT to compensate for any delay in receiving the sensing results. For this to work, the 6GS should have means to measure the time it takes to produce a sensing result and provide it alongside the result itself towards the DT.
- [PR 5.10-4] Allow a 6GS to link multiple Sensing Tasks to each other in order to synchronize the Sensing Results exposed towards the DT. These Sensing Results represent different sensing processes (e.g. holistic sensing process, precision sensing process), each with distinct KPIs.
- [PR 5.10-5] Allow a 6GS to offer the ability to change KPIs of an on-going Sensing Task to vertical applications (e.g. the DT in this use case).

5.11 Use Case on precise localization for robot grasping

5.11.1 Description

Precise localization of robot grasping is to enable successful determination of grasping points of a target object, which is essential information for execution of grasping by robot arms and further engagements, based on a combination of sensing operations over target objects and surrounding environment, and effective information exchange between robots and base stations.

For example, robots, which are cooperatively relocating a heavy rubble (as a target object) from a construction site, need to exchange sensing data among themselves and base stations, in order to retrieve information of that rubble including material/localization/shape/orientation, and then accurately select/approach grasping points of the rubble for robot grasping.

For elaboration, required sensing operations for supporting pre-grasp may have two generic phases:

- Macro sensing phase: to detect the precise location of a target object, as well as to detect size, shape, weight, centre of gravity and material characterization, etc. of the target object, by using 6G sensing with applicable mono-static/bi-static/multi-static sensing operations.

NOTE Material characterization, including concrete, brick, plaster boar wood, metal, and etc, can be identified by unique frequency responses across multiple frequency bands [i.9], [i.10], [i.11].

- Micro sensing phase: to select potential grasping points considering material characterization, relative localization/motions, relative orientation, etc. of micro-targets of the target object, by combining 6G and non-6G sensing (e.g. by RGB-depth camera) data.

5.11.2 Pre-conditions

- Two or more Cooperative Robots (noted CRs in Figure 9) are cooperating to clear a rubble blocking an entry/path in a construction site. During two phases of pre-grasp, it is assumed with a slow relative mobility between robot arms, body or head and the rubble to position themselves, until all robots can grasp it together successfully.
- At least one nearby base station in the area has ISAC capabilities.
- Each robot has an embedded UE with diverse ISAC capability specifically operated from robot arms, body or head and registered to the 6G System (6GS).
- The functionality of material characterization can be provided via a 3rd party (e.g. one of the robots or an external application) or provided as a 6GS service.
- 6G and non-6G sensing fusion is supported by 6GS and sensing results can be fed back to robots by data communication.

5.11.3 Service flows

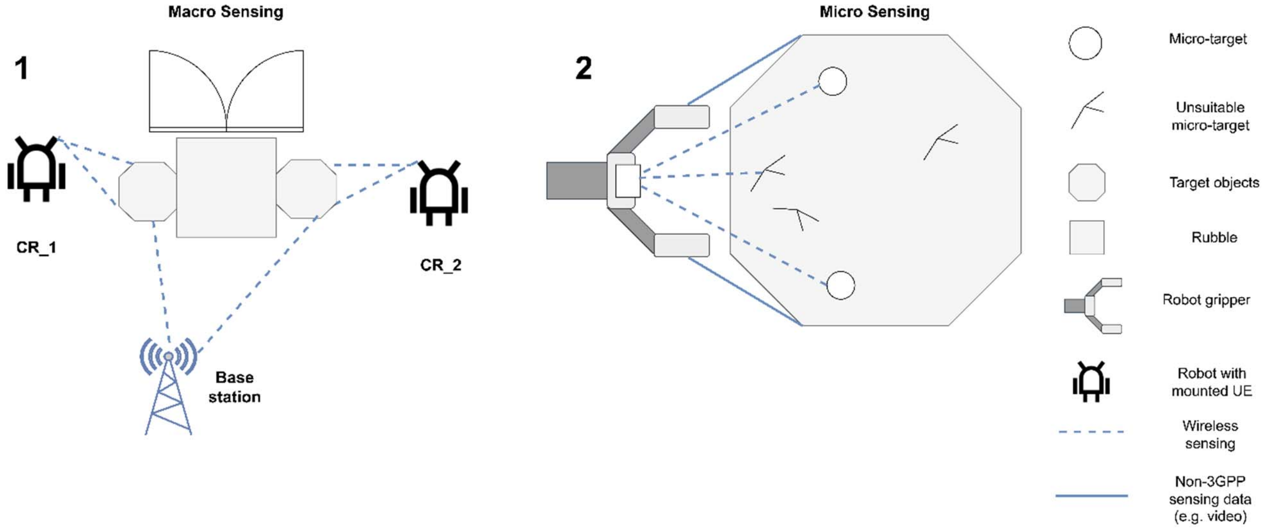


Figure 9: Precise localization of robot grasping

Step 1: [Macro sensing phase] A CR team leader sends a request to Mobile Operator X to ask for relocating a rubble from a construction site. A base station nearby and two robots, i.e. CR_1 and CR_2, determined by Mobile Operator X, are configured with mono-static/bi-static/multi-static sensing operations, and perform sensing over the rubble. Corresponding sensing data are fed back to operator X's network.

Step 2: Mobile Operator X detects main characteristic of the rubble (as a target object), including dimension, 3D-shape, weight and centre of gravity considering derived material characterization, etc., by processing and/or fusing sensing data from numerous sensing operations above, and then determines potential grasping points (as micro-targets) of the rubble for next phase.

Step 3: [Micro sensing phase] CR_1 and CR_2 collect high resolution multimodal data (e.g. generated by 6G wireless sensing with mono-static sensing operations performed by each robot gripper, and non-6G depth camera) by closely sensing potential grasping points of the rubble further, up to 10 cm proximity toward rubble surface. Corresponding sensing data are fed back to operator X's network.

Step 4: Mobile Operator X, by jointly considering all sensing data collected from both macro and micro sensing phases, selects the most suitable micro-target(s) for each robot, considering material characterization, relative localization/motions, relative orientation, etc. Relative motion between a robot arm and a grasping point can be 1~10 cm/s. Corresponding sensing results, e.g. coordinates of selected micro-target(s)/grasping point(s), are delivered to CR_1 and CR_2 respectively for further execution.

Step 5: [Execution phase] CR_1 and CR_2 execute the pre-grasp phase by moving/rotating their robot arms and approaching selected grasping points simultaneously. Sensing results are regularly provided by Mobile Operator X toward robots for safe and steady engagement.

Step 6: Once contact is made, the pre-grasping is complete.

5.11.4 Post-conditions

With ISAC from robot UEs and nearby base station(s), grasp positions were determined. The robots successfully grasped the target object.

5.11.5 Potential requirements

Existing features partly or fully covering the use case functionality include the following:

- Low clock synchronicity budget requirement to support number of devices in one communication group is already supported for robotic application (A.2.2.5 cooperative carrying fragile & elastic work pieces Table 7.2.3.2-1: Direct device connection clock synchronization service performance requirements for 5G System [i.5]).

- Accuracy of horizontal and vertical positioning estimate by sensing (for a target confidence level) requirement to support in range of 0,2 m for sensing category 7 which has more stringent requirements (e.g. for KPIs such as positioning accuracy and sensing resolution) [i.2].

Potential new requirements needed to support the use case:

- [PR 5.11-1] Subject to user consent, regulation, and operator's policy, the 6G system should support detecting characteristics of a target object, e.g. for material characterization, relative localization/motions, relative orientation, etc., with respect to each micro-target of the target object.

EXAMPLE 1: A target object is detected with micro-targets as potential grasping points.

- [PR 5.11-2] Subject to user consent, regulation, and operator's policy, the 6G system should support the precise localization, with [1 - 10 mm] accuracy [i.6], [i.7], [i.8] of relative 3D distance between sensing transmitter/receiver and given micro-target, at 99 % confidence level, up to 10 cm proximity.

EXAMPLE 2: Given micro-target is a grasping point that robot arm is approaching to.

- [PR 5.11-3] Subject to user consent, regulation, and operator's policy, the 6G system should provide continuous precise localization at sufficient refreshing rate, e.g. [10 ~ 100 ms].

EXAMPLE 3: It is assumed that relative motion between robot arm and a grasping point can be 1 ~ 10 cm/s.

5.12 Use case on real time cyber-physical systems in industrial worksites

5.12.1 Description

It is expected that 6G systems open the way to Cyber Physical Systems (CPS) where physical and cyber world interact and provide mutual feedback. In industrial worksites, the use of robots can answer to a great number of issues, such as working in hazardous and challenging environments where humans find themselves at risk, accessing remote sites difficult of access, realizing remote very precise operations, retrieving more precise information than human senses, etc. Robots can further collaborate among them as described in clause 5.10, interact with humans, or reproduce human behaviour by learning and predicting human activity e.g. based on sensing information.

In such a scenario, skilled individuals can intervene simultaneously on multiple sites, remotely share and teach specific skills, remotely and safely manipulate hazardous materials, or perform (with the use of a remotely controlled robot) difficult or precise tasks beyond the capacity of a human, as depicted in Figure 10.

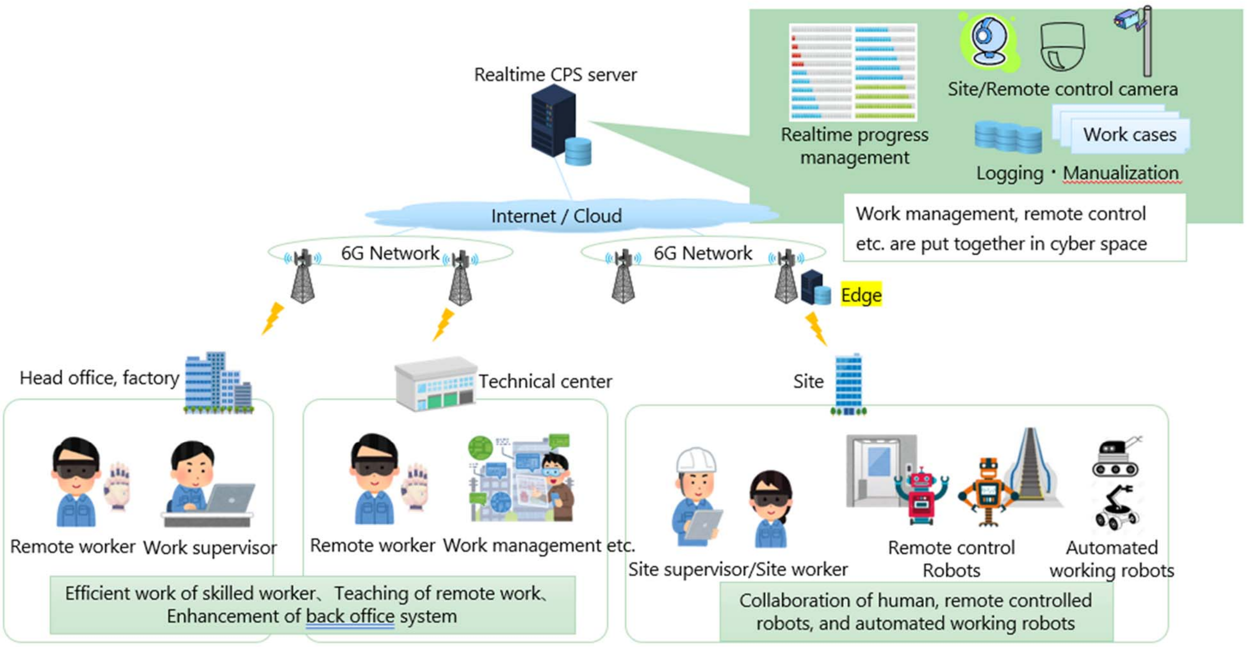


Figure 10: Realtime CPS for remotely controlled robots in industrial worksites

5.12.2 Pre-conditions

Remotely controlled robots in industrial worksites are equipped with sensing and communication capabilities. The human operator console on the controller site, the remotely controlled robot and all other involved equipment in the plant (e.g. sensors) have access to very high throughput connectivity. The remote and controller sites are connected through a communication link with guaranteed latency and throughput. In case of link failure, a fail-safe mechanism ensures security within the factory.

5.12.3 Service Flows

Step 1: The remotely controlled robot and in-factory sensors retrieve sensing information beyond human capability, positioning information, and high-resolution video stream of the worksite.

Step 2: Sensing data is collected and processed by a R-CPS function that can be deployed in the 6GS or provided by an external application or a combination thereof. The exact separation of functionalities between those entities is not further explored in the framework of this use case. Fusion of sensing data from different trustworthy sources is possible. Time alignment between data from different sources is performed during processing and/or fusing.

Step 3: The R-CPS server provides a cyber-physical space where work management, remote control operations, monitoring and supervising tasks can be performed in real time from a remote location.

Step 4: At the controller site, human operator can visualize high-resolution video stream of the robot operations and can pilot robots on various sites. Work management of various sites can be performed simultaneously. Robots can perform precise tasks in collaboration with humans or other robots.

Step 5: If parts of the network/service fail, the application is notified and any risk is mitigated by a fail-safe/back-up mechanism, e.g. by reducing the speed of the robots operating in areas where people are present.

5.12.4 Post-conditions

Extremely precise tasks can be executed. Handling of hazardous material or conducting missions in hazardous sites can be done without endangering human health. Skilled workers' efficiency is enhanced.

5.12.5 Potential requirements

Potential requirements for this use case may highly vary depending on the type and required precision of task to be accomplished. A minimum set of requirements should at least encompass the following:

- [PR 5.12-1] The 6G system should provide 3D sub-cm sensing/positioning accuracy for human-robot interaction, millimetre-level for precise actions [i.25].
- [PR 5.12-2] The 6G system should guarantee the privacy, integrity, and reliability of the sensitive data (including sensing data) throughout the life cycle (e.g. creation, storage, usage, sharing, archiving, destruction, etc.).
- [PR 5.12-3] The 6G system should be able to collect and fuse sensing data from different sources (including 6GS and non-6GS).
- [PR 5.12-4] The 6G system should guarantee tight synchronization between the different streams of multi-modal information (6GS and non-6GS sensing, e.g. haptic, video, audio streams, etc.).
- [PR 5.12-5] The 6G system should guarantee tight synchronization between the information at remote/local sites.
- [PR 5.12-6] The 6G system should guarantee tight synchronization between the physical space and its digital representation.
- [PR 5.12-7] The 6G system should be able to transparently flag when the requested/agreed sensing KPIs (e.g. reliability) cannot be met. (This will allow the robots to execute the fail-safe procedure).

NOTE: KPIs and requirements for real time digital twinning and/or real time cyber-physical interactions, figures in the order of 99,99999 % reliability and millisecond level end-to-end latency are often cited [i.26]. Real time automation and control protocols usually support cycle times of 31,25 μs to 1 ms with a jitter of less than 1 μs [i.27].

5.13 Use case on micro-deformation sensing

5.13.1 Description

Micro-deformation sensing stands as a cornerstone in the realm of structural health monitoring for buildings, bridges, and mining-sites. This technology plays a pivotal role in offering insights into the structural integrity of infrastructure, unveiling hidden deformation patterns arising from daily activities, and serving as an early warning system by detecting abnormal patterns, as depicted in Figure 11. By harnessing micro-deformation sensing, stakeholders gain a comprehensive understanding of the structural health, empowering advance maintenance and intervention strategies for enhanced safety and longevity.

Traditional micro-deformation sensing methods often rely on the deployment of highly sensitive sensors on the target. Those sensors include GNSS, radar, optical Doppler vibrometer. The traditional sensing facilities tend to be customized and expensive, presenting barriers to widespread adoption. Overcoming these limitations is crucial for advancing the field of structural health monitoring, necessitating the development of more efficient, cost-effective, and scalable sensing solutions. As more and more bridges/buildings reaching the second half of their designed lifetime globally, it is more financially viable to have general surveillance infrastructure.

