5GAA
Automotive Association

Study on integrated sensing and communication (ISAC) for C-V2X application

5GAA Automotive Association
Technical Report

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Contents

Introduction

Based on the observed trends of next-generation vehicular communication systems by the 5GEB WI [1], the different stakeholders of the C-V2X ecosystem have identified Integrated Sensing and Communications (ISAC) as one of the relevant key technologies for the realization of connected and automated mobility. The goal of ISAC is to use communication functions to perform sensing by sharing of resources, hardware or common signals over the air. Sensing information derived by the integrated system can be seamlessly provided to improve communication functions. The communication functionality can enhance sensing quality of the integrated system by facilitating cooperation between sensing functions. Due to its promising potential, ISAC has attracted significant interest of the academic and industry research community all over the globe.

The pre-standardization and standardization community have actively started to define use cases, sensing requirements and evaluation/modeling methodologies for ISAC as well as its technology components. It is expected that ISAC will be a key functionality for next generation vehicular communication systems. Therefore, necessary pre-standardization work has commenced at various organizations such as the ETSI Industry Specification Group (ISG) ISAC, among others, to pave the way for the subsequent standardization of the technology.

Accordingly, the present technical report aims to identify valuable use cases, derive potential key sensing requirements and key technology components to facilitate the application of ISAC in C-V2X scenarios. The 5GAA ISAC WI , aims to discuss the value and impact of ISAC in the connected and automated mobility ecosystem among all the stakeholders including Vehicle OEMs, IOOs and Service Providers. One of the main goals is to define, extend and analyse V2X use cases in terms of ISAC sensing to derive sensing-related requirements. The focus of current 5GAA use cases is V2X communication [2] [3] [4]. By outlining use case implementation description focused on ISAC sensing, relevant information to derive sensing-related requirements is clarified. From an automotive perspective, sensing systems must satisfy requirements that vary depending on the application. Sensing requirements include a multitude of ranging-related, speed-related and angle-related key performance indicators that vary depending on the use case, e.g. use cases related to convenience, traffic efficiency or functional safety. We elaborate on a unified ISAC concept from automotive perspective and use case analysis methodology of V2X use cases from ISAC perspective in Chapter 4. Based on said methodology, use case implementation descriptions focused on ISAC sensing of the selected V2X use cases are analysed in Chapter 5. For reference, the modified use case descriptions of selected ISAC-applicable use cases in terms of sensing are described in Annexe A.

Besides the aforementioned benefits of ISAC, the integration of communication and sensing systems can potentially bring significant benefits in terms of reduced hardware costs and serve as a complement to existing automotive sensors by increasing their sensing reliability as well as improving overall sensing performance. To better understand the achievable gains of ISAC, fundamentals of ISAC sensing and considerations related to sensing topology are described. In the subsequent chapters, key technology features of ISAC for automotive are identified and advantages/disadvantages of the different ISAC integration levels are discussed from an automotive perspective. Based on the findings in terms of sensing requirements and key technology features of ISAC for the automotive domain, a common automotive view of the value, requirements and potential of ISAC are outlined. The expectation of this report is to serve as a blueprint/framework to guide technology development of ISAC tailored to the requirements of the automotive sector. Future studies will take into consideration other aspects as ISAC evolves.

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2 Definitions, Symbols and Abbreviations

2.1 Definitions

For the purposes of the present document, definitions from the 3GPP Technical Report [5] apply, as outlined below:

3GPP sensing data: Data derived from 3GPP radio signals impacted (e.g. reflected, refracted, diffracted) by an object or environment of interest for sensing purposes, and optionally processed within the 5G system [5].

non-3GPP sensing data: Data provided by non-3GPP sensors (e.g. video, LIDAR, sonar) about an object or environment of interest for sensing purposes [5].

Sensing receiver: An entity that receives the sensing signal which the sensing service will use in its operation. A sensing receiver is an NR RAN node or a UE, and it can be located in the same or different entity as the sensing transmitter [5].

Sensing result: Processed 3GPP sensing data requested by a service consumer [5].

Sensing transmitter: The entity that sends out the sensing signal which the sensing service will use in its operation. A sensing transmitter is an NR RAN node or a UE, and it can be located in the same or different entity as the sensing receiver [5].

Target sensing service area: A cartesian location area that needs to be sensed by deriving characteristics of the environment and/or objects within the environment with certain sensing service quality from the impacted (e.g. reflected, refracted, diffracted) wireless signals. This includes both indoor and outdoor environments [5].

Moving target sensing service area: The case where a target sensing service area is moving according to the mobility of a target from a sensing transmitter's perspective.

The following key performance indicators (KPIs) apply to the definition of the automotive use cases and implementation descriptions on sensing service level requirements:

Accuracy of positioning estimate describes the closeness of the measured sensing result (i.e. position) of the target object to its true position value. It can be further derived into a calculation of horizontal sensing accuracy – referring to the sensing result error in a 2D reference or horizontal plane, and into a measure of vertical sensing accuracy – referring to the sensing result error on the vertical axis or altitude [5].

Accuracy of velocity estimate describes the closeness of the measured sensing result (i.e. velocity) of the target object's velocity to its true velocity [5].

Confidence level describes the percentage of all the possible measured sensing results that can be expected to include the true sensing result considering the accuracy [1].

Sensing resolution describes the minimum difference in the measured magnitude of target objects (e.g. range, velocity) to be allowed to detect objects in different magnitudes [1].

Missed detection probability denotes the ratio of missing events to acquire a sensing result over all events during any predetermined period when the 5G system attempts to acquire a sensing result. It applies only to binary sensing results [1].

False alarm probability denotes the ratio of detecting an event that does not represent the characteristics of a target object or environment over all events during any predetermined period when the 5G system attempts to acquire a sensing result. It applies only to binary sensing results [1].

New terms defined during the ISAC WI for the automotive use cases and implementation descriptions are:

ISAC sensing information consumer: Entity that receives and consumes sensing results derived from wireless sensing. Entities include vehicles, road infrastructure, road or building operators, UEs, networks, V2X applications, etc.

ISAC vehicle: Vehicle-mounted UE with ISAC sensing capabilities.

ISAC infrastructure: TRP or stationary UE with ISAC sensing capabilities. A typical example of ISAC Infrastructure is a RSU or TRP which performs ISAC sensing.

Reference point (RP): Reference spatial points where sensing information is known. Reference point can be active (ARP) or passive (PRP).

> **Active reference point (ARP):** Device with communication and signal-processing capabilities (e.g. TRP or UE).
>
> **Passive Reference Point (PRP):** Object which provides a unique reflection characteristic from a specific known position (e.g. a reflector). PRPs do not have communication and signal-processing capabilities.

2.3 Abbreviations

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

3GPP	3rd Generation Partnership Project
5GAA	5G Automotive Association
ADAS	Advanced Driver Assistance System
AI	Artificial Intelligence
AS	Application Server
TRP	Transmit-Receive Point
BSM	Basic Safety Messages
CAM	Cooperative Awareness Message
C-V2X	Cellular Vehicle-to-Everything
ETSI	European Telecommunications Standards Institute
IFFT	Inverse Fast Fourier Transform
IOO	Infrastructure Operator and Owner
ISAC	Integrated Sensing and Communication
ISO	International Organization for Standardization
ITS	Intelligent Transportation System
KPI	Key Performance Indicator
LIDAR	Light Detection and Ranging

MEC	Mobile Edge Computing
MNO	Mobile Network Operator
OEM	Original Equipment Manufacturer
OFDM	Orthogonal Frequency Division Multiplex
RAN	Radio Access Network
RCS	RADAR cross section
RSU	Road Side Unit
SLR	Service Level Requirement
SP	Service Provider
UC	Use Case
UCI	Use Case Implementation Description
UE	User Equipment
UWB	Ultra-Wideband
V2I	Vehicle-to-Infrastructure
V2I	Vehicle-to-Network
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VRU	Vulnerable Road User

3 Work Item Objectives and Scope

The Work Item "Study on Integrated Sensing And Communication for C-V2X Application", referred to by its acronym WI ISAC, aims to discuss the integration of sensing and communication systems into one system from an automotive perspective. The WI ISAC aims to identify key features relevant for the realization of the selected automotive use cases. The Technical Report outlines the objectives and goals of the work item, implementation descriptions of automotive use cases with ISAC and key technology trends to facilitate the application of ISAC in C-V2X scenarios. The objectives of the work item are thus:

Analysis of ISAC use cases and ISAC concept development

- Identify applicable ISAC use cases for connected mobility from 5GAA, academia, standards organizations (SDO) such as 3GPP SA1, etc.
- Define criteria/rationales to select a subset of use cases.
- Update use cases to identify the value and impact of ISAC technologies.
- Derive sensing requirements for selected use cases.
- Establish quantitative general metrics to evaluate and measure the performance of ISAC solutions to guide research and standardization.
- Describe an ISAC concept based on existing technologies in the automotive sector/field.

Study possible ISAC technology trends

- Do state-of-the-art study of the evolution and technology trends of new ISAC features in research and SDOs (e.g. 3GPP, ETSI) and analyze the potential impact on both communication and sensing systems from the automotive perspective.
- Analyze ISAC technology features relevant for the identified automotive use cases.

4 Overview: ISAC Concept and Methodology

As identified by the 5GEB WI [1], the trend of next-generation communication systems beyond 5G is to integrate communication and sensing functionality into a single system. For V2X communication-centric system design, the integration of sensing is achieved by adapting and optimizing existing communication hardware and protocols. This integration of communication and sensing functionality can be done to different extents (referred to as integration levels detailed in Chapter 7.3.1 ISAC Levels of Integration). The foreseen convergence of wireless sensing and wireless communication results in a new design paradigm for network infrastructure and vehicle systems. It is therefore of utmost importance to derive an ISAC concept based on a common understanding of ISAC technology features and their potential benefits for the automotive sector based on the views of the different stakeholders in 5GAA. In addition, to drive ISAC technology tailored for automotive, a use case analysis methodology facilitates a systematic identification of sensing requirements for automotive use cases. Precise identification of sensing requirements for automotive use cases will guide the technology development of ISAC to guarantee its effective application for the needs of the connected and automated mobility ecosystem. We describe both aspects in the present section.