As integrated sensing and communications becomes a feature in future 6G networks, the prospect of ubiquitous micro-deformation sensing becomes increasingly viable. A 6G base station with sensing function integrated can be used for its nearby targets' micro-deformation sensing. The base station transmits sensing signals to a monitored target, receives echoes from the target's permanent scatterers, and evaluates the deformation level accordingly. The building or bridges management teams subscribing to the sensing service can collect the deformation data from the sensing function of 6GS exposed by the operator. Network operators coordinate different base stations to enable multi-static sensing to the same target, with improved sensing accuracy, coverage and robustness. Furthermore, highways and railways in urban deployments are covered by many existing cells. It makes ISAC micro-deformation sensing a more economical, all-time alternative.

Overall, micro-deformation sensing stands as an indispensable tool in the toolkit of structural engineers and infrastructure managers, offering invaluable insights into the health of buildings and bridges. The integration of sensing and communications in the 6GS further enhances the flexibility and ubiquity of micro-deformation sensing, ensuring reliable sensing services for engineers.

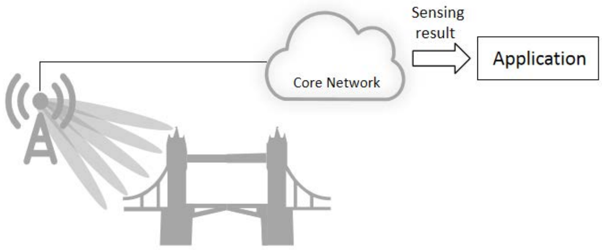


Figure 11: An illustration for micro-deformation sensing

5.13.2 Pre-conditions

The transportation department #A takes care of the safety of bridges and highways. The office needs to monitor the deformation of bridges, highways and any other constructions requiring structure-safety oversight. The office can schedule construction maintenance, monitor the life cycle of the constructions and initiate evacuation alarm if abnormal deformation is detected. There are clear Line of Sight (LoS) paths between sensing base stations and the sensing target. Reconfigurable Intelligent Surfaces (RIS)-assisted NLoS sensing is also viable. Base stations working on sub-6GHz or mmWave spectrum can both participate into the deformation sensing. Under Additive White Gaussian Noise (AWGN) assumption, the relation between Signal to Noise Ratio (SNR) and the carrier phase Cramer-Rao Lower Bound (CRLB) can be referred to $\mathrm{CRLB}(\hat{\phi}) = \frac{1}{2SNR}$, where the SNR is the total SNR having all the reference symbols combined coherently [i.15], [i.15], [i.16]. Given the relationship between the accuracy of carrier phase and deformation, i.e. $\Delta_\mathrm{R} = \frac{\lambda\Delta_\phi}{4\pi}$, the SNR and their corresponding accuracy is given in Table 9.

Table 9: Total SNR vs. carrier-phase accuracy and deformation accuracy

Total SNR(dB)	Carrier-phase accuracy σ_{Δ_ϕ}(degrees)	Deformation accuracy Δ_R (mm)		
		3,5 GHz	4,9 GHz	26 GHz
30	1,28	0,152	0,109	0,021
20	4,05	0,482	0,344	0,065
10	12,81	1,525	1,089	0,205

5.13.3 Service Flows

Step 1: The local transportation office has a subscription for the premium service of deformation-sensing for the city-wide bridge health monitoring.

Step 2: MNO has the sensing base stations deployed nearby the sensing targets.

Step 3: The nearby base stations report their sensing capability to the RAN.

Step 4: According to different sensing capabilities, the RAN schedules sensing tasks and distributes sensing jobs to the base stations.

Step 5: The base stations collect deformation results every duty circle, and report to the sensing function.

Step 6: The RAN obtains the 6G sensing data and the 6G system processes the 6G sensing data to obtain sensing results and exposes the 6G sensing results to the deformation sensing system via the core network.

Step 7: Based on the sensing results above, the application server obtains the deformation data associated with location information.

Step 8: The transportation office establishes real-time monitoring system according to the deformation sensing results.

5.13.4 Post-conditions

The transportation department officers and engineers could check the deformation level of the bridge in the monitor room. Accordingly, the officers and engineers make plans for future maintenance and infrastructure renewal.

5.13.5 Potential requirements

- [PR 5.13-1] The 6GS should support collection of the sensing data from the 6G base station.
- [PR 5.13-2] Based on operator's policy, the 6GS should support mechanisms to process the sensing data to derive the sensing results.
- [PR 5.13-3] Based on operator's policy, the 6GS should provide mechanisms to expose the sensing results with sensing contextual information, e.g. location, to a trusted third-party application via the core network.
- [PR 5.13-4] The system should support micro-deformation sensing services with the following KPIs:
  - Deformation threshold: deformation is usually a local change. There are usually multiple observation points ($P_1, P_2, ..., P_n$) on a given target. Each observation point will record the deformation value ($\Delta d_1, \Delta d_2, ..., \Delta d_n$). The deformation value above the threshold will trigger the hazard alarm.

During the consistent sensing, the degree of deformation of each observation point can be evaluated as:

- Deformation accuracy: The difference between the true deformation value and the estimated deformation value. The accuracy is preferably mm-level to enable highly accurate structural health monitoring.

Furthermore, the level of timely sensing is evaluated as:

- Refreshing rate: fast refreshing rate of deformation results is useful for construction expert to investigate the hidden pattern in structural health problem. The recommended refreshing rate is 1 s.
- Max sensing service latency: consistent sensing is important for timely alarm to the sudden hazard. The recommended maximum sensing service latency is 100 ms.

5.13.6 Enabling technologies and frequency bands

Main potential technologies related to micro-deformation sensing:

- Extremely high-accurate (e.g. sub-centimeter) deformation estimator: the estimation high-accuracy algorithm enabled by the joint design of beamformer and waveforms.
- Network structure and interaction procedure for multi-static sensing for a given deformation sensing target.
- Channel modeling method for micro-deformation sensing to help determination of permanent scatterers.

5.14 Use case on traffic throughput and safety on road intersections

5.14.1 Description

Cities are increasingly strained improving mobility & safety at the one hand, while (public) space/services are increasingly under pressure due to urbanization. There is a strong emphasis on steps that improve quality of life. As a result, urban mobility is increasingly prioritized in the following order:

- walking;
- (e-)Biking;
- public transport;

- mobility as a Service (MaaS e.g. car sharing); and
- private car i.e. the so called WBPMP [i.12] as shown in Figure 12.

To further increase public space, experiments are being conducted with zero parking residential areas, having only mobility hubs at the edge of the residential area.

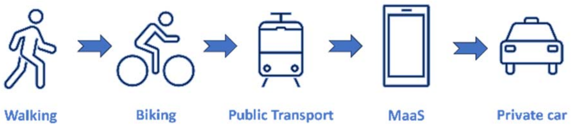


Figure 12: Urban mobility priority order

Cities want to promote these mobility policies favouring mobility means which have less impact on the citizens through traffic management and improving safety over time. At road intersections, decisions are made regarding the duration of green light for different traffic participants within a given cycle, e.g. 90 seconds. This can be adjusted to prioritize certain groups e.g. by extending the duration of green light for bikes going to school in bad weather or switching traffic signals to green faster to allow bikes to pass without stopping. On traffic network level, flows within the city can be favoured over those coming into and out.

Across Europe, the traffic infrastructure varies significantly. However, a common characteristic is that most road intersections are unsupervised. The majority of these intersections operate on (fixed) time-based schedules, with detection systems implemented only in the vicinity of the intersection itself. This often results in traffic participants having to wait at red lights even in the middle of the night when no other traffic is present. As a consequence, a large number of traffic participants run the red lights, raising the risks of accidents and fatalities.

For example, the Netherlands boasts some of the most advanced detection and traffic management systems in its cities, featuring truly mobility dependent traffic control. Vehicle detection is primarily achieved through inductive loops embedded in the tarmac, while for bikes and pedestrians, pushbuttons are the most common means of detection. These inductive loops are reliable but are hard to repair and have limited information (only whether a vehicle is present or not). Repair causes nuisances and additional operating expenses (OPEX) due to permits & redirection of traffic as a new inductive loop needs to be installed in the tarmac. In addition, some European cities employ radars for the detection of vehicles and bikes, offering the benefit of simpler maintenance and repairs. Dedicated radars have several drawbacks such as high costs, limited standardized (complicating leveraging the data) products and ecosystem. Finally, cameras are also used for traffic detection, but these have privacy concerns. In addition to the well-established systems described above, LIDAR is also being experimented with, but it struggles to perform according to the norm in adverse weather conditions such as fog. An emerging technology is the use of floating location data from cars and bikes for traffic detection. However, such data of these sources are not accurate enough and widely adopted to replace local detection systems. These are also highly dependent on Global Navigation Satellite System (GNSS) which introduces system performance risk due to GNSS-spoofing and other manipulative tactics. Moreover, outside busy hour and for users not willing to share this location data due to privacy concerns, there will always be a need for alternative traffic detection methods.

3GPP TS 22.137 [i.2] has identified several advanced 5G use cases related to detecting traffic participants, such as pedestrian or animal intrusion detection on highways, railway intrusion detection, and crossroads with or without obstacles, as well as vehicle sensing for Advanced Driver Assistance Systems (ADAS). However, none of these use cases address complex scenarios that require the detection of traffic participants with the high reliability presented in this use case [i.13].

Much of technology adoption in mobility is dependent of various factors such as vehicle-and-bike industry, human behaviour, etc. ISAC offers cities an alternative approach to improve safety and mobility, empowering them with greater control over urban development and transportation solutions. In a distant future, it would allow cities also to address the risk of Connected, Cooperative and Automated Mobility (CCAM) on specific locations for all citizens (connected or not) by placing additional sensing to protect vulnerable road users around the corner.

The (optimal) sensing service (i.e. traffic detection) range required to support this use case primarily depends on the speed of the traffic participant. For example, on a 80 km/h suburban road, a sensing service range of 150 m is needed to prevent suboptimal stops. In contrast, in 30 km/h cities zones, a sensing service range of 60 m is often enough. The scheduling of traffic light is designed in cycles that can vary in time (e.g. duration of green light) based on the traffic. Some inefficiencies are introduced during traffic light switching, which are mandatory times to ensure that the road intersection is cleared before changing signals. The communication of ISAC is needed to share to the traffic participants the schedule of the intersection(s) so it can adopt its behaviour. The sensing of ISAC can validate whether it corresponds with the (expected) traffic (behaviour). If there is misalignment between the two, the green schedule can be adopted to improve efficiency.

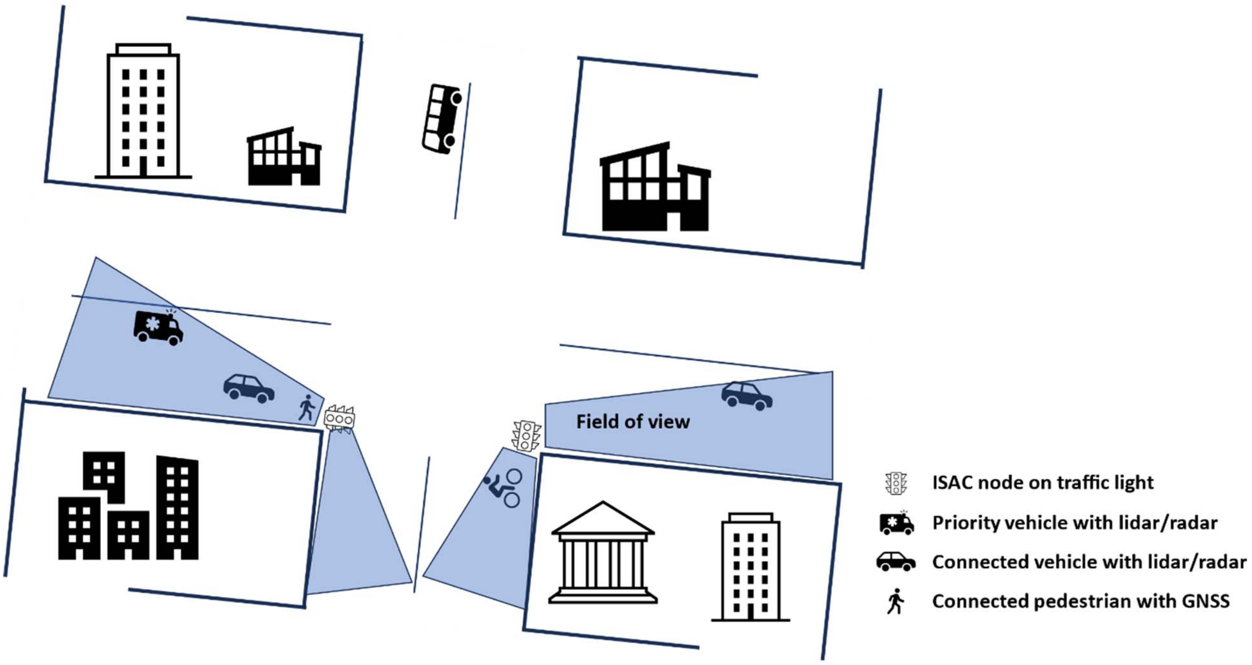


Figure 13: ISAC on road intersection

In the hypothetical road intersection as depicted in Figure 13, traffic participants need to be identified at 60 m with a very low probability of false negative (< 0,01 %). Additionally, a horizontal resolution of less than 1 m is required to distinguish traffic participants between lanes, facilitating the appropriate signal changes for bikes, trams, emergency vehicles and motorized traffic. Low probability of the false negative (failed detection) is key, because people tend to ignore the red light if they have to wait (very long) when there is no other traffic. Especially passing red light is a safety risk on intersections. Similarly, there is an opportunity to improve detection and prevent redlight negation, e.g. (carbon) motorbikes which are difficult to detect with inductive loops or intersections with no/limited inductive loops in which one has to wait even when there is no traffic.

The primary case refers to vehicles, but having the ability to also identify vulnerable road users also known as (e-)bikes closer by at a higher resolution and even closer pedestrians is a highly desired extension. Today vulnerable road users are digitally identified by a myriad of implementations. Similarly, being able to classify 7 vehicle types, speed and crossing red light are preferred capabilities. After identifying traffic participants and their categories, the ISAC system can optionally engage in direct communication with them. This facilitates proactive and automated decision-making, such as triggering automatic responses in connected vehicles and bicycles and sending alerts to pedestrians' smartphones. Such interactions are instrumental in enhancing overall traffic safety. Four ISAC nodes are shown in extension to the connected vehicles/pedestrians, the choice of four is highly hypothetical. The number of nodes is in the end dependent on meeting the requirements, deployment ease and affordability. Detail overview of technical requirements per road types, is captured in Table 10.

Table 10: Technical requirements

Scenario	Probability of false positive	Probability of false negative	Sensing service range (m)	Horizontal resolution (m)	Cycle time (ms)
City zone (30 km/h)	< 0,1 %	< 0,01 %	60	< 1	100
Sub-urban zone (80 km/h)	< 0,1 %	< 0,01 %	100	< 2	100
Highway zone	< 0,1 %	< 0,01 %	250	2	100

Increasingly, the (priority) vehicles have information on their environment (e.g. point-clouds) to improve safety and efficiency of the intersection that are communicated (anonymously) to the ISAC nodes. In the sensor fusion, the data from vehicles would be used to *enhance and assist* the detection of all traffic participants on the intersection. For pedestrians/(e-)bikes this is likely a smaller dataset on their environment/location. For traffic management/safety on the intersection the trust level is lower than the sensors placed/managed in the public domain. This is because these are, physically and legally outside the public domain sensors of the intersection. Obviously, all sensor data of vehicles/pedestrians should not be traced back to any individual outside the ISAC system for privacy, tech adoption & trust reasons unless legally required otherwise.

5.14.2 Pre-conditions

- Traffic Participants (e.g. private vehicles, bikes, pedestrian, emergency vehicles, public transport) are coming towards a road intersection in a city zone.
- ISAC nodes are deployed at the traffic signal posts to support the right angle of detection, configured to filter noise below the reflective surface of the traffic participant and the required range/resolution.
- Traffic participants are provisioned to communicate their sensing data locally, securely, privately and legally with the ISAC system.
- ISAC post-processing is optimized to identify the selected subjects & information.
- Integration into sensor fusion & traffic management systems with standard protocols/application programming interface used in Cooperative Intelligent Transport Systems (C-ITS) Traffic Management.

5.14.3 Service flows

Step 1: An approaching traffic participant e.g. vehicle, bike, pedestrian, reflective surface is detected up to 150 m away from the traffic signal post.

Step 2: The traffic participant (if cooperative) communicates with the ISAC system locally to share its information on its environment, vehicle, etc.

Step 3: Traffic light switches to green or the duration of green light is extended if possible (in low traffic scenario).

Step 4: A traffic participant is identified in which lane it is taking on a distance of 60 m measured from the stop line.

Step 5: Traffic light switches to green or the duration of green light is extended if possible.

Step 6: A traffic participant is identified stopping or passing the traffic light.

Step 7: Traffic light switches to red or the duration of green light is reduced.

Step 8: ISAC system or traffic management system/communicates with other approaching traffic participants to warn about change in traffic signal.

Step 9: Other approaching traffic participants (e.g. connected vehicles, bicycles, pedestrian) stop at the traffic light.

5.14.4 Post-conditions

- ISAC system has detected of the traffic participants (in two stages preprocessing & postprocessing).

NOTE: The post-processing part can also be outside of the ISAC system.

- Sensor fusion is done within the 6GS (preferred) to improve calibration of vehicle, reliability, accuracy and take advantage of the 6G communication (e.g. vehicle updates/route/warnings, etc.) & localization technologies.
- Sensing results have been exposed to traffic management system.
- Traffic management system optimizes road traffic for all traffic participants according to the regulatory policy.
- Traffic participant passes the cross section.
- By using the data from the ISAC monitoring system (heartbeat), traffic management system is aware of situations when there is no traffic at the road.

5.14.5 Potential new requirements needed to support the use case

- [PR 5.14-1] For vehicles, sensing service range should be up to 150 m with at least a horizontal resolution of 1 m (at a 100 m distance).
- [PR 5.14-2] For vulnerable road users, sensing service range should be up to 100 m with at least a horizontal resolution of 30 cm (at a 20 m distance).
- [PR 5.14-3] Radar Field of view of the ISAC node should support detection of vehicles with placement of antenna on the corner of the intersection detecting two lanes.
- [PR 5.14-4] Total cycle time of the traffic scheduling algorithm (including sensing processing) should be under 100 millisecond.
- [PR 5.14-5] Vehicles should be detected with a false negative under 0,01 %.
- [PR 5.14-6] 6GS should allow the fusion of 6GS sensing and 6GS localization data.
- [PR 5.14-7] 6GS should have an standardized API designed according to traffic management standard.
- [PR 5.14-8] 6GS should allow flexible deployment of ISAC nodes.
- [PR 5.14-9] 6GS should allow hybrid deployment of 3GPP ISAC with existing detection means (e.g. inductive loops, dedicated radar).
- [PR 5.14-10] 6GS should allow sensor fusion among the sensing data and data from the existing detection means within and outside the system.
- [PR 5.14-11] 6GS should allow the possibility of detecting underperforming sensing module (e.g. through sensor fusion deviation or statistical deviations).
- [PR 5.14-12] 6GS should be intrinsically (native) privacy safe and meeting legal requirements.
- [PR 5.14-13] 6GS should prefer a specification which leverages (existing/evolving) radar/lidar ecosystem of vehicles, rather than creating a separate partially overlapping system.

5.15 Use case on safe & economic UAV transport

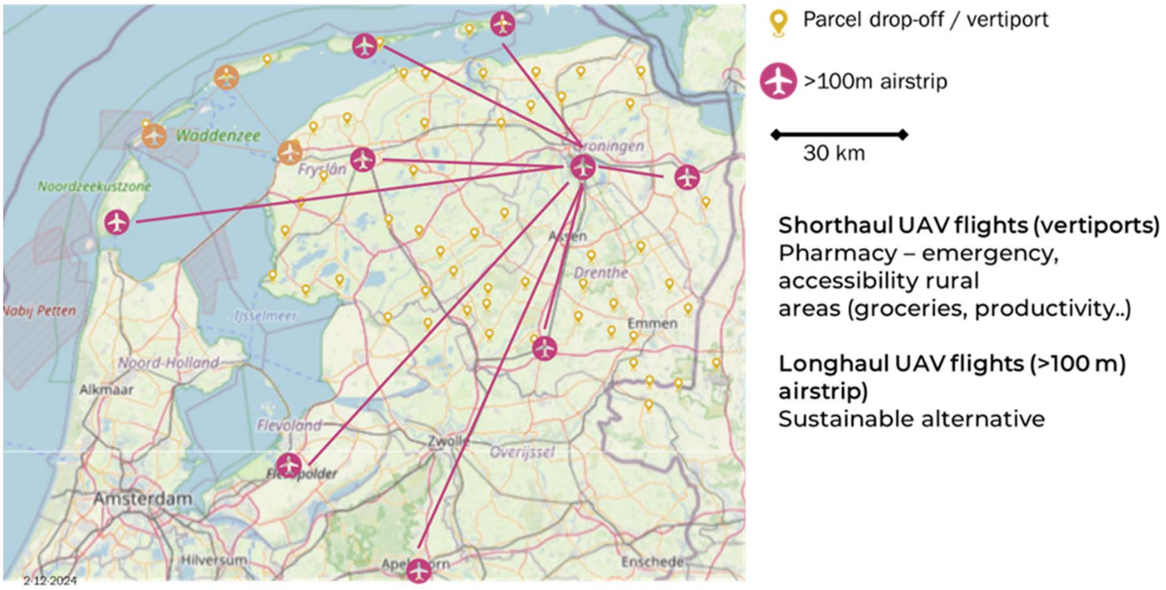
5.15.1 Description

In rural regions, the scarcity of labour and the limited access to services necessitate the adoption of alternative, efficient transportation methods. Unmanned Aerial Vehicles (UAVs) hold significant potential in this regard. However, the current regulatory framework presents a challenge, as obtaining operational permits is both time-consuming and expensive, often requiring extensive risk mitigation measures. The realization of large-scale Beyond Visual Line of Sight (BVLoS) UAV operations, free from protracted permitting and onerous mitigations, hinges on effectively addressing risks associated with telemetry and tracking. This would substantially reduce both ground and mid-air collision risks. The Integrated Sensing and Communication (ISAC) technology shows great promise in enhancing the safety of telemetry and tracking systems, thereby facilitating safer integration of UAVs into the airspace.

Many countries are exploring new transportation methods for goods that are quicker, more sustainable, less reliant on labour to avoid problems such as urban road congestion, labour shortages, as well as to reduce pollution. Unmanned Aerial Vehicles (UAVs) present a promising solution, yet their economic viability remains a challenge. To foster the growth of the UAV-based transportation sector, a system should be established that supports safe long-haul Beyond Visual Line Of Sight (BVLoS) flights with low operational cost and sufficient drop-off points.

The Netherlands faces challenges in its sparsely populated northern regions, where an ageing population relies on access to essential services such as pharmacies and groceries beyond regular hours. For professionals like engineers and veterinarians. distances are significant. Without proper equipment readily available on the job, productivity suffers considerably, especially since there may not be readily available experts to compensate for these setbacks. The situation is specially critical in the Wadden islands area in the north of the country, where limited ferry services (e.g. only 3 roundtrips per day [i.28]) can turn a simple mistake into a lost workday. There is growing support in the Dutch parliament to use UAVs for the urgent delivery of medicines to these islands [i.29].

While UAVs could potentially fly anywhere, widespread approval by the regulatory authority is unlikely in the near future. Hence, the envisioned UAV infrastructure for 2030 (as illustrated in Figure 14) includes parcel drop-off points/ vertiports and 100 m airstrips for fixed-wing UAVs. The fixed-wing UAVs, capable of flight speeds up to 200 km/h (in the direction of the wind) [i.30] and carry-load capacity up to 150 kg, requires a small airstrip of 100 m. Conversely, parcel drop-off points/vertiports are strategically located in communities without such a requirement. These vertiports can only be reached with slower moving UAV (< 70 km/h) with lower load capacity (< 15 kg) aiming at express deliveries (< 60 minutes).



NOTE: Based on "OpenStreetMap© contributors - see openstreetmap.org/copyright).

Figure 14: Illustration of future UAV ground infrastructure in the Netherlands (see note)

The Dutch airspace, heavily utilized by manned aircrafts, does not allow a separate UAV-only airspace. The rise in near-miss incidents i.e. < 10 m away [i.31] reported by manned traffic (see Figure 15) in the Netherlands is concerning. This is likely the tip of the iceberg, as only in Amsterdam, 23 000 unauthorized UAV flights (predominantly recreational flights) were detected per year which influences professional UAV regulations. Therefore, stringent control over airspace for unmanned traffic is imperative for safety.

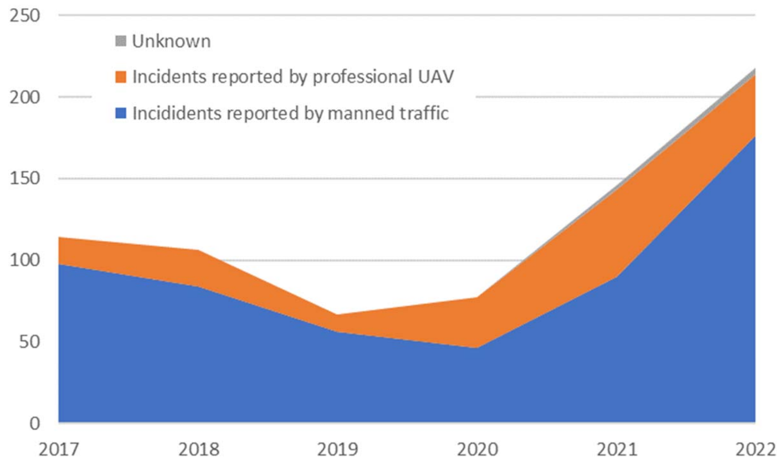


Figure 15: Incidents reported on unsafe UAV operations in the Netherlands based on data from [i.31]

Active radars are used to detect and classify UAV (among other things like birds) near restricted or controlled airspaces. However, the range of such systems is limited to 15 km. Beyond these areas, the absence of detection capabilities compromises air safety. Both UAV operator and the government require reliable verification systems as current telemetry relies on GNSS which is known to be vulnerable (e.g. due to GNSS spoofing). Although, this can be mitigated by an operator taking over control of the UAV, it hurts the economic model which depends on an operator managing 15 up to 30 UAVs simultaneously. Moreover, GNSS failure, can result in a group failure of UAVs in a corridor/area when a certain scale is achieved. In addition, it is expected that recreational UAV flights will fly unauthorized near professional UAV operations. Although on board systems of professional UAV likely comprise obstacle detection and avoidance sensors, this information needs to be shared with the unmanned air traffic control to ensure the safety of professional UAV flight paths. While previous generations of mobile networks have support for localization, these are only supported by advanced triangulation of direct involved cells potentially with beamforming. The requested capability goes beyond this, requiring verification of location of the UE also by non-serving cells (sensing). This should support more demanding BVLoS densities, when UAVs fly 100 m apart from one another at high speed. Depending on the degree of certainty, more and longer timeframe can be used.

Currently, the primary navigation system enables UAVs to follow a predefined, approved flight path. Onboard sensors, such as GNSS, ensure accurate navigation, with this data relayed to the unmanned traffic management system. However, for safety reasons, it is considered necessary to implement an independent secondary system to validate the UAV's self-reported location data. The envision ISAC system described in this use case may act both as the primary or the secondary system.

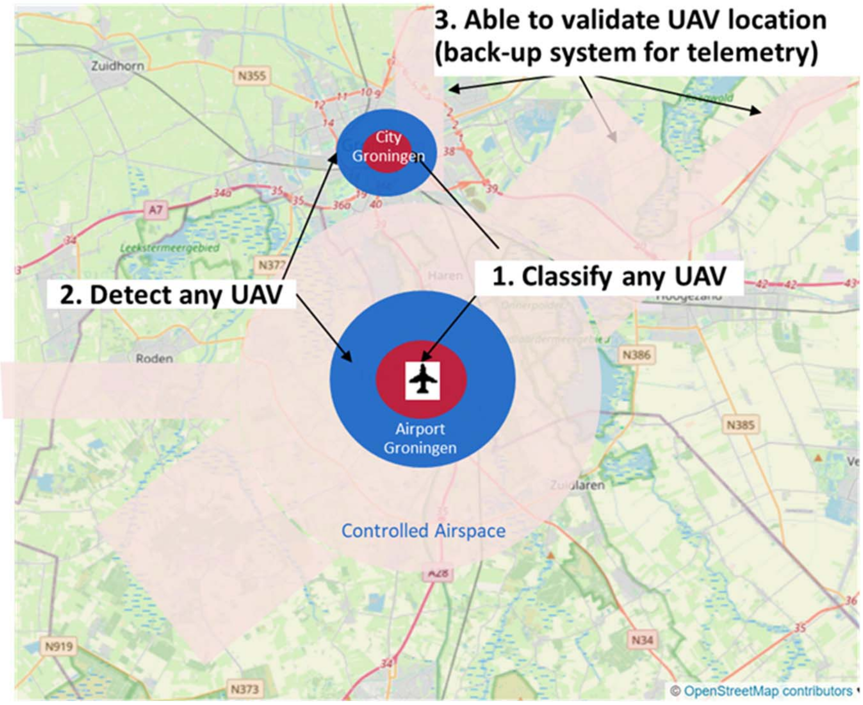


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Figure 16: Airspace management and the potential role of ISAC

Airspace management can be categorized into three distinct types based on their locations, as illustrated in Figure 16:

- In the RED zones, *classification* of *non-compliant* objects is essential. This involves *classifying* any UAV, other flying objects, and birds that are not transmitting their RemoteID or transponder signals. This requirement is crucial in high-risk locations such as airports and city centres. The system should detect these objects when they move above rooftop level.
- In the BLUE zones, *detection* of *non-compliant* objects is often enough. This focuses on *detecting* any UAVs, other flying objects, and birds that are not transmitting their RemoteID or transponder signals, particularly around high-risk locations.
- In the PINK zones, *detection and validation* of *compliant* UAVs are adequate. This entails *detecting and validating* UAVs that are transmitting their RemoteID or transponder signals within Controlled Traffic Regions (CTR), UAV corridors, or operating BVLoS with a connection to any mobile network. In these areas the ISAC system serves as a secondary/back-up system to ensure safety.