4.1 ISAC Concept for Automotive

The paradigm of sensing and communications convergence is not new – it appeared in the 1960s [6] – but it is only recently that is has become widely recognized as one of the key topics for current and future wireless communications, including 3GPP cellular systems [7]. Currently, ISAC applicability includes several industry verticals, such as factory automation [8], internet of things (IoT([9], and the automotive sector [10] [11]. However, it is worth noting that the ISAC framework comprises many different industry verticals, but in general covers multiple aspects such as the identification of use cases, deployment scenarios, system architecture, security and privacy aspects, sustainability, technology-enabling components, business models, etc. Thus, it is not trivial defining what ISAC actually means for different industry verticals.

For the automotive sector, ISAC touches on two well-established yet independent systems/functions: telematics/connectivity and Advanced Driver-Assistance Systems (ADAS). Indeed, with the advent of C-V2X, the last decade has witnessed a progressive synergy between the telecom and automotive industries. ISAC has contributed to that development. In addition, with the advent of millimeter-wave (mmW) communications in 5G, and the developments in (sub)THz technology, the gradual convergence of sensing and communications towards the same frequency bands makes sense, notwithstanding existing spectrum regulations/limitations. Meanwhile, different possible integration levels of automotive-ISAC are gradually being adopted, as discussed in Chapter 6.3.1 ISAC Levels of Integration. In this sense, it is also worth mentioning that, at least in the short-to-medium term, 3GPP-based ISAC is not expected to replace conventional automotive sensing systems, such as LIDAR, cameras, RADAR, etc., but to complement and improve 1) in-cabin and environment/surroundings perception, and 2) wireless connectivity.

Since ISAC is currently being studied and introduced 'as a service' in 5G-Advanced (5G-A), it is also expected that 6G will provide a more native, broader support of ISAC principles, including in-built features such as sensing-assisted communications and/or communications-assisted sensing. While it is not clear how 6G will emerge, without discussing details such as backward-compatibility, the ISAC concept for automotive does not need to be limited to 5G-A. This is consistent with the technology-agnostic approach followed in other contexts by 5GAA.

All in all, automotive ISAC concept can be regarded, in very broad terms, as follows:

A system or set of systems (e.g. 3GPP and/or non-3GPP, onboard and/or infrastructure/network-based) that performs (possibly with different levels of integration) both wireless connectivity (i.e. telematics) and sensing (e.g. RADAR) functions.

It should be noted that the previous statement is broad enough to cover all relevant and applicable sensing-modes (e.g. mono-static, bi-static, multi-static), communication scenarios (V2V, V2I, V2N, etc.), and foreseeable implementation architectures. It also encompasses most of the visions of 5GAA, including connected/digital roads [11], with the corresponding benefits for operators and the whole mobility ecosystem.

The previous vision is depicted in Figure 1 and Figure 2, where the automotive ISAC-concept is illustrated from a vehicle-centric and non-vehicle-centric perspective, respectively. Figure 2 does not preclude the scenario where the network provides sensing results to the vehicle, which it then combines with its own sensors (i.e. vehicle-based sensing with network-based assistance), or conversely, the vehicle shares its sensing results to the network which are then combined with the network's own measurements (i.e., infrastructure-based sensing with vehicle-based assistance).

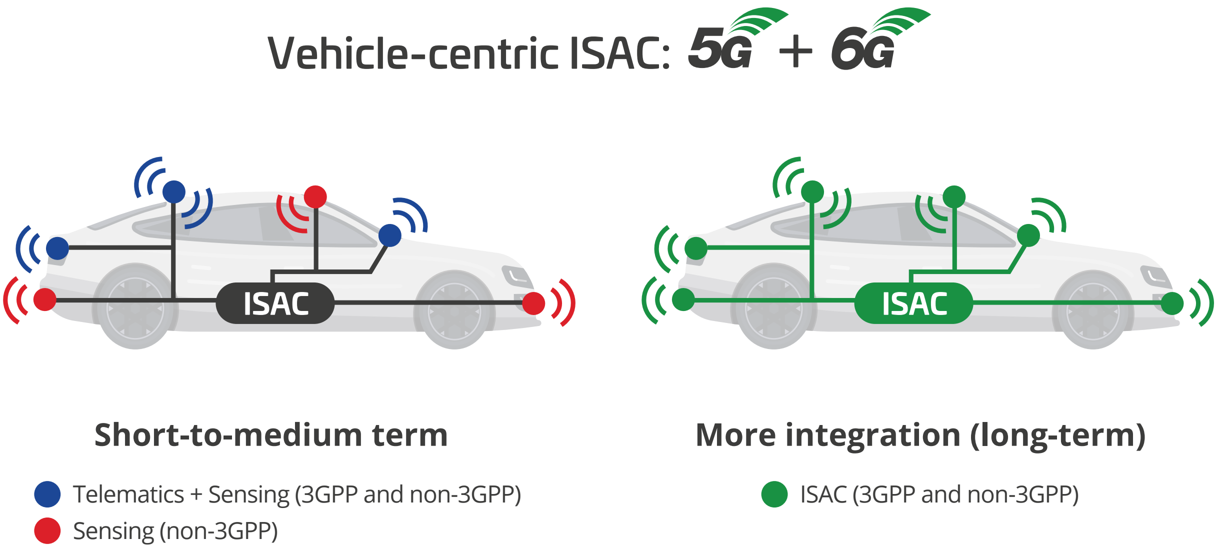


Figure 1. Automotive ISAC-concept: vehicle centric

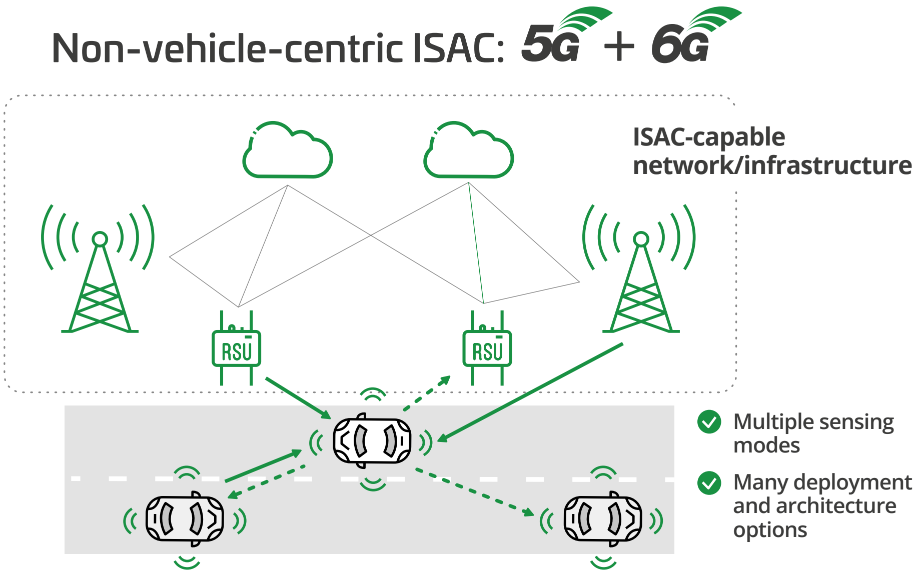


Figure 2. Automotive ISAC-concept: non-vehicle-centric

4.2 Use Case Analysis Methodology

The present section describes the methodology used to analyze the automotive use cases in terms of ISAC sensing. Current automotive use cases defined in 5GAA [2] [3] [4] are focused on communication-related aspects and the requirements of the use case. To derive ISAC sensing service level requirements (SLRs), it is necessary to extend the already existing 5GAA use cases beyond communication to include sensing-related aspects with ISAC sensing function. 5GAA use cases are defined in a technology-agnostic way, which means they are not confined to using a specific technology. Accordingly, implementation descriptions help to realize use case SLRs with a specific technology (e.g. 5G-V2X). As the current use case implementation description template is focused on communication-related aspects, the template is adapted for the sensing-related aspects of the use case and its realization with ISAC sensing.

Each V2X use case has different potentially suitable implementations to realize the sensing SLRs of the use case. The use case template descriptions were reviewed and extended. The following methodology was derived and applied during the review process:

I. Review original use case description and make minimal modifications to enable ISAC-sensing functions to be performed by infrastructure and/or within vehicle. The extended use case descriptions can be found in the Annex of the present document. Use cases are renamed to distinguish the previously agreed 5GAA use cases, and to reflect the focus on the sensing function. For example, the 'Intersection Movement Assist' use case is renamed to 'Sensing for Intersection Movement Assist'.

II. The use case implementation description template has been adapted as follows:

a. Overview: A high-level description of the use case and an indication of the specific user story (or alternative flow) the implementation description realizes in terms of sensing with ISAC.

b. Actors: Specify the role of the different producers and consumers of the ISAC sensing service as well as the ISAC nodes (whether active or passive) which perform the ISAC-sensing operation.

c. Assumptions: Indicate the necessary capability and role of the different actors to ensure the realization of the use case with ISAC sensing.

d. Process: An indicative message flow or illustration that highlights the main actors and the ISAC-sensing operation to realize the use case. A detailed step-by-step process is described with a focus on the ISAC-sensing operation based on the message flow or illustration. The last step of the process considers the successful ISAC-sensing operation that satisfies the sensing SLRs of the selected user story or alternative flow.

e. Template: The use case implementation description template is a table that describes the deployment considerations to realize the use case with ISAC sensing such as frequency bands, sensing topology, sensing targets, radio interface for sensing, bandwidth requirements, etc. The template is described below.

Aspect of ISAC implementation	Indicate the title of the use case, according to latest WG1 master list.
Consumer of ISAC sensing	Indicate the consumer of the ISAC-sensing result (e.g. vehicle) of the use case.
Sensing target and environmental objects (clutter)	Indicate the sensing target that is sensed with ISAC to realize the use case.
ISAC operation mode	Indicate the sensing topology of the ISAC-sensing operation from the six possible options to realize the use case. The options are: UE mono-static, UE-UE bi-static, UE-TRP bi-static, TRP mono-static, TRP-TRP bi-static, and TRP-UE bi-static.
Radio interface for sensing	Indicate the 3GPP radio interface to perform the ISAC-sensing operation associated with the propagation direction of the wireless signal from sensing transmitter to sensing receiver (i.e. sidelink, uplink and downlink).
Operating frequency	Indicate the frequency bands (intended or not intended for communication) to realize the use case (e.g. licensed band, unlicensed band, etc.) with ISAC-sensing function.
Potential bandwidth requirement	Indicate the potential bandwidth required to perform the ISAC-sensing operation to realize the use case.
Deployment scenario	Indicate the environment where ISAC-sensing functions would be deployed (e.g. urban, rural, indoor).