Coverage and market considerations:

- The pink zones represent the largest coverage area, necessitating extensive detection and validation capabilities.
- High-end detection and classification in the red and dark blue zones are essential for maintaining safety in specific, high-risk locations.
- Interoperability between these zones and UAVs enhances overall quality and contextual awareness.
- The market targeting solutions for high-end detection and classification is likely more niche compared to that targeting broader/basic detection of unauthorized flights.
- In the pink zones, economic factors may dictate that only UAVs can detect other unauthorized UAVs that have intentionally disabled their RemoteID.

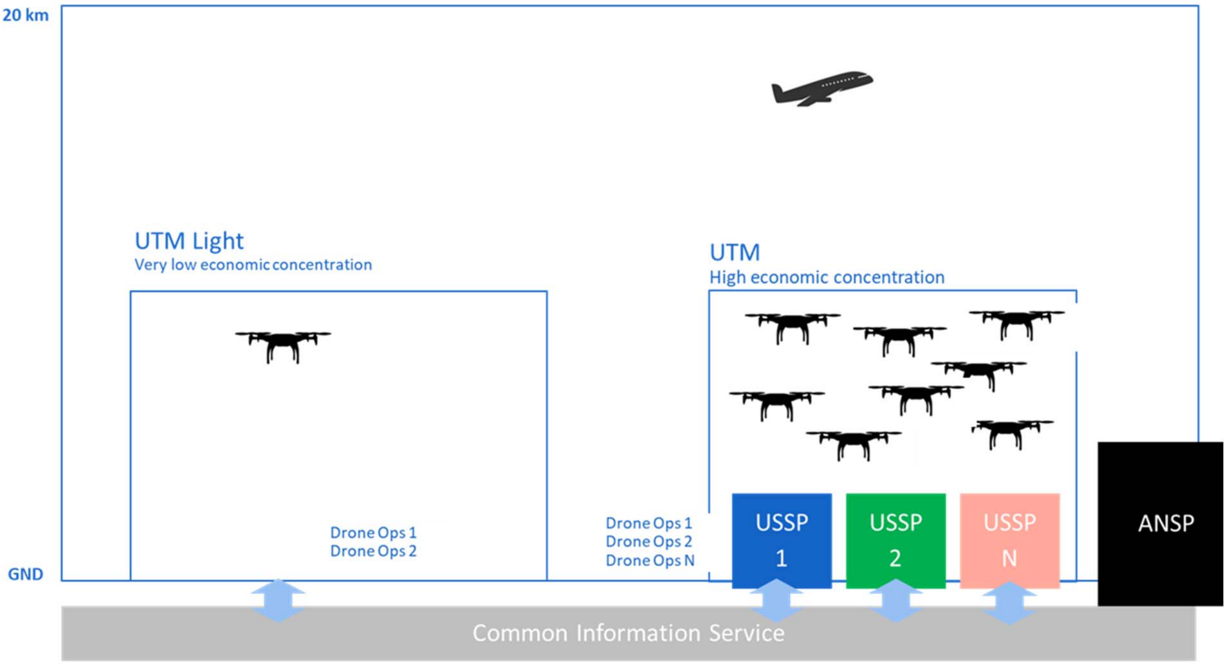

Figure 17: UTM-space operation concept.

When an operator flies BVLoS, the safety of the operation relies on accurately tracking the UAV's location within the Unmanned Aircraft System Traffic Management (UTM)-Space, as shown in Figure 17. If the UAV's location is determined inaccurately, it risks deviating from its intended flight path, potentially causing accidents. The user equipment already has access to GNSS position data, which is relayed to a central data base known as Common Information Services (CIS). The UTM-Space Service Provider (USSP) is responsible for offering various services to UAV operators as well as updating UAV's flight path/location within the CIS. In areas with low concentration of economic activity an USSP may not be economic viable. A simplified UTM structure connecting Ground (GND) Control directly to CIS may offer an approach to enable these UAV flights. In areas with low concentration of economic activity an USSP may not be economic viable. A simplified UTM structure connecting Ground Control directly to CIS may offer an approach to enable these UAV flights. The Air Navigation Service Provider (ANSP) performs a similar role for manned traffic. In the Netherlands, this is task is managed by Luchtverkeersleiding Nederland (LVNL) for civil aviation and by Commando Luchtstrijdkrachten (CLSK) for military aviation. The technical requirements of this use case are summarized in Table 11.

Table 11: Technical requirements of safe & economic UAV transport

Category	Requirements	Note
Mobility	< 200 km/h	Fixed wing can achieve 120 km/h with rear wind this increases to 200. Person carrying UAV and Manned traffic are excluded as these are possibly faster.
Flights per day in NL (estimated)	> 200 000	See the note for calculation for 2030.
Connection density (km^2)	20	GNSS failure can happen in a 1 km^2 cluster.
Location update	< 1 s	To stay within limits of air corridor, height information should be deducted from other sensors.
Accuracy	< 50 m X,Y > 99,99 % of time	Low accuracy as it not the primary means of navigation. As the secondary system is used for safety the confidence should be very high. If the confidence is not so high, it can result in false positive and unnecessary mission termination.
Synchronization	< 10 ms	Without synchronization no sensor fusion is possible.
Third party sensing	Yes	To allow interoperability with other sensors/radar point cloud data.
Service availability	99,999 %	Similar to core network of operators.
NOTE: Euro control expect 70 fold increase in UAV air fleet compared to commercial manned fleet - conservatively translating this to NL (only accounting commercial flights operations of 200 per hour) this leads to 200 000 million.		

The Dutch 6G flagship project [i.13], Future Network Services [i.13], believes that 5G ISAC standardization misses a significant opportunity to utilize ISAC for airspace management: a safety support system for cooperative small/medium-sized UAVs flying BVLoS in the lower airspace (up to 200 m). This use case proposes the use of ISAC as a supporting safety system for widescale BVLoS UAV operations below 200 m flight ceiling. Independent redundant systems are integral to safety in airspace and are a prerequisite for the large BVLoS UAV operation. ISAC offers high value for this emerging market segment, which is expected to have the largest volume below a 200 m height ceiling with parcels less than 2,5 kg.

Today's available technologies and procedures for UAVs are designed for limited manned flight, holding back the potential of the BVLoS UAV transport market for society. Examples include laborious procedures (e.g. flight permit and clearance), insufficiently resilient/secure technologies (e.g. GNSS, Automatic dependent surveillance-broadcast ADS-B systems), and no independent real-time oversight of flight data in lower airspace (e.g. onboard UAV sensors).

Despite studying several UAV specific use cases, the requirements identified in 3GPP TR 22.837 [i.1] did not address the highly valuable safety role below a flight ceiling of 200 m. More specifically:

- The most stringent Cat4 offers a confidence interval of 99 %, with 3 % missed detection and 1 % false alarms. These requirements are too low to serve as a backup (secondary) safety system. However, the provided accuracy measures can be relaxed, as airspace separation can be planned > 50 m, and it is a secondary system (the primary is the UAV itself).
- The size of the UAV is assumed to be too large to support widescale BVLoS UAVs. Based on this, today's commonly used UAVs with their compact size and smaller reflective surface area would likely remain undetected.
- The vast majority of packages are less than 2,5 kg, and [i.55] found that UAVs in this lower category are more carbon-efficient. Increased weight or larger UAVs impose more regulations/restrictions to reduce ground risk. Consequently, the proposed dimensions of a UAV may only be applicable to a niche market.
- The proposed architecture design is deemed too closed, with processing only inside the 5G system. There should also be room for a specialized certified third party to process all raw RF sensing data (and other data sources, including the drone itself to meet integrity and liability requirements.

Moreover, the 3GPP TS 22.137 [i.2] does not relate to the existing UTM space procedures in conjunction with onboard UAV sensors, localization services, and communication to the network. In the lower airspace, assuming cooperative UAVs (of which parts may fail), leveraging the terrestrial network for connectivity and localization as a pre-condition is logical.

5.15.2 Pre-conditions

- An UAV is coming towards an airspace.
- ISAC nodes comprising sensing transmitters and sensing receivers are deployed at airspace to support airspace management.
- The UAV is provisioned to communicate their sensor data set locally, securely, privately and legally with the airspace ISAC system.
- ISAC post-processing is optimized to identify the selected subjects & information.

5.15.3 Service Flows

For the case when onboard GNSS of the UAV is failed

Step 1: GNSS fails due to one or more of the following:

a) high-rise buildings;

b) poor weather conditions;

c) GNSS interference of any other kind.

Step 2: Mismatch between sensing data & underperforming GNSS is detected by UAV for 30 s.

Step 3: Sensing data becomes primary data source for telemetry of UAV (over GNSS) - declaration of an emergency.

Step 4: Centralized System/UTM-Space provider automatically increases the guard distance between the UAV and other air traffic to 10 s.

Step 5: Operator has to take over the operation - deciding over mission continuation/alteration/safe landing within 30 seconds.

Step 6: If operator has not taken over mission control - return to safe heliport procedure on safe height is automatically triggered.

For the case when UAVs detect unauthorized recreational flights in the corridor:

Step 7: UAV on board sensors detect anomaly in the air.

Step 8: Anomaly data (e.g. point cloud, images) is continuously shared with UTM Space provider.

Step 9: In case of collision risk, UAVs adjust their flight path within permitted flight area.

Step 10: Anomaly data is centrally fused with the data from other sensors (including network sensors) to improve and classify risk.

Step 11: Flight corridor is adjusted according to the assessment.

5.15.4 Post-conditions

- Airspace ISAC system has detected the UAV.
- By using the sensing data from the airspace ISAC monitoring system, safety of the UAV operation is improved.

5.15.5 Potential requirements

- [PR 5.15-1] Field of view of the ISAC node comprising sensing transmitters and sensing receivers should allow sensing & localization of UAVs connected to *any* terrestrial network (RF-link).
- [PR 5.15-2] 6GS should provide means to be certified for widescale BVLoS UAV operations below 200 m flight ceiling.
- [PR 5.15-3] 6GS should be capable of providing location updates in under 1 s.
- [PR 5.15-4] 6GS should be detect and track UAVs flying at a speed of 200 km/h.
- [PR 5.15-5] 6GS architecture should allow the fusion of 6GS RF sensing, 6GS localization data and 3rd party dedicated sensing (e.g. radars).
- [PR 5.15-6] 6GS should allow sensing data fusion between UAV and terrestrial sensing.
- [PR 5.15-7] 6GS should allow the possibility of detecting underperforming sensing module (e.g. through sensor fusion deviation or statistical deviations).

5.16 Use case for automated guided vehicles travelling in airports

5.16.1 Description

ISAC simply makes use of signals in a sophisticated manner, and will possibly transform conventional communication concept by adding sensing capability to network systems, and 6G systems will thus operate in network as a sensor mode by means of this invaluable capability [i.49]. Radio frequency sensing will play an important role by rethinking some of the existing concepts such as radar communication and self-supervised learning for radio sensing [i.49], [i.50] and will enable to realization of novel use cases. Automated guides vehicle operations will one of the fields that may benefit from ISAC concept.

Overall system is depicted in Figure 18. The proposed use case will be an airport scenario of ISAC application where Automated Guided Vehicles (AGVs) providing buggy services in a large indoor area will be boosted by ISAC capability in passengers' transportation in an environment where the base stations (3-4) will be equipped with ISAC capability enabled by deep learning techniques (19-21). In the proposed system, 3GPP data mainly will be the mainly used data for sensing task. In addition, non-3GPP data inclusion from camera, lidars, gyroscopes etc. may also be fused with these data to enhance quality of the sensing task. AGVs in the airports will possibly encounter some physical obstacles such as escalator (6), billboards (2-16), walking passengers (7), columns (12-13-14), seating people in waiting place (17), kiosk machines (10-11-15), ticket office (8-9), etc. AGVs should discern these obstacles, and then spot them as accurately as possible. Finally, the automated vehicles should avoid collisions with these obstacles. In this sense, the base stations assisting in the AGVs with ISAC capability will help environment mapping for the AGVs (1) through integrated deep learning techniques. U-Net architecture that produces efficient object segmentation and semantic segmentation results will likely contribute to this mapping task.

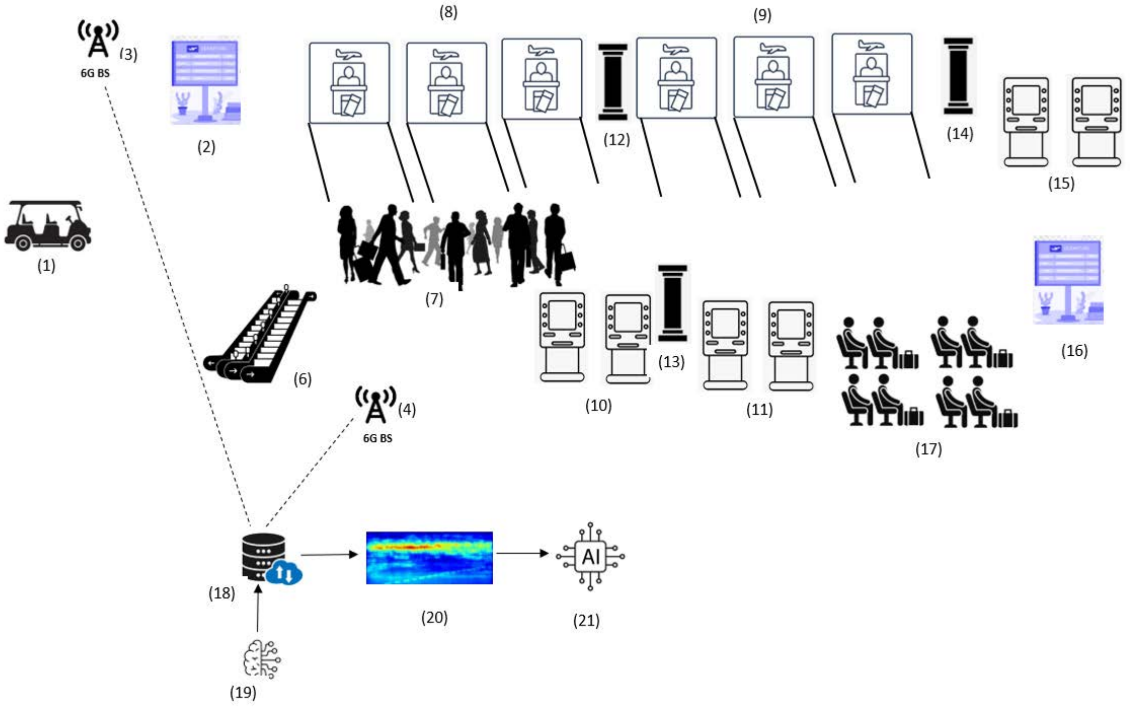

Figure 18: ISAC-assisted AGV in airports

5.16.2 Pre-conditions

Conditions for the proposed use case are presented within this proposal with infrastructure settings here:

- Infrastructure Requirements:
    - **Existing Infrastructure:** The deployment requires the special base stations in nearby areas in an airport. Deployment of these small base stations in a dense manner along with wider bandwidth systems in 6G networks will have potential to be used for sensing purposes.

- **Regulatory Compliance and Data Privacy:** The system complies with data regulations. Collected data through 5G-Advanced and 6G signals are processed, saved and stored in compliance with global privacy standards that do not violate privacy and security.
- **Technological Compatibility:** Existing infrastructure will have array antennas equipped with beamforming feature which the antennas provide both high-rate low latency communication and RF-sensing capability in a native manner. Base stations in the system uses the same spectrum for communication and sensing that the radar integration in-band is available [i.49]. ISAC system will utilize U-Net deep learning model for environment mapping.
- **ISAC-assistance:** AI model will use RF signals in-band to create the environment's mapping for AGV operation in the airport, and supply this mapping information to AGV in real-time or near real-time. This assistance will facilitate the realization of the proposed use case.

5.16.3 Service Flows

Step 1: The AGV moves in the airport to complete its assigned tasks by receiving the signals from base stations in the environment.

Step 2: The AGV communicates and exchange information with the base stations, and received RF signalling (6G data for both sensing and communication) information of the environment is collected in a server-like device in base stations. The environment information includes billboards, kiosk machines, columns in the environment, waiting places, walking passengers, etc.

Step 3: The network uses collected information (data), and process it by U-Net deep learning technique that makes efficient semantic segmentation, classification and object detection to create the environment's map in real-time or near real-time through data processing by a Graphic Processing Unit (GPU) and/or a Tensor Processing Unit (TPU).

Step 4: The AGV is assisted by ISAC capability. The environment's map is conveyed by the network to the AGV for travelling in the airport in a safe navigation way.

5.16.4 Post-conditions

Collaborative deployment: The AGVs assisted by ISAC capability will pave the way for collaborative deployment of AGVs in crowded areas in a safe manner. It will not be limited to providing buggy services for passengers in the airports, but also the system will likely be used for different purposes of the AGVs in the airports such as luggage carrying operations in airport warehouses, etc.

5.16.5 Potential requirements

Some functional requirements for the proposed use case are given as follows:

- [PR 5.16-1] Base stations are capable of performing different sensing modes (mono-static, bi-static and multi-static).
- [PR 5.16-2] 6GS has capabilities to fuse different kind of sensing data and serve it for integrated sensing and communication.
- [PR 5.16-3] 6GS provides integrated sensing and communication service without violating data privacy and by protecting data integrity for better, secure and reliable service.

Additionally, there are KPI-related requirements for the use case proposed. Operating field of the proposed use case here is somehow similar to both indoor and outdoor settings, and relevant KPIs for the proposed use case as per its operational field dynamics are as following:

- KPI-related requirements proposed for the use case are as follows:
    - **Positioning accuracy** for moving and static objects: < 0,5 m radius for moving objects, and 0,25 m vertical and horizontal distance for static objects.
    - **Confidence level**: > 96 %.

- **Accuracy of velocity estimate** by sensing: 2 m/s both in vertical and horizontal orientation for pedestrians, 20 m/s both in vertical and horizontal orientation for moving vehicles.
- **Sensing resolution**: Range resolution < 0,5 m, and velocity resolution 0,3 m/s both in horizontal and vertical orientation.
- **Maximum sensing service latency**: ≤ 5 ms.
- **Refreshing rate:** ≤ 0,1 s.
- **Missed detection rate:** < 1 %.
- **False alarm rate**: ≤ 2 %.

5.16.6 Enabling Technologies

- **Data Collection:** The 6GS collects positioning, localization, tracking, etc. in a distributed or centralized manner in cloud or edges depending on the application requirements of AI model deployment.
- **AI module:** The base stations equipped (or natively-integrated) with advanced RF-sensing capabilities will have AI module to process radar-like information to create the environment maps that will assist the AGVs.

5.17 Use case on emergency vehicle route planning

5.17.1 Description

In a busy city, there are many daily occurrences of emergency response teams such as police, ambulances, fire department, patient transport between health units, civilian emergency driving (e.g. to a hospital), recovery of broken vehicles, etc. These vehicles and the responding workers operate under strict time constrains, and it is of major importance they get to their destination as quickly as possible without any hurdles.

These vehicles have however to sometimes operate in peak traffic hours, where there are many other vehicles on the road, causing bottlenecks to the emergency operation, increasing delays, and ultimately, aggravating the emergency that triggered the emergency vehicle in the first place.

Figure 19 shows an example of a 4 km route that could potentially take 30 minutes in peak traffic hours. The total route length is of 4 km only, which under ideal conditions could be done by a car in significantly less time.

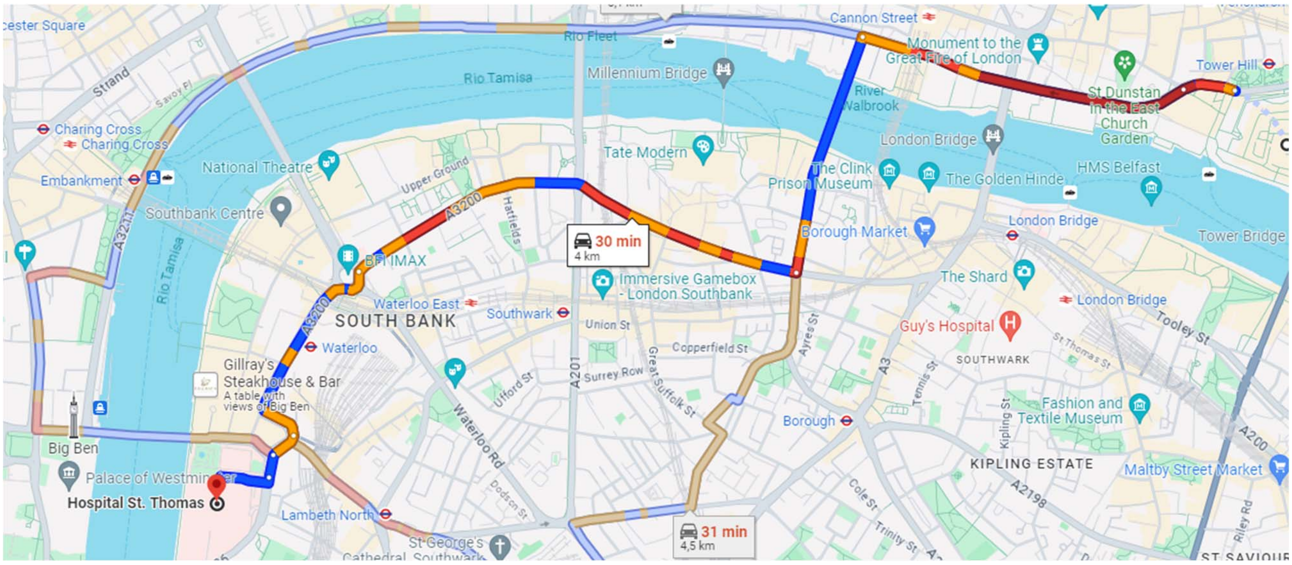

Figure 19: An example of a 4 km route that could take 30 minutes in peak traffic hour (Map source: Google Maps: © Google)

The same example route could take potentially 10 minutes under very low traffic conditions. The emergency vehicle route planning aims at the planning of a route for an emergency vehicle once triggered, to efficiently manage all the traffic between the two end points, in such a way that the emergency vehicle route is optimized, and potentially traffic free, while minimizing the impact on the other road vehicles.

5.17.2 Pre-conditions

There is a driving and traffic management application that is a Digital Twin (DT) of the city roads, and has relevant information such as road dimensions, can communicate with the 6GS, and has been granted access to the exposure service for sensing results from the 6GS.

Furthermore, the following pre-conditions exist:

- On road vehicles are self-driving and are connected to the DT:
    - Self-driving cars are equipped with wireless communication & sensing device and have the appropriate identification and authorization means to attach to the network.
- Cars equipped with wireless communications device are connected to DT and can report on traffic density information, road conditions, pedestrian density, etc.
- Both cars (UEs) and BSs have sensing capabilities and can operate in monostatic, bi-static or multi-static sensing modes in all UE/BS combinations.
- Any non-public information from both cars and BSs in this use case is removed before sensing results are exposed to the DT.

5.17.3 Service flows

The action and presence of an emergency vehicle is triggered with the emergency team. The two end points for the trip the emergency vehicle is about to make, i.e. stating point and destination, are known. The traffic DT determines one or more routes for the emergency vehicle. It may consider the best route for the emergency vehicle is, e.g. the fastest route. This route may then be communicated to the road users and emergency vehicle.

Upon the calculation of the route by the DT applications, the DT requests a sensing service from the 6GS with the precise route information. This allows 6GS to start a sensing service for the purpose of traffic density assessment along and around the provided route(s) by the DT. Sensing traffic along the route allows for a first assessment if that route is suitable for the emergency. This is achieved by exposing the sensing contextual information by the 6GS back to the DT application. An assessment around the route may be necessary as well, because in peak traffic hours, it may be extremely difficult to move traffic to adjacent roads to let the emergency vehicle pass through quicker. This information is fed to the driving and traffic management DT.

As the emergency vehicle moves towards the destination, the traffic ahead is also recurrently assessed or scanned. This is necessary to ensure conditions have not changed in a significant way, i.e. that the current assessment of the best route is maintained. The assessment rate changes accordingly to the initial assessment and may change along the emergency vehicle's route to the destination. Sensing for the assessment may be carried out by the 6GS, with the support of the connected cars, but may also be carried out by the connected cars, e.g. in case of impairments in the 6G sensing process (e.g. when confidence level of vehicle density cannot be accurately determined) from the 6GS. This is realized by the 6GS sensing function by either modifying sensing radio resource allocation, switching between sensing modes, or collecting sensing information from other non-6G sensing sources such as video or LiDAR.

It is also important to note that sensing of traffic in proximity of the target object (vehicle) is carried out along the vehicle's route and should be a forward-looking assessment. In the example provided, if the emergency vehicle is close to its destination, the useful area would be around the vehicle and towards the destination, and it would be of little significance for the DT or even inefficient to assess traffic conditions elsewhere, e.g. close to its route's starting point. Therefore, the 6GS assessment needs to consider the provisioning of the best possible resources in the sensing service area, e.g. considering latency of communication towards the DT or other requirements like processing of sensing data. The choice of the best resources will therefore change along the route, and 6GS needs to ensure smooth transition of system resources allocated for the use case. In addition, along certain routes, connectivity and coverage problems, as well as lower speed zones may be a reality.

For coverage and connectivity problems, mechanisms to assess the quality of the connectivity along routes or in certain areas are required, namely as means to anticipate breaks in service or unfulfillment of KPIs, instead of reactively dealing with them when the emergency vehicle is already heading towards its destination. This could be achieved e.g. by keeping historical data of connectivity quality, as well as driving time related history of vehicles that previously used the route.

The connected car can provide useful sensing related information for the use case resorting to either 6GS or non-6GS (RF, video or LiDAR based) sensing. However, both video and LiDAR as sensing sources can also experience impairments. This could be due to weather conditions such as heavy rain that can impair the performance of computer vision algorithms [i.46] and cause LiDAR performance degradation due to bright sun, fog, rain, dirt and spray [i.47].

Different sensing modes should be considered as well because their resource usage is not equal, and same for their performance. For instance, a 6G BS operating in mono-static mode might not achieve the correct vehicle count resolution, as it may be difficult to distinguish between different reflective paths from different closely located vehicles. Operating in V2V or V2X bi-static mode or multi-static modes could help overcome this issue, but drawbacks include interference that might arise from simultaneous vehicle sensing signal transmissions, as well as additional sensing processing and coordination operations that would be required.

The area that is being sensed along the route will change in requirements. Optimal sensing procedures for this use case need distinction between e.g. empty and heavily loaded roads.

EXAMPLE: A 6G BS with a camera mounted with a clear view to a long stretch of empty road with no pedestrians in sight could prevent excessive resource allocation to RF sensing transmissions for a given 6G RAN node, or could help time sequential activated transmissions for two or more 6G RAN nodes, where the activation would follow the emergency vehicle's route.

The DT benefits from this information and may change the best route for the vehicle. If this happens, the new route is then communicated to the road users and emergency vehicle. As the emergency vehicle progresses on its route, the DT may send all sort of notifications and/or indications to any of the cars on the road, it being e.g. a warning that an emergency vehicle is approaching, a request for the vehicle to clear the road ahead, or perform a manoeuvre to clear the way, turn left/right to take a different route, etc.

The presented use case may be extended and applicable to different service level agreements between a customer, e.g. a taxi service user and a service provider of such type. The same technical principles would apply, and the DT could consider traffic prioritization for customers who have e.g. a fast-track subscription service.

5.17.4 Post-conditions

The emergency vehicle arrives at its destination with as little delay as possible. The route disturbance of other vehicles is minimized.

5.17.5 Potential requirements

Existing features partly or fully covering the use case functionality include positioning features.

New functional requirements in this use case are:

- [PR 5.17-1] The 6GS should be able to adapt the target sensing service area to be sensed over time to the emergency vehicle's route.
- [PR 5.17-2] The 6GS should be able to provide the best resources in the target sensing service area being sensed taking into account specific connectivity requirements and vehicle traffic limitations (e.g. speed limit) to achieve the sensing KPIs.
- [PR 5.17-3] The 6GS should ensure smooth transition of the allocated resources as the target sensing service area being sensed changes with the vehicle's position.
- [PR 5.17-4] The 6GS should be able to adapt the size of the target sensing service area to be sensed depending on the environment condition, both in location being sensed and physical size of the area being sensed.
- [PR 5.17-5] The 6GS should be able to selectively determine sensing sources by their location and sensing reachability to the concerned target sensing service area.

- [PR 5.17-6] The 6GS should be able to switch between sensing modes amongst -6G BSs and UEs for the detection and tracking of all elements relevant to the use case.
- [PR 5.17-7] The 6GS should be able to selectively determine suitable sensing transmitters and/or receivers by type depending on diverse weather conditions (e.g. bright sun, fog, rain, dirt and spray).
- [PR 5.17-8] The 6GS should be able to fuse sensing data from different sensing receivers to produce more accurate sensing results, e.g. under adverse weather conditions.
- [PR 5.17-9] The 6GS should be able to generate charging related information based on the information provided to the DT.

5.18 Use case on enhanced network performance and efficient use of resources via sensing-aided communications

5.18.1 Description

By combining sensing and communication capabilities on the same infrastructure, mobile networks can predict and comprehend the surrounding environment for indoor and outdoor NLoS UEs that require high speed reliable data, such as autonomous vehicles in industrial scenarios, surveillance UAVs in an urban setting, cloud game streaming, video conferencing, airplane or train cabin entertainment, Sensing-aided Ultra-high Throughput for Indoor Users and Sensing-aided local area collaboration for vehicular applications.

Urban areas or complex terrain pose challenges in establishing unobstructed Line of Sight (LoS) communication due to the presence of impediments such as buildings, trees, and uneven terrain. In Non-Line of Sight (NLoS) settings, multipath fading occurs as signals reflect off surfaces and traverse several routes. The overlapping of these reflections results in signal deterioration. The environment surrounding stationary UEs can be unpredictable and undergo changes because of a variety of factors, including the movement of other objects, changes in atmospheric conditions, and changes in network conditions, such as when there is network congestion or interference. Thus, UEs may not always retain a LoS connection. Tracking both the UEs and objects in their vicinity is vital for improving communication performance. The Positioning Reference Signal (PRS) is an essential component that aids in determining the location of the UE. However, this alone may not be adequate in complex scenarios for example obstacles impeding the LoS of the UE. The ISAC system can provide valuable information regarding the location and movement of passive objects. This allows the network to better adapt to dynamic environments and improve communication performance. Furthermore, for indoor UEs, sensing may be used by the system to identify indoor UEs that would benefit from an outdoor-to-indoor (O2I) relay to limit the effect of the O2I penetration loss. The communications node may also use sensing to identify the best beam for transmission.

The efficient utilization of resources could be both the network resources and UE resources. If a UE changes from LoS to NLoS (either because it has moved or an obstruction has moved in the LoS), then the best choice of base station to serve that UE may change. For example, if the UE is on a bus and moves behind a building, then this can be anticipated and the handover from nearest base-station to next-nearest base station (with or without an intermediate RIS) can commence before the shadowing occurs, thereby avoiding call dropping. This will free up resources at the initial base-station and the UE will need less transmit power, despite moving to a more distant base-station. Furthermore, efficient allocation of resources such as spectrum, time slots, and power utilization results in lower hardware/maintenance costs. This may be achieved via a fully integrated ISAC system on a single waveform, using the same frequency and hardware, or using different frequency bands for sensing and communication (for example, communication on sub-6GHz, and sensing on millimetre wave or THz frequencies) or alternatively allocating alternating time slots for sensing and communication on the same sub 6-GHz frequency or in high-band communications frequencies that require beam-based communications such as mmWave and THz.