III. Based on the sensing target and expected environmental objects (i.e., clutter) of the use case, the sensing SLRs can be derived. The following general sensing SLR table tailored for automotive sensing requirements was derived:

SLR Title		SLR Unit	SLR Value	Explanations/Reasoning/Background
Ranging-related estimate	Maximum range	[m]		
	Range resolution	[m]		
	Range accuracy	[m]		
Speed-related estimate	Maximum speed	[m/s]		
	Speed resolution	[m/s]		
	Speed accuracy	[m/s]		
Angle-related estimate	Azimuth FoV	[degree]		
	Azimuth resolution	[degree]		
	Azimuth accuracy	[degree]		
Update rate		[fps]		
Reliability of sensing result	Sensing confidence level	[%]		
	Missed detection	[%]		
	False alarm	[%]		

Different criteria/rationales to sub-select use cases previously defined in 5GAA were used to understand the added value of ISAC sensing. As a starting point, clear understanding and Day-1 close-to-market use cases such as the Automated Valet Parking (AVP Type 2 in particular), were selected. Automotive use cases related to ISAC infrastructure were the main focus (such as the Parking-Lot Management use case). However, experience led to the observation that different use cases could be implemented with ISAC-sensing functionality on both vehicle and infrastructure sides (e.g. AVP Type 3). Use cases including infrastructure and/or vehicle-based sensing with ISAC- sensing function were sub-selected and developed (e.g. Vehicle Sensing for ADAS, Intersection Movement Assist and Hazard Information, and Road Event Collection for AVs use cases). A use case focused on detecting Vulnerable Road Users (VRUs) was also realized in view of ISAC sensing functionality.

4.3 Standardization Status

The work towards ISAC in 3GPP RAN1 corresponds to the Study Item (SI) “Study on channel modeling for Integrated Sensing And Communication (ISAC) for NR”. Currently, the overall progress is around 50%, which can be said to be “on-track”. This study item has two main tasks: deployment scenarios and channel modeling.

The deployment scenario part is about to complete the set of evaluation parameters for unmanned aerial vehicle (UAV) sensing scenarios, which is one of the five target groups. Other sensing targets include humans indoors and outdoors, automated guided vehicles, automotive vehicles, and objects creating hazards on roads/railways (the last two of relevance for automotive).

The channel modeling part is also on course; some terminology has been agreed and the fundamental model for the ISAC channel has been agreed. It is composed of two terms, one corresponding to the channel of the target, and the other to the channel of the background. Details on how to model these two channels are currently being discussed. Several propagation cases have been identified depending on the line-of-sight (LoS) condition between Tx, target, and receiver. It has also been agreed to consider the RADAR cross-section (RCS) approach for sensing targets, how it affects the channel model, and other factors. Spatial consistency has also been confirmed by the ISAC channel model.

Regarding the liaison statement (LS) sent from 5GAA WI ISAC to RAN1 (R1-2405964) and subsequently presented in RAN1#118, after several discussions between the parties, the following **conclusion** was reached.

> *RAN1 will consider the recommendations for the physical characteristics (e.g. sizes, shapes, materials, velocities, etc.) of sensing targets and objects provided in 5GAA LS (R1-2405964), along with the relevant characteristics defined in 3GPP TRs, within the scope of the Rel-19 study item. No LS response from RAN1 to 5GAA is necessary. R1-2405964 is proposed to be NOTED.*

Finally, at the time of writing, the overall progress and possible re-scoping of the SI is being discussed in RAN#105, with outcomes to be reported.

5 Use Case Implementation Descriptions with Integrated Sensing And Communication

This section outlines the implementation description of selected 5GAA use cases including roadmap [2, 3] [4] with ISAC sensing. It also includes implementation descriptions for newly defined use cases from a sensing perspective.

5.1 ISAC for Parking-Lot-Management UCID

The use case description of the present implementation description is outlined in Annex A.1.1 ISAC for Parking-Lot Management user story description. The ISAC-related user story description of the use case can be briefly described as follows.

> *The use case is based on the communication between a car driving through the parking lot, scanning its surroundings, and a car looking for a free parking space. The car on the lot may activate its sensors (including an ISAC-sensing function), if the parking density exceeds a set limit, and it scans its surroundings for free parking spaces and their characteristics (e.g. size). The gathered data is processed and shared with other cars nearby*.

Implementation Description

This use case implementation description outlines the **Alternative Flow #2** in Annex A.1.1 ISAC for Parking-Lot Management user story, where a cloud system (CS) (e.g. with parking-lot management entity) collects parking facility information in a geographical area.

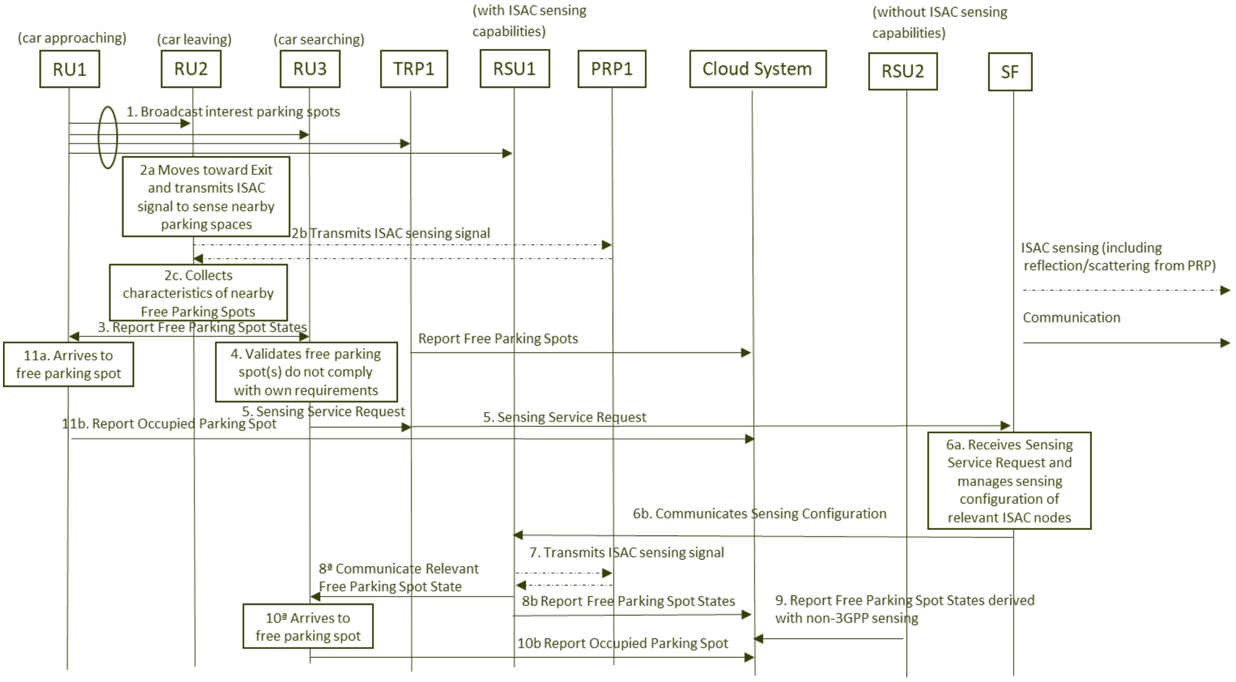


Figure 3. Sequence chart – alternative user story 3

Actors

- Road User 1 (RU1), Road User 2 (RU2), Road User 3 (RU3), Transmit/Receive Point (TRP1), Roadside Unit (RSU1), Passive Reference Point (RP1), Cloud System (CS)

Assumptions

- RU1 is a connected car approaching (yellow) and has ISAC-sensing capabilities.
- RU2 is a connected car leaving (green) and has ISAC-sensing capabilities.
- RU3 is a connected car searching (blue) and does not have ISAC-sensing capabilities.
- TRP1 is a TRP with ISAC capabilities and is deployed outdoors.
- RSU1 is ISAC equipment and it is deployed outdoors within the parking garage; transmitter and receiver may or may not be co-located and can be ceiling-, wall- or floor-mounted.
- RSU2 is a non-ISAC equipment (e.g. cameras, LIDAR, UWB, etc.) and it is deployed outdoors within the parking garage.
- TRP1 and RSU1 are active reference points (ARP).
- RP1 is a passive reference point (PRP) and it is deployed outdoors within the parking garage.
- IOO AS or SP AS is deployed in the CS (CS collects ISAC-sensing results related to free parking spots; CS can thereafter forward ISAC-sensing results to OEM App/SP App deployed in other RUs.

- TRP1 and RSU1 sense free parking spots with ISAC and provide it to the CS/RU1/RU3.
- Parking space is a public outdoor multi-story parking garage with installed RPs.
- OEM App or SP App intended to collect/share postprocessed data related to free parking spots is deployed in RU1, RU2 and RU3.

<u>Parking Space Determination: Parking-Lot-Management</u>

1. RU1 arrives at a parking lot and broadcasts its interest in certain parking spaces (e.g. specific dimensions) to other road participants and ISAC infrastructure.
2. RU2 moves towards the exit of the parking lot and receives parking spot interest from RU1. RU2 transmits ISAC- sensing signals to sense nearby parking spaces. Optionally, RP1 reflects transmitted ISAC signals from RU2 uniquely from a known incidence location/point to improve RU2 sensing results.
3. RU2 reports the state (e.g. position, dimensions, other characteristics) of the previously occupied parking spot as well as other nearby parking spots sensed with ISAC.
4. RU3 is already in the parking lot and receives reports of nearby spots from other road/facility participants (i.e. RU1 and RU2). Reported states of free parking spots do not comply with the parking spot requirements of RU3.
5. RU3 then sends a sensing service request to TRP1 (e.g. TRP deployed outdoors) to detect free parking spaces in a public outdoor multi-story parking garage.
    a. Sensing service ID
    b. Target sensing service area of parking lot (e.g. cartesian (x,y,z) locations)
    c. Sensing requirement (i.e. position accuracy, length 5m x width 2.5m of typical parking space) to detect a free parking space.
    d. Max. sensing service latency
    e. Refresh rate of sensing result
    f. Etc.
6. TRP1 receives a sensing request and configures RSU1 to provide the ISAC-sensing service for a target area and sensing requirement. TRP1 provides the ISAC-sensing service to SP AS/IOO AS deployed in CS.
7. RSU1 transmits ISAC-sensing signals in the parking area and senses free spaces within the facility.
8. RSU1 communicates the accurate position and state information (e.g. dimensions, charging station nearby) of free parking spaces to RU3 and CS. The SP AS/IOO AS deployed in CS collects ISAC-sensing results related to free parking spots.

9. CS aggregates sensing results from other non-ISAC sensing data (e.g. cameras, LIDAR, UWB, etc.) related to free parking spaces.
10. RU3 arrives at the parking spot safely and efficiently with the help of ISAC infrastructure.
11. RU1 arrives at the parking spot safely and efficiently with the help from parking spot reports from other road/facility participants.

Field	Description
Consumer of ISAC sensing	RU1 (“car approaching”) (OEM App/SP App), RU3 (“car searching”) (OEM App/SP App), CS (IOO/SP AS)
Sensed object or action	Sensed object: Free parking spots Action: Sensing results are provided to RU1, RU3 (main flow and alternative flow #2), CS (alternative flow #3)
Suitable ISAC operating mode (e.g. gNB-to-UE bi-static, UE mono-static, gNB-to-gNB bi-static, etc.)	All six modes are suitable
Radio interface for sensing	Sidelink, uplink and downlink
Operating frequency for ISAC sensing	FR1, FR2 and FR3
Potential bandwidth requirement	TBD
ISAC deployment scenario	Urban, rural, indoor

SLR Title		SLR Unit	SLR Value	Explanations/Reasoning/Background
Accuracy of positioning estimate	Horizontal	[m]	0.5	To position parking spot. Position accuracy less critical than space measuring capabilities. The sensing target corresponds to empty space around neighboring automotive vehicles, environmental objects or parking-lot/building infrastructure.
	Vertical	[m]	0.5	
Accuracy of velocity estimate	Horizontal	[m/s]	0.1	To detect when vehicle is parking or leaving a parking space.
	Vertical	[m/s]	N/A	
Sensing resolution	Range resolution	[m]	2.5 (NOTE1) 5 (NOTE2)	NOTE1: Perpendicular to the parking space NOTE2 Parallel to the parking space. Widths of typical parking spaces. The sensing target corresponds to empty space around neighboring automotive vehicles, environmental objects or parking-lot/building infrastructure.
	Velocity resolution	[m/s]	N/A	
Max detection range		[m]	1000	The particular parking lot and a surrounding area of up to 500m from the entry or 100m from the exit.
Max detection velocity		[m/s]	5.55 (20 km/h)	Parking space only allows low velocities.

Reliability of sensing result	Sensing confidence level	[%]	95	Low reliability as not safety critical.
	Missed detection	[%]	1	
	False alarm	[%]	5	

5.2 ISAC for Automated Valet Parking UCID

The use case description of the present implementation description is outlined in Annex A.1.2 ISAC for Automated Valet Parking. The ISAC-related user story description of the use case can be briefly described as follows.

> *The main user story is based on a vehicle that arrives at the designated hand-over zone, the driver leaves the vehicle, and the vehicle is parked by using the vehicle's own ISAC function or being operated by an ISAC Infrastructure-assisted Automated Valet Parking System (AVPS) after being authorized by the driver.*

Implementation Description

Use case implementation description of the main event flow (**AVP Type 2**), Alternative Flow #1 (**AVP Type 1**) and Alternative Flow #2 (**AVP Type 3**) described in Annex A.1.2 Sensing for Automated Valet Parking user story. The parking space determination for all AVP types can be performed by ISAC infrastructure and the sensing result is provided to AVP management sub-system.

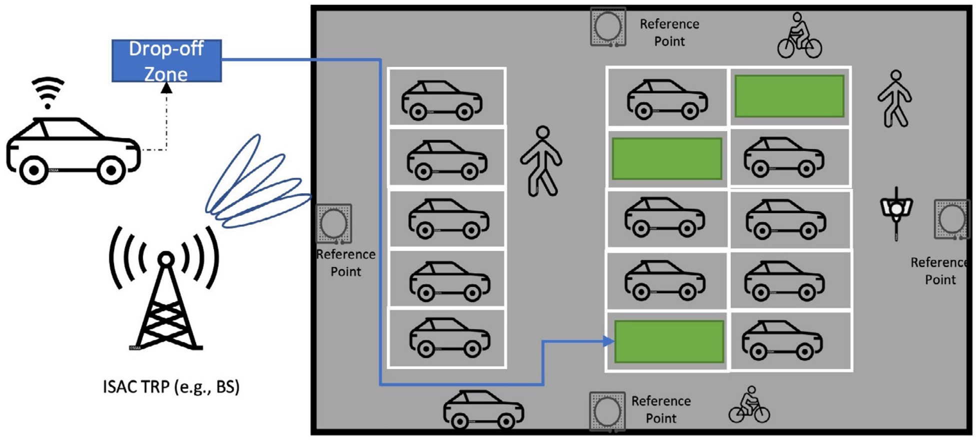


Figure 4. ISAC for Automated Valet Parking

AVP Type 1 – Remote Destination Assignment

Action

Object and event detection (Host vehicle, HV, onboard vehicle operation subsystem) for AVP mission supervision.

Actors

Road User 1 (RU1), Road User 2 (RU2), Road User 3 (RU3), Transmit/Receive Point (TRP1), Road Side Unit (RSU1), Reference Point (RP1), Automated Valet Parking System (AVPS), Parking Facility Management (PFMS).

Assumptions

- RU1 is AVP vehicle (HV) and has ISAC-sensing capabilities.
- SP App/OEM App is deployed in RU1 and consumes AVP services. OEM AS authenticates AVP services consumed by OEM App.
- RU2 is unconnected VRU.
- RU3 is unconnected vehicle moving in parking garage.
- TRP1 is a TRP with ISAC capabilities and is deployed outdoors.
- RSU1 is ISAC equipment and it is deployed indoors within the parking garage. Transmitter and receiver may or may not be co-located and can be ceiling-, wall- or floor-mounted.
- TRP1 and RSU1 are ARP.
- RP1 is PRP and deployed indoors.
- AVPS system component is a SP AS/IOO AS that provides AVP services.
- Parking space is a public indoor multi-story parking garage with installed RPs.
- PFMS is an IOO AS that collects data of free spots in the parking space.

AVP Mission (AVP Type 1)

1. RU1 arrives to hand-over zone.
2. The driver hands the RU1 (vehicle) over to AVPS.
3. AVPS communicates high-definition MAP and free parking space to RU1.
4. RU1 onboard vehicle operation subsystem plans route and trajectory based on the received MAP from AVPS.
5. RU1 establishes a reliable unicast communication link and starts AVP mission in an autonomous manner (L4) to selected free parking space with onboard vehicle operation subsystem.
6. AVPS sends a sensing service request to TRP1 to supervise AVP mission (e.g. dynamic update of high-definition map surrounding RU1) of RU1
    a. Sensing service ID.
    b. Moving target sensing service area along AVP path to free parking space (e.g. cartesian (x,y,z) locations).
    c. Max. sensing service latency.
    d. Refresh rate of sensing result.
    e. Sensing requirement (i.e. position accuracy, 5m length x 2m width x

1.6m height of a vehicle type A).

  i. Position accuracy of RU1 (AVP vehicle) at sub-m-level

ISAC-sensing results complement existing sensors (e.g. UWB, cameras) by improving the trustworthiness of RU1's onboard and other non-ISAC sensors in the parking lot.

7. TRP1 informs the presence and position of RP1 to RU1.
8. To improve the positioning and sensing result, RU1 transmits ISAC-sensing signals during the AVP mission. The ISAC-sensing signal reflects uniquely from RP2 with a known location, providing additional input to improve sensing/positioning results.
9. RU1 timely detects RU2 and RU3. RU1 safely avoids collision. Movement of RU2 and RU3 is not disrupted.
10. RU1 arrives at the free parking space safely and efficiently. OEM App/ SP App deployed within RU1 confirms successful AVP mission to SP AS in AVPS.

AVP Type 2 – Remote Motion Guidance

Action

Object and event detection (AVPS's remote vehicle operation subsystem) for AVP mission supervision.

Actors

Road User 1 (RU1), Road User 2 (RU2), Road User 3 (RU3), Transmit/Receive Point (TRP1), Road Side Unit (RSU1), Reference Point (RP1), Automated Valet Parking System (AVPS), Parking Facility Management (PFMS).

Assumptions

- RU1 is AVP vehicle (HV).
- SP App/OEM App is deployed in RU1 and consumes AVP services. OEM AS authenticates AVP services consumed by OEM App.
- RU2 is an unconnected vulnerable road user (VRU).
- RU3 is an unconnected vehicle moving in the parking garage.
- TRP1 is a TRP with ISAC capabilities and is deployed outdoors.
- RSU1 is ISAC equipment and it is deployed indoors within the parking garage. ISAC transmitter (Tx) and receiver (Rx) may or may not be co-located. ISAC Tx and Rx may be ceiling-, wall- or floor-mounted.
- TRP1 and RSU1 are active reference points (ARP).
- RP1 is a passive reference point (PRP) and is deployed indoors.
- AVPS subsystem component is a SP AS/IOO AS that provides AVP services and performs real-time object and event detection. ISAC and non-ISAC infrastructure within parking lot facility provide sensing results to AVPS

subsystem.

- TRP1 and RSU1 sense free parking spots with ISAC and provide the information to AVPS subsystem.
- Parking space is a public indoor multi-story garage with installed RPs.
- PFMS is an IOO AS that collects data about free spots in the parking space.