This use case can be placed in any scenario with UEs that require high speed data, or an industrial scenario such as, e.g. a smart factory (warehouse, production, etc.) where autonomous vehicles are part of the day-to-day production to carry goods within the factory. The warehouse is equipped with a sensing-enabled 6GS that offers sensing services and non-6GS sensors (e.g. video, radar, lidar) are in use. The vehicle is also equipped with non-6GS sensors and has a communication radio allowing it to use the mobile network for data connectivity. 6G base stations may use sensing capability to detect beam blockage to machinery and/or autonomous vehicles and consequently apply beam update in advance to avoid interruption to the autonomous vehicles and/or machinery.

The use case aims at improving the radio communication using the fusion of sensing data from all available sensors to aid the RAN behaviour. The coordination of the sensing data collection, fusion and analytics is, e.g. conducted by the Core Network including the exposure of sensing results back to the RAN.

Figure 20 illustrates the sensing-aided communications use case where a single UE travels from a LoS position (1) to a NLoS position (2) and then further to a LoS position again (3). Furthermore, a Sensing Network Functions may be considered as an extension of the Core Network facilitating the coordination of sensing tasks independently from sensing modes. It encompasses fusion capabilities over sensing data from different sensors or sensor types, as well as analytics to determine sensing results and their exposure to other system components, i.e. BSs, UEs and other network functions. While doing so, a range of sensing capabilities are leveraged to detect the target object which breaks the line of sight including monostatic and bi-static sensing modes as well as external sensors. The gained knowledge about the environment is then used by the base station to optimize communication resources while the UE traverses the NLoS area, based on sensing results from itself, the UE and the Core Network. Furthermore, it is foreseen that the fusion of sensing data can be achieved in any of the sensing-enabled system components.

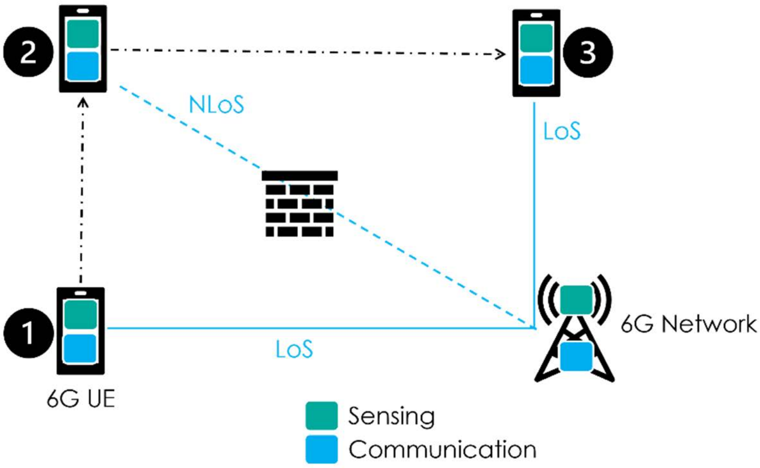

Figure 20: Use Case on Enhanced Network Performance via Sensing-Aided Communications

5.18.2 Pre-Conditions

The UEs support 6G communications and are registered on the RAN. The UEs and Base Stations (BSs) have sensing capabilities and may work in monostatic, bi-static, or multi-static sensing modes in the UE and BS configurations that are appropriate to the scenario under study.

5.18.3 Service Flows

Step 1: The UEs have an established connection with the 6GS that offers sensing services including 6GS and non-6GS sensing, to gather non 6GS sensing data, such as data from cameras and Lidar, at the BSs, UEs or both.

Step 2: The 6G BSs/UEs can transmit sensing and communication signal(s) to the UEs/BSs and objects in the UE's/BS's environment that may cause signal blockages.

Step 3: The BSs or UEs that are equipped with sensing receivers can decode the reflected sensing signals, or echoes, caused by the sensing target and perform processing of sensing data. The estimated parameters can aid in the sensing and tracking of the environment. The received signal is decoded to extract the transmitted data. The properties of the environment sensed may include the presence/absence of obstacles, the location of the UEs indoors/outdoors and the speed/velocity of their trajectory/blockage. Knowledge of the UE's location data is beneficial, but it is not always a requisite as valuable functionality may still be available without it. For example, CSI, can help determine UE identities, and signal quality measurements may suggest that there are obstacles in the LoS between the UE and the gNB. However, certain applications, like emergency services, may require exact location information to be known.

Step 4: The 6GS employs sensing processing for internal 6GS sensing as well as non-6GS sensing to improve communication and optimize the allocation of radio resources, hence improving the quality of service.

Step 5: For call maintenance, when the network/UE detects blockage in beam 1 and no blockage in alternate beam 2 based on sensing. UE and network can transfer link to alternate beam for minimal interruption in service.

Step 6: For UEs in motion, the communication node senses UE's movement and re-selects another beam pointing to the UE at the new position. The communication node continues to transmit the received data to the indoor UE with minimized interruption due to UE movement.

Step 7: For indoor UEs, the UE may connect to a detected out of band communication relay node. The communication node detects the presence of the indoor UE. Based on the sensing outcome, the communication node selects a proper beam pointing to the UE. The communication node receives data from the network via a backhaul link. The communication node transmits the received data to the indoor UE via a high-band frequency link. The communication node senses UE's movement and re-selects another beam pointing to the UE at the new position. The communication node continues to transmit the received data to the indoor UE with minimized interruption due to UE movement. The indoor UE disconnects with the communication node when the application ends.

Figure 21 illustrates the service flow for enhanced network performance via sensing-aided communication that has been detailed above.

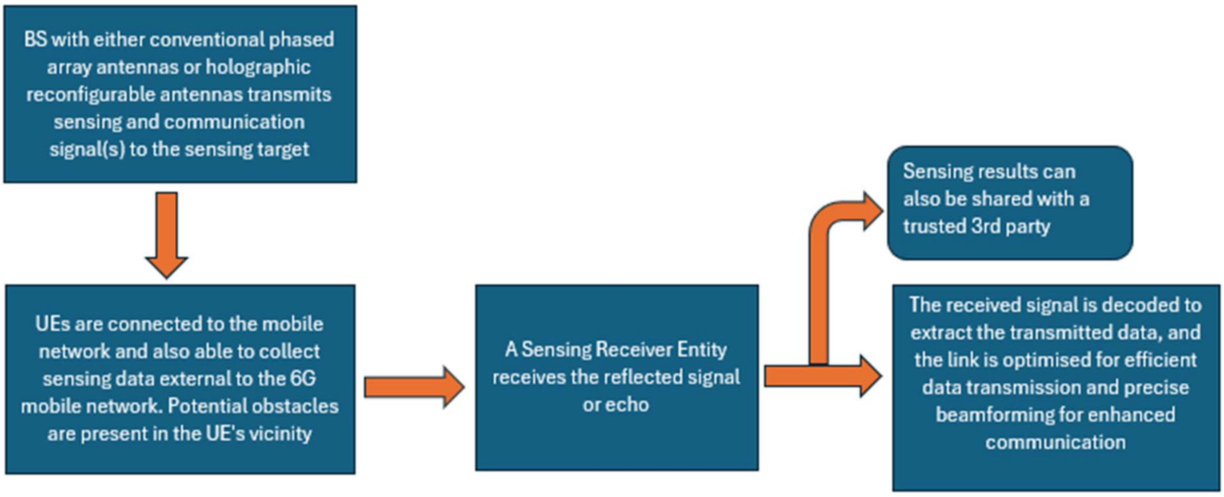

Figure 21: Service Flow for Enhanced Network Performance via Sensing-Aided Communications

5.18.4 Post-Conditions

Thanks to the sensing capabilities offered by ISAC, non-Line of Sight (NLoS) users have an improved Quality of Experience with ubiquitous and seamless data connectivity.

5.18.5 Potential Requirements

- [PR 5.18-1] The 6GS can support and be able to identify and configure sensing transmitters and sensing receivers with enhanced capabilities that may satisfy the request for sensing-aided communication for performance enhancement.
- [PR.5.18-2] The 6GS can support mechanisms for combining 6GS sensing data and non-6GS sensing data (e.g. from Lidar, cameras.) depending on location, availability of non-6GS sensing data.
- [PR 5.18-3] The 6GS is able to support the positioning and sensing-related KPI requirements in Table 12 relevant to ISAC adapted from 3GPP TR 22.837 [i.1] and 3GPP TS 22.137 [i.2].
- [PR 5.18-4] The extension of the Core Network's functionality to enable sensing, as described in Figure 21, should follow Service-Based Architecture principles and enable the implementation of different General Data Protection Regulation (GDPRs) across jurisdictions. Moreover, the extension of the Core Network to enable sensing should be designed so that a 6GS can also be deployed without sensing, e.g. for private networks solely enabling a service type that does not rely on ISAC capabilities being available. This includes considerations for either 6G RAN or 6G CN not supporting ISAC and leveraging either Service-Based Architecture (SBA) principles or dedicated capability exchange procedures to bootstrap the network successfully.

- [PR 5.18-5] The indoor UE should support detecting/sensing, connecting to and communicating with the communication node. It should have high data rate support from the network to the communication node and a good link budget from the communication node to the indoor UE to combat the severe propagation conditions at high band frequencies.

Table 12: Performance Requirements for Enhanced Network Performance via Sensing-Aided Communications

Service Description	Confidence Level	Pos./Sensing Accuracy Vertical/ Horizontal	Pos./Sensing Range Resolution	Pos./Sensing Velocity Resolution	Max. Response Time/ Latency	Reliability
Indoor/Outdoor NLoS UEs (such as for uninterrupted streaming, cloud gaming or video conferencing (note 1)	95 %	1 m/1 m	1 m	1 m/s	5 ms ~ 250 ms	≥ 98 %
Indoor NLoS non-stationary Autonomous Vehicles in Industrial Scenarios (note 2)	95 %	0,5 m/0,5 m	0,5 m	0,5 m/s	5 ms ~ 100 ms	≥ 99 %
Outdoor NLoS non-stationary Autonomous Vehicles Industrial Scenarios/Surveillance UAVs (note 2)	95 %	1 - 2 m/1-2 m	10 m	10 m/s	10 ~ 1 000 ms	≥ 95 %
Indoor/outdoor Object to be detected: Factory AGV/AMR, human, animals, vehicles, and other related obstacles (note 2)	95 %	0,5 m/0,5 m	0,5 m	Industrial scenarios: 0,5 m/s	10 to ~1 000 ms	≥ 97 %

NOTE 1: KPIs in this row refer to the positioning accuracy and resolution requirements. They are only applicable if required by the application.
NOTE 2: KPIs in this row refer to the sensing accuracy and resolution requirements.

6 Considerations on 6G use cases for ISAC

6.1 Considerations on deployment scenarios

Based on the use case description in clause 5, the following criteria can be considered for deployment scenarios description:

- Indoor (I), outdoor (O), mixed indoor/outdoor (I2O, O2I).
- Micro (Mi) or/and macro (Ma) cell.
- Urban (U), rural (R), in-Factory (InF), in-household (InH), indoor office, aerial vehicles (AV), highway, Urban grid.
- Mobility type (including motion of sensing targets in the range of centimeters): static (S), pedestrian (P), vehicular low-average, vehicular high.
- In coverage (IC) or/and Out of Coverage (OoC).

Table 13 summarizes the typical deployments of the considered use cases.

Table 13: Mapping of deployment scenarios to the considered use cases

Use case	Deployment type	Deployment scenarios	Sensing target type and mobility	Other characteristics
Human motion recognition	Indoor and/or outdoor	UMa, UMi, In-H, Indoor office	Human, low mobility	Fine movement detection
Airborne-based sensing for environmental reconstruction	Outdoors	UMa-AV, RMa-AV	Low/Medium/high mobility	The deployment scenario covers the surroundings of the vehicle flight area, both on the ground and in space, which depends on the different height levels of airborne vehicles (e.g. about 100 m for UAVs; up to a few km for LAPS; around 20 km for HAPS)
Real-time monitoring of health hazard and disaster risk	Outdoors, mixed indoor-outdoor	UMa, UMi, RMa, UMa-AV, UMi-AV, RMa-AV	All target types (human, vehicles, buildings, objects) with low/medium mobility	
Emergency search and rescue	Indoor and/or outdoor	UMa, Umi, RMa	Human target, static or low mobility (centimetre level)	Sensing is performed in a small area around the UE(s) In and out of coverage
Remotely controlled robots for senior citizen monitoring and care	Indoor	In-H, indoor office	Humans (static, low mobility) and objects	
Precise localization for robot grasping	Outdoor, indoor	UMa, UMi, InF	Objects, static or low mobility	
Micro-deformation sensing	Outdoor	UMa, UMi, Urban grid	Building, bridge, other infrastructure, static with vibration/deformation	
Traffic throughput and safety on road intersections	Outdoors	UMa, Urban grid, urban canyon	Pedestrian, vehicles with low/medium mobility	
Collaborative robots based on digital twinning	Indoors	InF	Objects, robots with low mobility	One sensing-enabled base station and multiple robots that also act as UEs
Body proximity sensor	Indoor, outdoor	UMa, UMi, In-H, indoor office	Human, static, low mobility (centimetre level)	In coverage or/and out of coverage
High resolution topographical maps	Outdoor	Any outdoor	Static objects/buildings, humans, vehicles with all mobility levels	
Outdoor healthcare sensing and monitoring	Outdoor	Any outdoor	Humans with low mobility	
R-CPS in industrial worksites	Indoor	InF	Humans, objects, robots, static or with low mobility	
Use case on safe & economic UAV transport	Outdoor	UMa, UMi, RMa, UMa-AV, UMi-AV, RMa-AV	UAVs, aircrafts	
Use case on emergency vehicle route planning	Outdoors	UMa, Urban grid, urban canyon, highway	Vehicles with low/medium/high mobility, environment objects	Nodes with different sensing capabilities may impact the sensing coverage for the use case
Sensing-aided communications	Indoor and outdoor	Any		In coverage or/and out of coverage
Use case for automated guided vehicles travelling in airports	Large indoor area or mixed indoor/outdoor area.	Large indoor such as airport halls	Humans or vehicles with low/medium mobility	
Vison-aided sensing	Outdoors	UMi, UMa, Urban grid, highway	Vehicles with low/medium/high mobility and humans	

Ongoing and future work on channel modelling carried out in ETSI GR ISC 002 [i.56] on Channel Modeling, Measurements and Evaluation Methodology [i.56] needs to take into account the considered deployment scenarios.

For many use cases proposed in clause 5, the baseline approaches for channel modeling can be used for the potential evaluation. For example, 3GPP Rel-19 ISAC channel modeling can be used for object detection and/or tracking including UAVs, human indoors and outdoors, AGV, Vehicle, Objects creating hazards on roads/railways, and even environment objects. This channel modeling is valid for many of the above use cases, including for the use case of body proximity sensor in clause 5.2, airborne-based sensing for environment reconstruction in clause 5.3, high-resolution topographical maps in clause 5.4, Use case on collaborative robots based on digital twinning in clause 5.10, use case on traffic throughput and safety on road intersections in clause 5.14, use case on safe & economic UAV transport in clause 5.15, use case for automated guided vehicles travelling in airports in clause 5.16, use case on emergency vehicle route planning in clause 5.17, use case on enhanced network performance and efficient use of resources via sensing-aided communications in clause 5.18.

Basically, for all use cases, RCS modeling for different types of sensing objects is needed for potential evaluation. An RCS modeling methodology is needed.

For some use cases, micro-Doppler modeling may be further needed to evaluate the human body's small-scale motion, such as human gesture, breathing, heartbeat, etc. This advanced channel modeling part is valid for some of above use cases, including for the use case on human motion recognition in clause 5.1, the use case on real-time monitoring of health hazard and disaster risk in clause 5.6, the use case on emergency search and rescue in clause 5.7, the use case for outdoor healthcare sensing and monitoring in clause 5.8, the use case on remotely controlled robots for senior citizen monitoring and care in clause 5.9.

For the use case on emergency search and rescue in clause 5.7, in the out of coverage scenario, specific modelling for UE-to-UE sensing channel is needed.

For another use cases, for example, the use case on micro-deformation sensing in clause 5.13, ray tracing simulation methodology can be used for specific scenarios, such as bridge micro-deformation.

For some other use cases, for example, the use case on precise localization for robot grasping in clause 5.11, the use case of body proximity sensor in clause 5.2, near-field modeling for sensing may be needed because the sensing transceiver may have large size of antenna array and may be very close to the sensing target.

Ongoing and future work carried out in ETSI GR ISC 003 [i.57] on system and RAN architectures needs to consider the complete set of deployment scenarios for these use cases. This is to ensure that that the issues and potential approaches discussed in ETSI GR ISC 003 [i.57] can fully support these use cases.

In addition to covering the various deployments of network infrastructure for these deployment scenarios, ETSI GR ISC 003 [i.57] should importantly ensure that the system and RAN architectures work considers both In Coverage (IC) and Out of Coverage (OoC) deployment scenarios. This is particularly relevant to use cases which list both of these coverage scenarios. These include, Emergency search and rescue (clause 5.7), body proximity sensor (clause 5.2) and sensing aided communication (clause 5.18).

6.2 Considerations on suitable frequency bands

For RF sensing, the operating frequency has consequences on the sensing characteristics and objects may have different RCS at different bands. Some important aspects are reflected in the following criteria:

- Higher frequency reduces the dimension (or space) of the antenna array for a given angular resolution. Alternatively, more antennas could use the same space to increase angular resolution, which is beneficial for UE and for the base station.
- Higher frequency simplifies achieving higher range accuracy and resolution due to the availability of a larger signal bandwidth.
- Higher frequency leads to more directional signals with less multipath components.
- Higher frequency leads to larger Doppler shifts for the same target velocity.
- Higher frequency leads to higher path loss.

These varying band-specific sensing characteristics can benefit from knowledge of the above spectral environment, particularly in the multi-spectral/multi-frequency band sensing cases.

Suitable frequency bands for the considered use cases are summarized in Table 14.

Table 14: Suitable frequency bands for the considered use cases

Use case	Sub-6 GHz	7-24,25 GHz	>24,25 GHz	Non-6GS bands
Human motion recognition	Yes	Yes	Yes	Yes
Airborne-based sensing for environmental reconstruction	Yes	Yes	Yes	
Real-time monitoring of health hazard and disaster risk	Yes	Yes	Yes	Yes
Emergency search and rescue	Yes	In assistance to low bands	In assistance to low bands	Yes
Remotely controlled robots for senior citizen monitoring and care	Yes	Yes	Yes	Yes
Precise localization for robot grasping		Yes	Yes	Optional assistance to 6GS sensing
Micro-deformation sensing	Yes	Possible	Possible	
Traffic throughput and safety on road intersections	Yes	Yes	Yes	Optional
Collaborative robots based on digital twinning	Yes	Yes	Yes	
Body proximity sensor	-	Yes	Yes	-
High resolution topographical maps	Yes	Yes	Yes	Yes
Outdoor healthcare sensing and monitoring	Yes	Yes	Possible	
R-CPS in industrial worksites	Yes	Yes	Yes	Yes
Use case on safe & economic UAV transport	Yes	Yes	Possible	Optional
Use case on emergency vehicle route planning	Possible	Yes	Yes	
Sensing-aided communications	Possible, in assistance to mid/high bands	Yes	Yes	Optional (for sensing optimization)
Use case for automated guided vehicles travelling in airports	-	-	Yes	
Vison-aided sensing	Yes	Yes	Yes	Yes

Use cases relying mostly or exclusively of 6GS RF sensing and targeting high precision positioning and/or sensing resolution mostly rely on high or middle frequency bands. This is the case for example for at least precise localization for robot grasping, body proximity sensor, or AGV in airports use cases. Mid/high-band frequency propagation suffers from high path loss. Although this issue is somehow limited when LoS conditions may be ensured such as in the case of UAVs in direct view, assistance from low bands (sub-6 GHz) is beneficial in complement of using mid/high bands. Such is the case for airborne-based sensing for environmental reconstruction, emergency vehicle route planning, or sensing-aided communications.

In other cases, sensing range is more important than sensing precision, hence low bands are primarily preferred, with potential assistance from mid/high bands operation. Such is the case for the use case on emergency search and rescue or micro-deformation sensing.

Some use cases either rely on or can benefit from sensing data fusion between 6GS RF sensing and other external sensors, regardless of the frequency band used for sensing, that can be complementary to 6GS sensing. Such is the case for example for real-time monitoring of health hazard and disaster risk, remotely controlled robots for senior citizen monitoring and care, precise localization for robot grasping, or R-CPS in industrial worksites. For these use cases in particular, and for all use cases in general, multi-band approaches where the used frequency band(s) for sensing may be chosen depending on various factors are beneficial. To enable efficient and adaptable ISAC systems, sensing knowledge of these multi-band environments can help optimize sensing accuracy, reliability, and effectiveness.

6.3 Considerations on sensing modes

Table 15 summarizes the appropriate sensing modes for each described use case.

Table 15: Mapping between use cases and sensing modes

Use case	TRP monostatic	UE monostatic	TRP-UE bistatic	UE-TRP bistatic	TRP-TRP bistatic	UE-UE bistatic
Human motion recognition	X	X	X	X	X	X
Airborne-based sensing for environmental reconstruction		X	X	X		X
Real-time monitoring of health hazard and disaster risk	X	X	X	X	X	X
Emergency search and rescue		X	(X) Note 2			X
Remotely controlled robots for senior citizen monitoring and care	X	X	X	X	(X) Note 1	(X) Note 1
Precise localization for robot grasping	X	X	X	X	X	X
Micro-deformation sensing	X				X	
Traffic throughput and safety on road intersections	X	X	(X) Note 2	X	X	(X) Note 2
Collaborative robots based on digital twinning	X	X	X	X	X	X
Body proximity sensor	X	X				
High resolution topographical maps	X	X	X	X	X	X
Outdoor healthcare sensing and monitoring	X	X	X	X	X	X
R-CPS in industrial worksites	X	X	X	X	X	X
Use case on safe & economic UAV transport	X	X	(X) Note 2	(X) Note 2	X	(X) Note 2
Use case on emergency vehicle route planning	X	X	X	X	X	X
Sensing-aided communications	X	X	X	X	X	X
Use case for automated guided vehicles travelling in airports	X	X	X	X	X	X
Vison-aided sensing	X		X	X	X	
NOTE 1: May be subject to deployment limitations in household environments. NOTE 2: If in coverage.						

For a majority of use cases there is no prerequisite requirement in terms of sensing modes. Making use of several sensing modes and being able to switch among them is recommended in order to meet the sensing results KPI requirements. Multiple sensing modes may thus be cooperative, and sensing results may be fused among sensing modes and/or with non-6GS sensing from external sensors. Whenever possible, adding TRPs and/or UEs to the deployment easily extends the sensing modes to their multi-static variants.

Some limitations may arise from specific deployments. For example, in case of in-household deployments, it may not be possible to ensure he presence of multiple TRPs and/or multiple UEs, hence TRP/TRP and UE/UE bistatic modes may not be feasible.

Some use cases mandated to operate in out of coverage scenarios or in the case of network or GNSS failure may be limited to UE monostatic/bistatic sensing.

All sensing modes are beneficial and should be supported. Depending on the deployment or required service, some sensing modes may be preferred for specific use cases at specific times. Selection of optimal sensing parameters across one or a combination of these modes can benefit or optimize the effectiveness of one or more of any of the modes and use cases.

Ongoing and future work carried out in ETSI GR ISC 003 [i.57] on system and RAN architectures needs to consider the listed sensing modes for these use cases. Many of the user cases can utilize all 6 of defined sensing modes. For some selected use cases, only a subset of the sensing modes is appropriate.

The selection of suitable sensing modes may further be driven by non-technical considerations. For example, it may be beneficial to use an appropriate sensing node, i.e. sensing transmitter and/or sensing receiver, close to the sensing target to reduce the energy consumption in order to achieve specific sustainability goals. Furthermore, single sensor operation may be preferred over fusion of multiple sensing nodes from sustainability perspective.

Considering privacy and security requirements may justify the decision towards a specific sensing mode, if the use case is realizable with multiple modes from a technical perspective. The work carried out in ETSI GR ISC 004 [i.58] on security, privacy, trustworthiness, and sustainability needs to study the sensing modes from the privacy and security point of view. This includes to identify if some sensing modes are more appropriate to some of the key issues that will be identified within this Work Item than others.

6.4 Considerations on integration levels

All described use cases include various versions that may be realized with all integration levels. Yet, some versions may require specific integration levels.

Tight integration offers a higher efficiency to perform simultaneous communication and sensing tasks by leveraging unified waveform and baseband design mechanisms and control. Such tight integration with joint unified waveform and/or signal design may increase performance, either using the same or different frequency bands for sensing and communications.

For example, in the case of micro-deformation sensing, strong integration is beneficial because of large coverage and potential features such as carrier phase detection offered by 6GS. Informing human around the detected dangerous building on time also benefits from strong integration.

In the example of collaborative robots based on digital twinning, robots will act as sensing enabled UEs and have constraints in terms of power supply and potential space to mount additional sensors. A tighter level of integration is beneficial.

In the case of use cases such as body proximity sensor, traffic throughput and safety on road intersections, or AGVs travelling in airports, an intermediate integration level with shared hardware and shared spectrum is beneficial.

For other use cases, loose integration is preferred when it is beneficial to combine 6GS sensing and sensing from other external sources, or when non-6GS-based sensing may be optionally used as a complement to 6GS-based sensing. This is the case for example for human motion recognition, real-time monitoring of health hazard and disaster risk, remotely controlled robots for senior citizen monitoring and care, precise localization for robot grasping, or R-CPS in industrial worksites.

Since all use case may be realized based on multiple integration levels, all integration levels are recommended to be supported and there is no required prerequisite or prioritized integration level.

A there are no required prerequisite integration levels for each user case, the ongoing and future work carried out in ETSI GR ISC 003 [i.57] on system and RAN will separately consider the sensing KPIs and communications KPIs of each use case and furthermore, if these two KPIs are required to be fulfilled simultaneously. This will ensure that the architectural work, conducted in ETSI GR ISC 003 [i.57] will be suitable to support these use cases.

The decision towards a specific integration level may further be driven by requirements of security and trustworthiness. Each integration level has its unique properties with specific interfaces and system functionalities that may have specific advantages and drawback in terms of security, potentially even depending on the use case. Especially the case of loose integration that utilizes non-6GS-based sensors needs to incorporate well-designed methods for authorization and authentication to expose sensing results only to those who are intended and authorized to have access to the sensing data and/or sensing results of these sensors. These aspects will be analysed in ETSI GR ISC 004 [i.58] on security, privacy, trustworthiness, and sustainability.

6.5 Considerations on 6G use case challenges

Use cases described in the present document identified that at least the following classes of applications need specific support from future 6G systems:

- Small scale motion/micro-movements (human motion, infrastructure vibration, fine tools movements).
- Realtime digital twin/cyberphysical systems.

- Human-robot and robot-robot interaction, remote control.
- Public safety/health (first responder, automotive, infrastructure).

Although motion classification and large scale motion are topics already investigated, wireless network support for fine scale motion and micro-movements has stringent requirements in terms of accuracy and may require specific sensing procedures.

The realtime aspect needed in several use cases is equally challenging. Sensing should allow extremely precise position, orientation and micro movements of tools (such as drills, skewers or hammers) and of people closely interacting with robots in realtime. This also calls out the necessity to synchronize XR data from/to robots (UEs) and the sensing results exposed to a remote site or to a digital twin, and to allow precise control algorithms for e.g. remotely controlled robots. For cases where robots are expected to assist and accompany humans, technologies enabling robots to reproduce human sensory and behavioural characteristics such as posture, poise, facial expressions, emotions, mood need to be developed.

The societal needs exposed in the use cases related to public health and safety also raise technical challenges, for example for achieving localization of individuals within a small service area and under difficult propagation conditions such as blockage and in the out-of-coverage case by leveraging UE-centric processing and fusion of sensors, or high resolution topographical, environmental or hazard maps. Automotive related use cases also demand reliable low-latency data processing and fusion capabilities that surpass traditional sensing systems, especially in high-density urban settings, to enable adaptive traffic control and safer road environments. High situational awareness with high mobility environment(s) which include(s) people and other moving objects (e.g. vehicles, AGVs, industrial machines) makes operational field very dynamic and challenging by introducing the possibility of collision, crash and resultant severe injuries in the environment.

Possible technical solution identified as beneficial for most described use cases include:

- Sensing/communication mutual assistance.
- Distributed sensing (e.g. airborne or terrestrial device to device).
- Fusion of sensing data from different sources.
- These technical areas need to be developed in order to enable 6G use cases.

6.6 Other considerations

For many described use cases, enabling technologies such as AI/ML, data fusion, or carrier phase detection have been identified as being beneficial. Many deployments share some of the characteristics of a distributed sensing network whose results can be further combined and exposed to a third-party application, or, on the contrary, take third party sensing results as inputs. Third party applications can provide sensing results based on RF sensing (Wi-Fi®, UWB, BLE (Bluetooth® Low Energy), radar, etc.) or non-RF sensing (e.g. lidar, cameras, other).

The interaction between physical and digital world (e.g. digital twin, cyber-physical systems) needs to take into account the impact of sensing service latencies on remote control operations and on control algorithms.

7 Consolidated potential requirements and KPIs for 6G

7.1 Consolidated Potential Functional Requirements

The Consolidated Potential functional Requirements (CPR) are categorized into four tables:

- Table 16: Consolidated potential sensing requirements for 6G systems.
- Table 17: Potential configuration requirements for Sensing-Enabled 6G Systems.
- Table 18: Potential exposure requirements for sensing-enabled 6G systems.
- Table 19: Potential security, privacy and trustworthiness requirements for sensing-enabled 6G systems.

NOTE: All CPRs are subject to regulatory requirements under Sensing Service Provider control and user consent.