AVP mission (AVP Type 2)

1. RU1 arrives at the hand-over zone.
2. The driver hands the RU1 (vehicle) over to AVPS.
3. AVPS communicates a free parking space to RU1.
4. RU1 establishes a reliable unicast communication link and starts the AVP mission to the selected free parking space with an onboard vehicle operation subsystem with motion guidance provided by AVPS.
5. AVPS computes and transfers the path, motion guidance (e.g. "forward 10m") and estimate information to RU1.
6. RU1 onboard vehicle operation subsystem performs the action based on the received motion guidance from AVPS.
7. AVPS sends a sensing service request to TRP1 to supervise the AVP mission (e.g. dynamic update of high-definition map surrounding RU1)
   a. Sensing service ID.
   b. Moving Target sensing service area along AVP path to the free parking space (e.g. cartesian (x,y,z) locations).
   c. Max. sensing service latency.
   d. Refresh rate of sensing result.
   e. Sensing requirement (i.e. position accuracy, 5m length x 2m width x 1.6m height of a vehicle type A).
   f. Position accuracy of RU1 (AVP vehicle) at sub-m-level.

   ISAC sensing results complement existing sensors (e.g. UWB, cameras) by improving the trustworthiness of RU1 onboard and other non-ISAC sensors in parking lot.
8. TRP1 configures RSU1 to perform ISAC sensing of a moving target service sensing area (surrounding area and path to selected free parking space) to determine the presence and state of pedestrians, vehicles and obstacles along the trajectory.
9. TRP1 informs the presence and state of PRP1 to RSU1.
10. RSU1 transmits ISAC-sensing signals to sense target objects in amoving target service sensing area. Optionally, RP1 reflects transmitted ISAC signals uniquely with a known incidence location to improve sensing results of RSU1.

11. RSU1 communicates sensing results to AVPS (including current state and position of RU1). AVPS computes motion guidance based on provided sensing result.
12. AVPS provides the current state and position to RU1 during the AVP mission within the parking facility.
13. AVPS provides motion guidance and sensing results (of objects and events in the vicinity) to RU1. RU1 timely detects RU2 and RU3 and safely avoids collisions. Movement of RU2 and RU3 is not disrupted.
14. RU1 arrives at the free parking space safely and efficiently. OEM App/SP App deployed within RU1 confirms the successful AVP mission to SP AS in AVPS.

AVP Type 3 – Remote Route Guidance

Action

Object and event detection (HV onboard and AVPS remote vehicle operation subsystem) for AVP mission supervision.

Actors

Road User 1 (RU1), Road User 2 (RU2), Road User 3 (RU3), Transmit/Receive Point (TRP1), Road Side Unit (RSU1), Reference Point (RP1), Automated Valet Parking System (AVPS), Parking Facility Management (PFMS).

Assumptions

- RU1 is AVP vehicle (HV) and has ISAC-sensing capabilities.
- SP App/OEM App is deployed in RU1 and consumes AVP services. OEM AS authenticates AVP services consumed by OEM App.
- RU2 is an unconnected vulnerable road user (VRU).
- RU3 is an unconnected vehicle moving in parking garage.
- TRP1 is ISAC equipment and is deployed outdoors.
- RSU1 is ISAC equipment and it is deployed indoors within the parking garage. ISAC transmitter (Tx) and receiver (Rx) may or may not be co-located. ISAC Tx and Rx may be ceiling-, wall- or floor-mounted.
- TRP1 and RSU1 are active reference points (ARP).
- RP1 is a passive reference point (PRP) and is deployed indoors.
- AVPS subsystem component is a SP AS/IOO AS that provides AVP services and performs real-time object and event detection. ISAC and non-ISAC infrastructure within parking lot provide sensing results to the AVPS subsystem.
- TRP1 and RSU1 sense free parking spots with ISAC and provide details to the AVPS subsystem.
- RU1 performs object and event detection with ISAC-sensing signals.
- TRP1, RSU1 and RU1 may cooperate to perform object and event detection

with ISAC sensing.

- Parking space is a public indoor multi-story parking garage with installed RPs.
- PFMS is an IOO AS that collects data about free spots in a parking space.

AVP mission (AVP Type 3)

1. RU1 arrives at the hand-over zone.
2. The driver hands the RU1 (vehicle) over to AVPS.
3. AVPS communicates a free parking space to RU1.
4. AVPS, based on received sensing result, computes the destination assignment and route plan to the free parking space and communicates it to RU1.
5. RU1 establishes a reliable unicast communication link and starts the AVP mission in an autonomous manner (L4) to the selected free parking space with onboard vehicle operation subsystem.
6. AVPS sends a sensing service request to TRP1 to supervise AVP mission (i.e. dynamic update of high-definition map surrounding RU1)
    a. Sensing service ID.
    b. Moving target sensing service area along AVP path to a free parking space (e.g. cartesian (x,y,z) locations).
    c. Max. sensing service latency.
    d. Refresh rate of sensing result.
    e. Sensing requirement (i.e. position accuracy, 5m length x 2m width x 1.6m height of a vehicle type A).
        i. Position accuracy of RU1 (AVP vehicle) at sub-m-level.

    ISAC sensing results complement existing sensors (e.g. UWB, cameras, etc.) by improving trust in RU1’s onboard and other non-ISAC sensors in the parking lot.
7. TRP1 configures RSU1 to perform ISAC sensing of moving target service sensing area (surrounding area and path to the selected free parking space) to determine the presence and state of pedestrians, vehicles and obstacles along the trajectory (i.e. object and event detection).
8. RSU1 communicates ISAC-sensing configuration and indicates the presence and state of RP1 to RU1. RSU1 and RU1 cooperate to perform object and event detection with ISAC sensing.
9. RSU1 and RU1 transmit ISAC-sensing signals to sense objects in the moving target service sensing area. Optionally, RP1 reflects transmitted ISAC signals uniquely from a known location to improve sensing results of RSU1 and/or RU1.
10. RSU1 communicates sensing result to RU1 and AVPS (including current state

and position of RU1).

11. RU1 timely detects RU2 and RU3 and safely avoids collision with the help of its onboard sensors (e.g. UWB, cameras, ISAC sensing, etc.) and sensors installed in the parking lot (RSU1 and non-ISAC sensors). Movement of RU2 and RU3 is not disrupted.
12. RU1 arrives at the free parking space safely and efficiently. OEM App/SP App deployed within RU1 confirms the successful AVP mission to SP AS in AVPS.

Object and event detection AVP Type 1, 2 and 3

SLR Title		SLR Unit	SLR Value	Explanations/Reasoning/Background
Ranging-related estimate	Maximum range	[m]	UE-based ISAC sensing: 50 Infra-based ISAC sensing: 250	For UE-based ISAC sensing, the parking lot with AVP service might be large, thus more than 50m may be needed. For infra-based ISAC sensing, the maximum range depends on the distance between base station and parking lot. Therefore, the value may be obtained from the inter-site distance (ISD) of the urban macro-base station defined in 3GPP TR 38.901 [12].
	Range resolution	[m]	1	This value is referenced from a typical automotive radar range resolution [13].
	Range accuracy	[m]	1.5	Range accuracy value may be required to determine the position of VRU in walking areas of a parking lot.
Speed-related estimate	Maximum speed	[m/s]	5.55 (20 km/h)	Parking lots typically allow speeds of up to 20km/h.
	Speed resolution	[m/s]	0.1	This value is referenced from a typical automotive radar speed resolution [13].
	Speed accuracy	[m/s]	[0.3]	A higher accuracy is required to determine the exact speed of a pedestrian or cyclist, for example 0.3m/s (1.08km/h).
Angle-related estimate	Azimuth FoV	[degree]	[120]	
	Azimuth resolution	[degree]	[1]	To classify a detected object such as pedestrian, 1~2 degree azimuth resolution is required. AVPS shall be capable of avoiding collisions with other facility users, especially with VRUs [14].
	Azimuth accuracy	[degree]	[1]	
Update rate		[fps]	10	Refer SDSM, CPM generation rate [15]
Reliability of sensing result	Sensing confidence level	[%]	95	Refer SDSM, CPM generation rate [15]
	Missed detection	[%]	[≤1]	
	False alarm	[%]	[≤1]	

	AVP Type 1	AVP Type 2	AVP Type 3
Consumer of ISAC sensing	HV (OEM App/SP App)	AVPS (SP AS/IOO AS)	HV (OEM App/SP App), AVPS (SP AS/IOO AS)

Sensed object	Objects in the parking lot	Objects in the parking lot	Objects in the parking lot
ISAC operation mode	All six sensing modes are possible	All six sensing modes are possible	All six sensing modes are possible
Radio interface for sensing	Sidelink, uplink and downlink	Sidelink, uplink and downlink	Sidelink, uplink and downlink
Operating frequency	Licensed band, unlicensed band	Licensed band, unlicensed band	Licensed band, unlicensed band
Potential bandwidth requirement	(TBD)	(TBD)	(TBD)
Deployment scenario	Urban, rural, indoor	Urban, rural, indoor	Urban, rural, indoor

5.3 UE Mono-static Sensing for ADAS UCID

The use case description of the present implementation description is outlined in Annex A.1.3 ISAC for UE sensing for ADAS of this document.

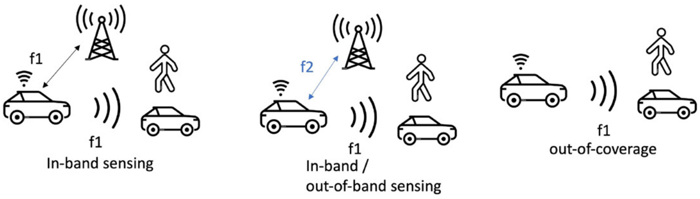
The ISAC-related user story description of the use case can be briefly described as follows.

> *The sensing results from UE mono-static sensing provided to the vehicle's ADAS; the ADAS takes into consideration the sensing results in making decisions, e.g. on the vehicle's maneuvers, interaction with the driver, etc.*

Implementation Description

The use case implementation description and user story is described as follows:

Use case name	UE mono-static sensing for ADAS.
User story/Use case scenario	ISAC capable UE mounted on a vehicle performs UE mono-static sensing by sending sensing signal and receiving the reflected signal. Results from the UE mono-static sensing are provided to the vehicle's ADAS; the ADAS takes into consideration the sensing results in making decisions, e.g. on vehicle's maneuvers, interacting with driver, etc.
Category	Convenience |Advanced Driving Assistance | Autonomous Driving
Road environment	Urban | Rural | Highway
Short description	▸ UE mounted on the HV senses the HV's surroundings by performing mono-static sensing. ▸ The sensing results are provided to the HV's ADAS. ▸ The HV's ADAS makes vehicle maneuver decisions (may include interacting with driver) taking into consideration the sensing results.
Actors	Vehicle, road users, environmental objects, mobile network operator
Vehicle roles	Host vehicle (HV): Performs mono-static sensing using its ISAC-capable vehicle-mounted UE.
Road and roadside infrastructure roles	N/A

Other actors' roles	▶ Road user (RU): Road traffic participant in the vehicle's surroundings; RU's presence and/or movement may affect HV's maneuvers and is an ISAC-sensing target. ▶ Environmental object (EO): Object in the vehicle's surroundings; EO's presence may affect HV's maneuvers and is an ISAC-sensing target. ▶ Mobile network operator (MNO): MNO may authorize and/or control HV's UE mono-static sensing operation when its frequency band is used for ISAC (e.g. for in-band sensing).
Goal	Sensing results from HV's vehicle-mounted UE improves the HV's ADAS performance and/or reduces the HV's ADAS hardware cost.
Needs	▶ The HV's vehicle-mounted UE needs to be ISAC-capable for performing UE mono-static sensing. ▶ The MNO needs to authorize the HV's vehicle-mounted UE for performing UE mono-static sensing in the MNO-owned frequency bands (e.g. for in-band sensing). ▶ The UE mono-static sensing needs to work in and out of network coverage.
Constraints/Presumptions	None
Geographic scope	Anywhere
Illustrations	Two implementation options for the use case: ▶ In-band sensing: UE mono-static sensing is performed in an MNO's communication frequency band. ▶ Out-of-band sensing: UE mono-static sensing is performed in a frequency band that is not designated for cellular communication. 
Pre-conditions	HV may have ADAS equipped.

Main event flow	Implementation Option-1 for in-band sensing: 1. ISAC-capable UE mounted on HV (V-UE) has a subscription with MNO and is authorized by the MNO to perform ISAC UE mono-static sensing in the MNO's frequency bands. 2. HV is moving on the road; the V-UE transmits sensing signals in one or multiple directions and receives reflected signal to detect relevant location (e.g. angle and distance) and speed of sensing targets (RUs/EOs). 3. V-UE may perform one or multiple of the following operations by performing UE mono-static sensing: a. Detect and track RUs, e.g. an RV or VRU that is moving in or close to road area, whose mobility may affect HV's maneuver decisions. b. Detect and identify EOs, e.g. an object on the road (e.g. debris on HV's lane) that may require vehicle to change path planning, an object in the HV's surroundings that may affect the HV's maneuver decision, etc.
Alternative event flow	Implementation Option-2 for out-of-band sensing: 1. V-UE is capable of mono-static sensing (transmitting sensing signal and receiving the reflected signal) in a frequency band that is not MNO managed, i.e. not used by a cellular system. 2. HV is moving on the road; the V-UE transmits sensing signals towards one or multiple directions and receives reflected signal to detect relevant location (e.g. angle and distance) and speed of sensing targets (RUs/EOs). 3. V-UE may perform one or multiple of the following operations by performing UE mono-static sensing: a. Detect and track RUs, e.g. an RV or VRU that is moving in or close to road area, whose mobility may affect HV's maneuver decisions. b. Detect and identify an EO, e.g. an object on the road (e.g. debris on HV's lane) that may require vehicle to change path planning, an object in the HV's surroundings that may affect the HV's maneuver decision, etc.
Post-conditions	1. Sensing results (e.g. RUs'/EOs' relevant location and relevant speed) from the V-UE are provided to the HV's ADAS; 2. the ADAS may determine the appropriate maneuver operations taking into consideration the sensing results, including interactions with drivers if needed; 3. The mono-static sensing performed by the V-UE enhances the HV's ADAS without incurring additional hardware cost.
Service level requirements	Accuracy and resolution of sensing target's relative location (range and angle) Maximum range of sensing target Accuracy and resolution of sensing target's relative speed Maximum relative speed of sensing target

Information requirements	For implementation of Option 1 in-band sensing: ▸ Authorization and/or control signaling from MNO to authorize and/or control V-UE's mono-static sensing. For implementation of Option 2 out-of-band sensing ▸ None

SLR Title		SLR Unit	SLR Value	Explanations/Reasoning/Background
Ranging-related estimate	Maximum range	[m]	30 to 300	Different maximum values may be desired for different sensing operation (e.g. long-range sensing vs short-range sensing)
	Range resolution	[m]	5 to 75	
	Range accuracy	[m]	±2 to ±40	
Speed-related estimate	Maximum speed	[m/s]	±50 to ±70; ±30	The two maximum velocity value ranges are for long-range sensing and short-range sensing, respectively.
	Speed resolution	[m/s]	0.1 to 0.6	
	Speed accuracy	[m/s]	±0.03 to ±0.12	
Angle-related estimate	Azimuth FoV	[degree]	±9-15; ±60-85	The two SLR value ranges for each SLR are for long-range sensing and short-range sensing, respectively.
	Azimuth resolution	[degree]	1-3; 3-9	
	Azimuth accuracy	[degree]	±0.1-0.3; ±0.3-5	
Update rate		[fps]	5-20; 20-50;	The two SLR value ranges are for long-range sensing and short-range sensing, respectively.
Reliability of sensing result	Sensing confidence level	[%]	95	Refer SDSM, CPM generation rate [15]
	Missed detection	[%]	[≤1]	
	False alarm	[%]	[≤1]	

Field	Description
Consumer of ISAC sensing	HV
Sensed object or action	Sensed object: RUs and Eos Action: sensing results for the objects are provided to HV ADAS.
Suitable ISAC operating mode	UE mono-static
Communication interface	N/A
Operating frequency for ISAC sensing	Licensed, unlicensed
Potential bandwidth requirement	Dependent on requirement for range resolution.

ISAC deployment scenario	For in-band sensing: ▸ Urban/Rural/Highway. ▸ Independent of cellular deployment (with MNO authorization). For out-of-band sensing: ▸ Independent of cellular deployment.

5.4 ISAC for Intersection Movement Assist UCID

The adapted use case of the present implementation description is outlined in Annex A.1.4 ISAC for Intersection Movement Assist of present document.

The user story description of the use case adapted to the ISAC function can be briefly described as follows:

> *Two vehicles are approaching an intersection. The vehicles determine the risk of a collision based on the vehicles' estimated trajectories. Infrastructure or road users with ISAC-sensing capability provide unconnected vehicles' states and/or trajectories.*

Implementation Description

The use case implementation description realizes the Main Event Flow, Alternative Flow #1, and Alternative Flow #2 described in Annex A.1.4 Sensing for Intersection Movement Assist user story.

Actors

Host vehicle (HV), Remote vehicle 1 (RV1), Remote vehicle 2 (RV2), Remote vehicle 3 (RV3), Remote vehicle 4 (RV4), Remote vehicle 5 (RV5), Infrastructure 1 (RSU1), Infrastructure 2 (RSU2), and Central server (CS).

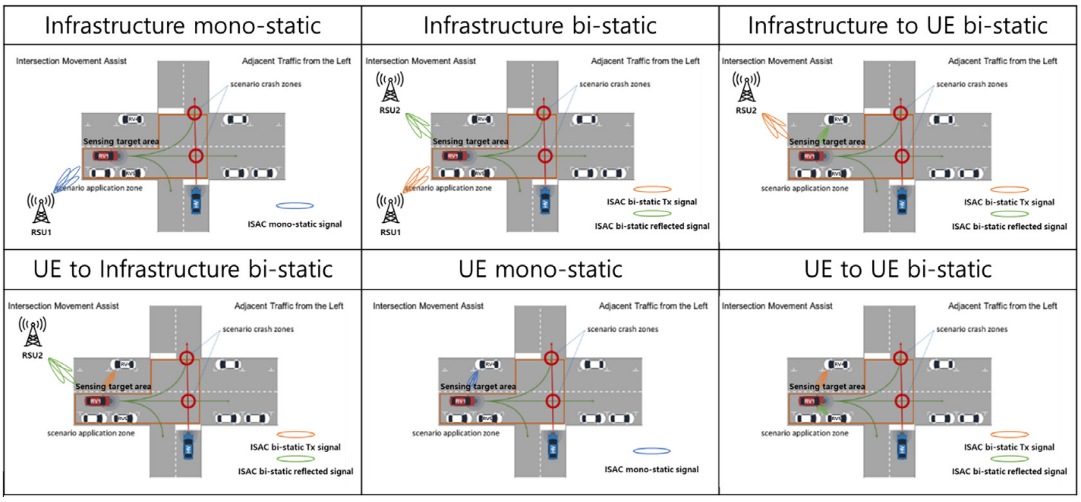
Assumptions

- HV is a connected vehicle approaching from the bottom of an intersection and requires ISAC sensing data -> Sensing data consumer.
- RV1 is an unconnected vehicle approaching from the left side of an intersection -> Sensing target.
- RV2 is an unconnected vehicle approaching from the right side of an intersection -> Sensing target.
- RV3 is an unconnected vehicle approaching from the upside of an intersection -> Sensing target.
- RV4 and RV5 are connected vehicles near the sensing target and are equipped with ISAC capability.
- RSU1 and RSU2 are deployed infrastructure at an intersection; they are connected and equipped with ISAC capability.

- RV4, RV5, RSU1 and RSU2 can sense RV1, RV2 or RV3 at an intersection and provide HV the presence of detected object(s).