Table 16: Consolidated potential general sensing requirements for 6G systems

CPR #	Consolidated Potential Requirements	Original PR #
CPR1-1	The 6GS should be able to classify and recognize multiple types of moving or static targets, their motions and their spatial relations to each other. (See note 2)	PR 5.1-1 PR 5.2-1 PR 5.2-2 PR 5.7-5 PR 5.8-1 PR 5.11-1 PR 5.11-2 PR 5.12-1 PR 5.13-2 PR 5.16-1 PR 5.18-1
CPR1-2	The Sensing Receiver should be able to deliver Sensing Data for further processing within the 6GS.	PR 5.3-3 PR 5.3-4
CPR1-3	The 6GS should be able to fuse Sensing Data or Sensing Results before they are exposed to the Sensing Service consumer.	PR 5.3-6 PR 5.6-1 PR 5.7-3 PR 5.12-3 PR 5.14-6 PR 5.15-5 PR 5.16-3 PR 5.17-8 PR 5.5-2 PR 5.5-3
CPR1-4	The 6GS should be able to process 6G and non-6G Sensing Data into Sensing Results.	PR 5.6-1 PR 5.7-2 PR 5.7-3 PR 5.12-3 PR 5.14-6 PR 5.14-10 PR 5.15-5 PR 5.17-5 PR 5.18-2 PR 5.5-1
CPR1-5	The 6GS should be able to synchronize multi-modality data flows with exposed Sensing Results. (See notes 1 and 3)	PR 5.9-1 PR 5.10-4 PR 5.12-5
CPR1-6	The 6GS should be able to assess the quality of the Sensing Results. (See note 4)	PR 5.14-11 PR 5.15-7
CPR1-11	The 6GS should be able to utilize Sensing Results within its own system entities.	PR 5.5-3 PR 5.18-1
NOTE 1: Multi-modality transmission refers to transmission coordination across different type of traffic flows, e.g. audio, video, sensor, pressure or tactile. NOTE 2: Examples of target classification include human vs non-human or type of non-human targets (e.g. cars, buildings). Examples of spatial relations are distances between Sensing Receiver and targets as well as among targets. This also includes relative position of target. Examples of motions include human body fine-motions such as breathing, heart rate or hand gestures, or fine-motions of non-human target such as vibration. NOTE 3: This may require the synchronization of Sensing Data flows with multi-modality data flows within the 6GS. NOTE 4: This also may require the 6GS to assess the quality of Sensing Data.		

Table 17: Potential configuration requirements for sensing-enabled 6G systems

CPR #	Consolidated Potential Requirements	Original PR #
CPR2-1	The 6G system should be able to identify suitable Sensing Transmitters and Sensing Receivers based on their capabilities and the Sensing Service requirements. The 6GS should be also able to (re-)configure the Sensing Task based on the Sensing Service requirements.	PR 5.2-3 PR 5.3-2 PR 5.4-1 PR 5.6-1 PR 5.6-2 PR 5.7-1 PR 5.8-2 PR 5.10-1 PR 5.10-2 PR 5.10-5 PR 5.17-2 PR 5.17-3 PR 5.17-1 PR 5.17-6 PR 5.18-1
CPR2-2	The 6GS should be able to enable Sensing Modes at 6G UEs that are out of coverage.	PR 5.7-4
CPR2-3	The 6GS should be able to authenticate third parties based on contextual information, e.g. location.	PR 5.6-2

Table 18: Potential exposure requirements for sensing-enabled 6G systems

CPR #	Consolidated Potential Requirements	Original PR #
CPR3-1	The 6GS should be able to expose Sensing Results to trusted third-party applications. This exposure can depend on contextual information. See note.	PR 5.3-1 PR 5.3-3 PR 5.3-5 PR 5.6-3 PR 5.8-4 PR 5.10-4 PR 5.13-3
CPR3-2	The 6GS should be able to notify the Sensing Service consumer if requested Sensing KPIs are not met.	PR 5.12-7
CPR3-3	The 6GS should be able to perform charging for the Sensing Service.	PR 5.17-9
NOTE: This includes the exposure of Sensing Results generated by a 6G UE to trusted third-party applications.		

Table 19: Potential security, privacy and trustworthiness requirements for sensing-enabled 6G systems

CPR #	Consolidated Potential Requirements	Original PR #
CPR4-1	The 6GS should be able to provide methods and procedures for collecting user consents, secure data collection, and authorized access to the Sensing Data and/or Sensing Results.	PR 5.8-3 PR 5.9-2 PR 5.11-1 PR 5.12-2 PR 5.14-12 PR 5.16-4 PR 5.5-3

7.2 Consolidated Potential Performance Requirements

This clause provides consolidate potential performance requirements from all use cases. The KPIs in Table 20 are to be considered in conjunction with any applicable existing KPIs from [i.1] and [i.2].

Fine Motion refers to a motion of the parts of the target. Examples include hand gestures, breath, heartbeat, blinking eyes, opening mouth, bridge vibrations, or the motion of construction tools (e.g. speed of drills).

Sensing Service Range refers to a distance in one or more axis from a reference point.

Table 20: Consolidated Key Performance Indicators

Use Case	Sensing Service Area	Confidence Level [%]	Accuracy of positioning estimate by sensing (for a target confidence level)		Accuracy of velocity estimate by sensing (for a target confidence level)		Sensing Resolution		Fine Motion Accuracy	Sensing Service Range [m]	Max Sensing Service Latency [ms]	Refresh Rate [s]	Missed Detection [%]	False Positive [%]
			Horizontal [m]	Vertical [m]	Horizontal [m/s]	Vertical [m/s]	Range Resolution [m]	Velocity Resolution [m/s]						
Airborne-based sensing for environment reconstruction (5.3)	Outdoor		0,5-1 Note 1	1,0 Note 1	1,5 Note 1	1,5 Note 1	3	5			≤ 100	≥ 0,1	≤ 3	≤ 3
High topology mapping (5.4)	Outdoor	Note 2	0,10	0,10	Note 2	Note 2	0,4	Note 2			50	Note 2	≤ 10	≤ 1
Vision-aided smart traffic management (5.5)	Outdoor	95	0,5 - 1 Note 15	1 - 5 Note 16	0,5 Note 17	1 Note 16, Note 17	0,5 Note 17	1 Note 17			≤ 100	≤ 0,03 Note 17	≤ 5	≤ 5
Search and Rescue (5.7)	Outdoor Indoor		0,5 Note 3	0,5 Note 3	0,1	0,1								
Health Monitoring (5.8)	Outdoor Indoor	95	0,5 - 1 Note 4 Note 5	0,5 - 1 Note 6	1,5 Note 6	1,5 Note 6	≤ 0,5 Note 6	2 - 3 Note 6	0,05 Note 4 Note 5		≤ 2 000	≤ 1 Note 6 Note 7	≤ 10 Note 6	≤ 2
Collaborative Robots (5.10)	Outdoor Indoor	95 Note 8	≤ 0,1 Note 9	≤ 0,1 Note 9					Note 13		Note 10			
Robot Grasping (5.11)	Outdoor Indoor	99 Note 11	0,001 - 0,01	≤ 0,2	0,01 - 0,1	0,01 - 0,1						0,01 - 0,1		
Realtime Cyber-Physical Systems (5.12)	Indoor Outdoor	Five 9s	≤ 0,01	≤ 0,01										
Micro-Deformation (5.13)	Indoor Outdoor								Note 14		≤ 100	1 000		
Safety on Road Intersections (5.14)	Outdoor						0,3-1			100	100			0,01
UAV Transport (5.15)	Outdoor	99,999								200	≤ 1 000	≤ 10		
Automated Guided Vehicles (5.16)	Indoor Outdoor	96	0,25 - 0,5	0,25 - 0,5	2 - 20	2 - 20	≤ 0,5	≤ 0,3			≤ 5	≤ 0,1	≤ 1	≤ 2

Video Streaming by NLoS UEs (5.18)	Indoor Outdoor	95	1	1			1	1			5 - 250		≤ 2	≤ 2
NLoS Autonomous vehicles (5.18)	Indoor	95	0,5	0,5			0,5	0,5			5 - 100		≤ 1	≤ 1
	Outdoor	95	1 - 2	1 - 2			10	10			10 - 1 000		≤ 5	≤ 5

NOTE 1: Actual values could change depending on the type of airborne vehicle.
NOTE 2: KPIs adapted from 3GPP TR 22.837 [i.1] use case 5.28.
NOTE 3: For distances up to 20 m.
NOTE 4: Sit-up rate = 30 times/min as reference, 0,05 Hz corresponds to 3 times/min.
NOTE 5: Push-up rate = 40 times/min as reference, 1/15 Hz corresponds to 4 times/min.
NOTE 6: Actual values could change due to outdoor activities like walking, running, cycling.
NOTE 7: Actual values could change due to sensing tasks, e.g. macro activity or micro activity sensing.
NOTE 8: Derived from [i.1], clause 5.1.2.3.
NOTE 9: The positioning KPI is a linear motion path accuracy requirement in x-y-z positioning. Furthermore, the use case described in clause 5.10 also requires an orientation accuracy across the x-y-z coordinates, which needs to be studied.
NOTE 10: This use case involves a Digital Twin and the maximum latency to generate sensing results can be potentially offset algorithmically, which requires further studies.
NOTE 11: Confidence level for distances of up to 10 cm from target object. For example, given micro-target is a grasping point that robot arm is approaching to.
NOTE 12: This accuracy is a relative motion between two objects (clause 5.11).
NOTE 13: As no existing work can be identified that provides experimental- or simulation-driven data to support this sensing KPI, new studies are required to provide precise numbers.
NOTE 14: The accuracy is preferably mm-level to enable highly accurate structural health monitoring.
NOTE 15: Width of vehicles roughly varies between 1 - 2 m as reference.
NOTE 16: Vertical movement is not critical in traffic scenarios.
NOTE 17: Actual values may change due to the environment being observed, as the dynamics of urban, rural and highway scenes are very different.

8 Conclusions and recommendations

The scope of the present document is to identify and describe advanced ISAC use cases and identify key requirements stemming upon future 6G communications systems to support these advanced use cases. The current work is placed in the framework of other parallel initiatives ongoing worldwide and supported by the whole research ecosystem, including standardization bodies, industrial individual members and stakeholder associations, academia, strategic national and regional collaborative projects. To set the foundations of ISAC, the present document gives an overview of relevant existing use cases developed by such parallel initiatives. It furthermore addresses the definition and description of 3 integration levels (tight, intermediate and loose integration) and 6 sensing modes (TRP-TRP bistatic, TRP monostatic, TRP-UE bistatic, UE-TRP bistatic, UE-UE bistatic and UE monostatic).

The present document further identified and described the following 18 advanced ISAC use cases:

- Human motion recognition.
- Airborne-based sensing for environmental reconstruction.
- Real-time monitoring of health hazard and disaster risk.
- Emergency search and rescue.
- Remotely controlled robots for senior citizen monitoring and care.
- Precise localization for robot grasping.
- Micro-deformation sensing.
- Traffic throughput and safety on road intersections.
- Collaborative robots based on digital twinning.
- Body proximity sensor.
- High resolution topographical maps.
- Outdoor healthcare sensing and monitoring.
- R-CPS in industrial worksites.
- Use case on safe & economic UAV transport.
- Use case on emergency vehicle route planning.
- Sensing-aided communications.
- Use case for automated guided vehicles travelling in airports.
- Vison-aided sensing.

For each identified use case, the present document provides description of the deployment scenario, pre-conditions required for the use case deployment, an example of service flows through a communication system supporting the use case, post-conditions enabled by the use case, and identified potential requirement. In some cases, the present document further identifies enabling technologies either unlocking or being highly beneficial for the associated use cases.

Mapping of use cases to pertinent deployment scenarios is conducted, exposing a large variety of possible deployments: indoors, outdoors, mixed in- and out-doors, in or out of network coverage, and with various types of sensing targets (e.g. humans, vehicles, UAVs, buildings, robots, objects) and all mobility levels. This impacts ongoing and future work on channel modelling, that would need to take into consideration the variety of possible deployments, RCS modelling covering of a vast number of target types, and some use case specificities requiring micro-Doppler or near-field modelling. System and RAN architecture design is equally impacted and needs to consider the complete set of deployment scenarios, in and out of coverage.

Regarding the pertinent frequency bands for sensing needs, the described use cases rely on either one or a combination of the following:

- 6GS RF sensing targeting high precision positioning and/or sensing resolution in high (mmWave and/or above) or middle (~7 - 24 GHz) frequency bands.
- 6GS RF sensing targeting high sensing range in lower (typically sub-6 GHz) bands.
- Non 6GS sensing (RF-based or from other non-RF sources, e.g. sensors, cameras, etc.).

Many use cases deem beneficial multi-band approaches where the used frequency band(s) for sensing may be chosen depending on various factors, or where sensing assistance from various frequency bands improves the sensing result. Fusion of 6GS and non-6GS sensing data (regardless of the frequency band used for performing the sensing operation) is often considered.

Although some sensing modes may be preferred for specific use cases at specific times (e.g. depending on deployment scenarios and constraints), there is no identified prerequisite requirement in terms of sensing modes. Making use of several sensing modes and being able to switch among them is deemed beneficial. All sensing modes are recommended to be supported, with no specific prioritization.

All described use cases include various versions that may be realized with all integration levels. While tight or intermediate integration may increase performance and have practical advantages (e.g. shared hardware), loose integration offers the flexibility of combining data from different sensing sources. System and RAN architecture should consider all integration levels. As previously tackled, fusion of 6GS and non-6GS sensing data is possible and beneficial for a number of use cases. Such fusion can be done either within the 6GS, or by an external third party, which leads to impacts on system architecture and security/trustworthiness.

The present document analyses the advanced ISAC use cases outlined in clause 5, which are anticipated to be enabled by the future 6G communication technology. The present document consolidates the potential new requirements for each use case into a unified set of requirements for 6G sensing services, focusing on both functional and performance aspects, as detailed in clause 6.5. The functional requirements are further categorized into four subgroups:

i) General Requirements;

ii) Network Configuration;

iii) Network Exposure; and

iv) Security, Privacy and Trustworthiness.

Additionally, the present document identifies several new Key Performance Indicators (KPIs), including Fine Motion Accuracy and sensing service range, specifically tailored for 6G sensing services.

Potential evaluation to justify the sensing feasibility for above identified use cases needs ISAC channel modeling. Hence, it is recommended for ETSI GR ISC 002 [i.56] on ISAC Channel Modelling, Measurements and Evaluation methodology to introduce sensing channel modeling about RCS, micro-Doppler, micro-deformation, near field, etc.

In summary it is recommended that ETSI GR ISC 003 [i.57] on System and RAN Architectures for ISAC considers the requirements of each user case to ensure that these can supported by the ongoing system and RAN architectural work. In particular, it is recommended, to consider the requirement of each use case separately in terms of a) the required sources of the sensing data and b) the required final sensing results with the specified KPIs and destination.

ETSI GR ISC 004 [i.58] on Security, Privacy, Trustworthiness and Sustainability for ISAC has the objective to study privacy, security, trustworthiness, and sustainability aspects of ISAC. With nine of the eighteen use cases having the primary goal to sense humans and six others dealing with sensing in the presence of humans, the need for this study becomes apparent. It is recommended to ETSI GR ISC 004 [i.58] on Security, Privacy, Trustworthiness and Sustainability for ISAC to conduct a detailed analysis of implications these use cases have on the privacy of sensed people and related sensing data.

The second big group of use cases focuses on industrial automation, drone monitoring and digital twinning with functionality primarily relying on the sensing input. It needs to be guaranteed that the 6G System including the sensing functionality is secured to avoid unauthorized access and malfunction of the system. ETSI GR ISC 004 [i.58] on Security, Privacy, Trustworthiness and Sustainability for ISAC should provide solutions to address these security aspects and propose measures to obtain a trustworthy 6G system.

While it is counterintuitive to improve environmental sustainability by adding a fundamentally new functionality such as sensing, some use cases address this issue by leveraging sensing to assist communications, allowing to operate under optimized conditions and to potentially reduce power consumption. It is recommended for ETSI GR ISC 004 [i.58] on Security, Privacy, Trustworthiness and Sustainability for ISAC to utilize the use cases presented in the present document to develop suitable approaches for a sustainable 6GS.

History

Document history		
V1.1.1	March 2025	Publication