Use Case Event Flow Using ISAC Sensing

1. When HV approaches intersection, it may broadcast its state message (e.g. BSM/CAM) including position, speed, and heading or send a sensing service request (e.g. region of interest – min., max. sensing distance and angle – target object class) to nearby vehicles which have ISAC-sensing capabilities and/or ISAC infrastructures (e.g. RSU, CS like IOO/OEM/SP AS).
2. ISAC transmitter and receiver (e.g. RV4, RV5, RSU1 and/or RSU2) operate ISAC sensing based on the state (e.g. position, heading, speed) of HV or the sensing service request. If the sensing service request is delivered to a CS, such as IOO/OEM/SP AS, the CS can coordinate the ISAC Tx and Rx for the ISAC-sensing operation.
    A. General operation of ISAC sensing
        i. ISAC transmitter and receiver set the configuration, such as sensing mode, sensing signal configuration including frequency bands, bandwidth, number of symbols, periodicity, etc.
        ii. ISAC transmitter transmits ISAC-sensing signals in the target sensing area.
        iii. If ISAC receiver receives the ISAC-sensing signal reflected by an object (e.g. RV1, RV2 or RV3), it calculates the state of the sensed object (e.g. position, speed, type of object).
        [NOTE] In case of mono-static, ISAC transmitter and receiver are one entity.
        [NOTE] Six ISAC sensing modes are possible for this use case.



Infrastructure mono-static | Infrastructure bi-static | Infrastructure to UE bi-static

UE to Infrastructure bi-static | UE mono-static | UE to UE bi-static

3. Sensor results (e.g. position, dimensions, attribute of RV1, RV2 or RV3) are provided to HV.
4. HV determines its path to cross the intersection considering the sensed objects on the trajectory from ISAC vehicles and/or ISAC infrastructures.

Field	Description
Consumer of ISAC sensing	HV
Sensed object or action	Sensed object: RV1 (main flow), RV2 (alt.1 flow) and RV3 (alt. 2 flow). Action: Sensing results (i.e. detected RV1, RV2 or RV3) are provided to HV to cross an intersection without collision with approaching vehicles.
Suitable ISAC operating mode (e.g. gNB-to-UE bi-static, UE mono-static, gNB-to-gNB bi-static, etc.)	All six modes are suitable.
Communication interface	N/A
Operating frequency for ISAC sensing	FR1, FR2, FR3
Potential bandwidth requirement	TBD (dependent on requirement for sensing range and resolution)
ISAC deployment scenario	Outdoor (urban, rural)

The sensing target (i.e. RV1, 2 or 3 in this use case) is considered as follows: [16]

	Size (Length x Width x Height)	Typical Velocity	Material	Remarks
Type 1/2 (passenger vehicle)	5m x 2m x 1.6m	16.67 m/s (60 km/h)	Steel	Speed referred from 3GPP TR 37.885 “Study on Evaluation Methodology of new Vehicle-to-Everything (V2X) Use Cases for LTE and NR” for urban V2X scenario [16].
Type 3 (truck/bus)	13m x 2.6m x 3m	16.67m/s (60km/h)	Steel	Referred from 3GPP TR. 37.855 [16].

To determine the sensing SLR, a smaller object should be considered, because the radar cross section (RCS) of small object could be smaller than that of larger object. Therefore, Type 1 may be a representative sensing target for this use case.

SLR Title		SLR Unit	SLR Value	Explanations/Reasoning/Background
Ranging-related estimate	Maximum range	[m]	UE based ISAC Sensing: 100 Infra based ISAC Sensing: 250	For big intersections in metropolitan environments, UE which has ISAC sensing capability might still be rather far away, thus more than 100 m may be needed. For infra-based ISAC sensing, the maximum range depends on the distance between the base station and intersection. Therefore, the value may be obtained from the inter-site distance (ISD) of urban-macro base station defined in 3GPP TR 38.901 [12].
	Range resolution	[m]	1	This value is referenced from a typical automotive radar range resolution [13].
	Range accuracy	[m]	1.5	Range accuracy value may be required to determine lane position of object.
Speed-related estimate	Maximum speed	[m/s]	28	Assuming speeds up to 100km/h at an intersection on a rural road.
	Speed resolution	[m/s]	0.1	This value is referenced from a typical automotive radar speed resolution [13].
	Speed accuracy	[m/s]	[1]	

Angle-related estimate	Azimuth FoV	[degree]	[120]	
	Azimuth resolution	[degree]	[1]	To classify a detected object such as pedestrian, 1~2 degree azimuth resolution is required similar with image radar.
	Azimuth accuracy	[degree]	[1]	
Update rate		[fps]	10	Refer SDSM, CPM generation rate [15]
Reliability of sensing result	Sensing confidence level	[%]	95	Refer SDSM, CPM generation rate [15]
	Missed detection	[%]	[≤1]	
	False alarm	[%]	[≤1]	

5.5 ISAC for Hazard Information and Road Event Collection for AVs UCID

The use case of the present implementation description is outlined in Annex A.1.5 ISAC for Hazard Information and Road Event for AV of present document.

The ISAC-adapted user story of this use case is:

> *Vehicles collect information on hazards and road events based on vehicle sensor data. To collect hazard information, ISAC can be used in this use case. Then, they share the resulting relevant information as processed data.*

Implementation Description

The use case implementation description realizes the Main Event Flow and Alternative Flow described in Annex A.1.5 Sensing for Hazard Information and Road Event for AV user story.

Actors

Host Vehicle (HV), Remote Vehicle (RV), Roadside Unit (RSU), and V2X Application Server (V2X AS) such as IOO/OEM/SP AP.

Assumptions

- HV is a connected vehicle and detects hazard and events using ISAC sensing.
- RV is a connected (automated) vehicle and will approaches the area where there is hazard and events detected by HV.
- Optionally, RSU can detect hazards and events using its own ISAC-sensing capabilities and provide to RV the detected information.
- Optionally, V2X AS can deliver hazard and event information from HV or RSU to RV or OEM/SP App equipped in RV, if they connect with V2X AS.

Use Case Event Flow Using ISAC Sensing

1. HV detects a hazard or a hazardous event (road, traffic, weather, etc.) using

ISAC-sensing capabilities (Optionally, RSU can also be used to detect a hazard and event using ISAC-sensing capabilities).

A. General operation of ISAC sensing

   i. ISAC transmitter and receiver set configuration, such as sensing mode, sensing signal including frequency bands, bandwidth, number of symbols, periodicity, etc.

   ii. ISAC transmitter transmits ISAC sensing signals in its surrounding environment/area.

   iii. If ISAC receiver receives the ISAC sensing signal reflected by object (e.g. roadwork, pothole), it calculates state of the sensed object.

   [NOTE] In case of mono-static, ISAC transmitter and receiver are one entity.

   [NOTE] Three UE-related ISAC sensing modes are possible for main flow and optionally Infra-related ISAC sensing modes are also possible.

2. HV/RSU sends out corresponding information of the detected hazard/event to RV (optionally, through V2X AS).
3. RV is approaching the scenario application zone and receives the information directly from the HV/RSU or indirectly through V2X AS.
4. Information on the detected hazard and road events are available and considered by RV for driving decisions.

Field	Description
Consumer of ISAC sensing	RV or OEM/SP App equipped in RV.
Sensed object or action	Sensed object: Hazard and hazardous event (animal, obstacle such as fallen object, roadwork, road traffic, weather, etc.). Action: Sensing results (i.e. hazard and event) is provided to RV or OEM/SP App equipped in RV for driving decisions.
Suitable ISAC operating mode (e.g. gNB-to-UE bi-static, UE mono-static, gNB-to-gNB bi-static, etc.)	UE mono-static, UE bi-static, infrastructure to UE bi-static. (Optionally) Infra-mono-static, infra-bi-static, UE to infra-bi-static.
Communication interface	N/A
Operating frequency for ISAC sensing	FR1, FR2, FR3
Potential bandwidth requirement	TBD (dependent on requirement for sensing range and resolution)
ISAC deployment scenario	Urban, rural, highway

The sensing target (i.e. hazard and hazardous event in this use case) is considered as follows:

	Size (Length x Width x Height)	Typical Velocity	Material	Remarks
Animal (Sheep/deer)	1.5m x 0.5m x 1m	18m/s (5km/h)		Referred from 3GPP TR 22.837 “Feasibility Study on Integrated Sensing And Communication (Release 19)”.

Obstacle (e.g. fallen Object)	(0.5-1)m x (0.5-1)m x 0.1m	Stationary object	Plastic	Typical obstacle on roads is a fallen object such as a box which may impact HV's maneuvers.
Pothole	>0.25m (horizontal dimension) >0.04m (depth)	Stationary object	Asphalt	For a carriageway, a pothole has been defined as a sharp-edged depression where part or all of the surface layers have been removed including carriageway collapses, surrounding ironwork and missing cat's eyes.
Weather (e.g. smog, rainfall)	N/A	9m/s [17]		Referred from 3GPP TR 22.837 "Feasibility Study on Integrated Sensing And Communication (Release 19)" [5]

SLR Title		SLR Unit	SLR Value	Explanations/Reasoning/Background
Ranging-related estimate	Maximum range	[m]	UE based ISAC Sensing: 100 [18] Infra based ISAC Sensing: 250	The typical maximum range of short-range radar in the automotive industry is 100m. For infra-based ISAC sensing, the maximum range depends on the distance between the base station and intersection. Therefore, the value may be obtained from the inter-site distance (ISD) of the urban macro-base station defined in 3GPP TR 38.901 [12].
	Range resolution	[m]	0.5	This value should be smaller than the size of the hazard.
	Range accuracy	[m]	1.5	A range accuracy value may be required to determine the lane position of object, e.g. it should be detected which lane a box is dropped in.
Speed-related estimate	Maximum speed	[m/s]	5	Assuming speeds up to 30km/h of the hazard and event.
	Speed resolution	[m/s]	1	High-speed resolution is not necessary for this use case, because the most commonly detected object is stationary.
	Speed accuracy	[m/s]	[1]	
Angle-related estimate	Azimuth FoV	[degree]	[120]	
	Azimuth resolution	[degree]	[1]	To classify a detected object such as a pedestrian, 1~2 degree azimuth resolution is required (similar with image radar).
	Azimuth accuracy	[degree]	[1]	
Update rate		[fps]	10	Refer SDSM, CPM generation rate [15]

Reliability of sensing result	Sensing confidence level	[%]	95	Refer SDSM, CPM generation rate [15]
	Missed detection	[%]	[≤1]	
	False alarm	[%]	[≤1]	

5.6 ISAC for Vulnerable Road User UCID

The use case of the present implementation description is outlined in Annex A.1.6 ISAC for Vulnerable Road User of present document.

The main user story of this use case from ISAC-sensing perspective is:

> *Alert HV of approaching VRU in the road or crossing an intersection and warn of any risk of collision using (ISAC) sensing functionality (awareness of the presence of VRUs near potentially dangerous situations).*

Implementation Description

Use case implementation description that realizes the Main Flow and Alternative Flow outlined in Annex A.1.6 ISAC for Vulnerable Road User of present document.

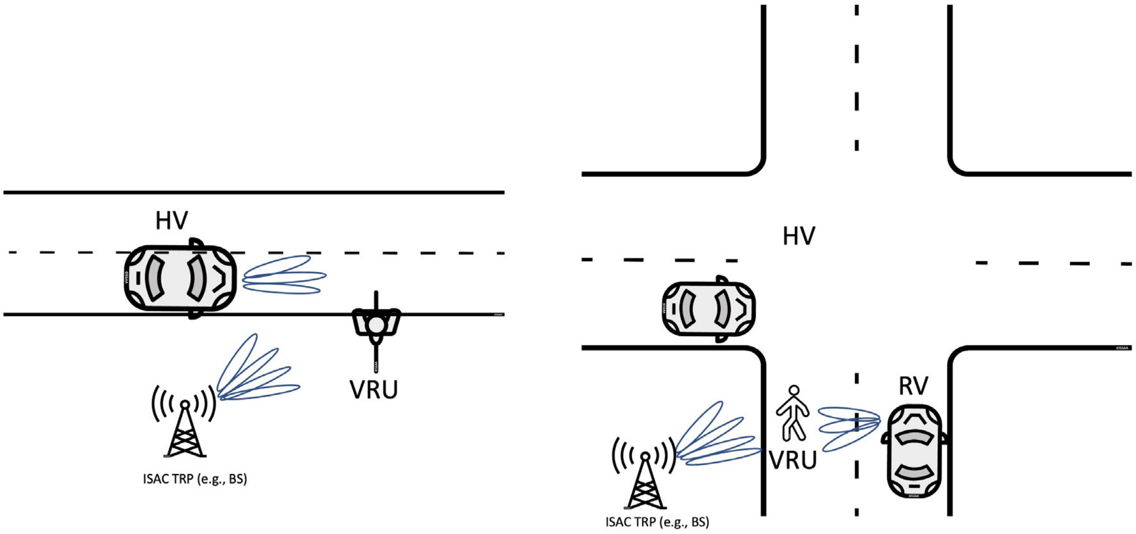


Figure 5. a) Left side illustrates "in-road" environment with VRU sensed by ISAC transmitter (e.g. TRP, HV) with ISAC-sensing function (Main Flow). b) Right side illustrates intersection environment with VRU sensed by ISAC transmitter (e.g. TRP, RV) with ISAC-sensing function (Alternative Flow)

Actors

Host Vehicle (HV), Vulnerable Road User 1 (VRU1), Vulnerable Road User 2 (VRU2), Transmit/Receive Point (TRP), and Remote Vehicle (RV).

Assumptions

- HV, RV are vehicles with ISAC sensing capabilities.
- VRU1 is an unequipped cyclist.
- VRU2 is an unequipped pedestrian (optionally, VRU2 can also be an e-scooter).
- TRP is an active reference point (ARP) with ISAC capabilities and is deployed outdoors.
- OEM App/SP App is deployed in HV intended to receive VRU collision warning and/or VRU near potential dangerous situation.
- TRP and RV sense VRUs (e.g. pedestrians, cyclists, e-scooters, motorcyclists, etc.) using ISAC-sensing function and communicate sensing results/data to HV (optionally, IOO AS or SP AS is deployed in MEC server to compute ISAC-sensing result from ISAC-sensing data forwarded by RSU – e.g. ISAC TRP – or RV.

“In-Road” or Intersection Road Environment

1. When HV moves forward along a road (or intersection), it may broadcast its own state messages (e.g. BSM/CAM) including position, speed, heading direction, or send a sensing service request (e.g. presence of VRUs within target sensing service area) to ISAC infrastructure (e.g. TRP) or other vehicles with ISAC-sensing functions (e.g. RV).
2. ISAC transmitter (e.g. TRP or RV) executes the ISAC-sensing operation based on the state (e.g. position, heading, speed) of HV and/or sensing service request by HV; general operation of ISAC is outlined in Section 4.4 of the present document (subsection A, steps i. to iii.).
3. As per step ii. from subsection A, ISAC transmitter (e.g. TRP) transmits ISAC-sensing signals within target-sensing service area (or pre-configured service area). Said signals scatter/reflect from different environmental objects as well as from the target VRU (i.e. VRU1 or VRU2). The distinct material, shape and size of VRU1 (i.e. cyclist) as well as its internal movement characteristics provide resolvable information for a sensing receiver or another entity to detect VRU.
4. Sensing result of VRU (e.g. cyclist on a potentially dangerous trajectory) is computed by the sensing receiver and it is communicated to HV. Optionally, IOO AS or SP AS deployed in a MEC server can compute the sensing result and communicate it to HV.
5. Upon reception of the notification (e.g. warning of a cyclist on a potentially

dangerous trajectory), HV adjusts its maneuvers to guarantee the safety of VRU.

Field	Description
Consumer of ISAC sensing	HV ("vehicle moving forward in road/intersection" or OEM App/SP App deployed in HV).
Sensed Object or Action	Sensed object: VRU(s) (e.g. cyclist, pedestrian, e-scooter, motorcyclist). Action: Sensing results are provided to HV or OEM App/SP App deployed in HV (main flow and alternative flow).
Suitable ISAC operating mode (e.g. gNB-to-UE bi-static, UE mono-static, gNB-to-gNB bi-static, etc.)	All six modes are suitable.
Radio interface for sensing	Sidelink, uplink and downlink
Operating frequency for ISAC sensing	FR1, FR2 and FR3
Potential bandwidth requirement	TBD
ISAC deployment scenario	Urban, rural, indoor

VRU ID	VRU Type	Size (Length x Width x Height)	Typical Velocity	Material	Remarks
A.1	Pedestrian	0.3m x 0.36m x 1.8m [1]	3km/h	Mass of Water	At high frequency bands (e.g. @77 GHz), thickness of worn clothes influences significantly the RCS [10].
A.2	E-Scooter	1m x 0.5m x 1.9m	20km/h	Mass of Water including aluminum [11]	Height measured from ground to E-scooter deck plus road user height. Aluminum pole with small RCS.
B.1	Cyclist	1.7m x 0.5m x 1.5m [12]	(17-25) km/h	Mass of water including Steel [13]	Dimensions and material composition based on road user riding non-electric bicycle.
B.2	Motorcyclist	2m x 0.8m x 1.5m [14]	60km/h	Mass of Water including Steel [15]	Dimensions based on road user riding motorcycle. Assuming speed from vehicle in urban V2X scenario [7].

SLR Title		SLR Unit	SLR Value	Explanations/Reasoning/Background
Ranging-related estimate	Maximum range	[m]	UE-based ISAC Sensing: 100 Infra-based ISAC Sensing: 250	For big intersections in metropolitan environments, UE with ISAC-sensing capability might still be rather far away, thus more than 100m may be needed. For infra-based ISAC sensing, the maximum range depends on the distance between the base station and intersection. Therefore, the value may be obtained from the inter-site distance (ISD) of urban macro-base station defined in 3GPP TR 38.901. The maximum range required for an “in-road” scenario is less than for an “intersection” scenario.
	Range resolution	[m]	1	This value is referenced from a typical automotive radar range resolution.
	Range accuracy	[m]	1.5	Range accuracy value may be required to determine the position of a VRU on a sidewalk or bicycle path.
Speed-related estimate	Maximum speed	[m/s]	16.67	The highest speed among the various VRU types is 60km/h from the motorcyclist.
	Speed resolution	[m/s]	0.1	This value is referenced from a typical automotive radar speed resolution [13].
	Speed accuracy	[m/s]	[1]	
Angle-related estimate	Azimuth FoV	[degree]	[120]	
	Azimuth resolution	[degree]	[1]	
	Azimuth accuracy	[degree]	[1]	
Update rate		[fps]	10	Refer SDSM, CPM generation rate [15]
Reliability of sensing result	Sensing confidence level	[%]	95	Refer SDSM, CPM generation rate [15]
	Missed detection	[%]	[≤1]	
	False alarm	[%]	[≤1]	

6 ISAC Technology for Automotive

6.1 ISAC Fundamentals

The ISAC-sensing operation involves an ISAC transmitter (Tx) which transmits RF (1) signals to derive state information (position, velocity and orientation) of sensing targets (e.g. vulnerable road user) with the scattered version of the transmitted signals (i.e. on the sensing target and environmental objects) at the ISAC receiver (Rx). Depending on the implementation architecture, the ISAC Tx and Rx may be co-located (referred to as mono-static sensing) or located at different entities (referred to as bi-static sensing for a single ISAC Rx or multi-static sensing for multiple ISAC Rx). Following the terminology of the 3GPP RAN1 ISAC Channel Modeling SI [10], the channel from the sensing target to the ISAC Rx is referred to as the "target channel" and the channel(s) from the environmental objects to the ISAC Rx are referred to as the "background channel" (see Chapter 4.3 Standardization Status). The multi-path reflections received from the different environmental objects are known as "clutter".

In order to detect accurate sensing targets to estimate their state(s), sensing resolution is a prerequisite in some domains (e.g. delay, doppler or angle) [19]. Sensing resolution refers to the ability to separate correlated sensing signals (e.g. propagation paths of two close-by objects). When there is sufficient sensing resolution in some domains, the ISAC Rx is able to distinguish two highly correlated objects. In an ISAC-sensing context, there exist three resolution domains to distinguish highly correlated objects, as depicted in Figure 6 (e.g. identify object l and object l' as two separate objects and not one) [20]:

- **Delay resolution (or "ranging"):** Two objects are distinguished if the delay difference $|\tau_l - \tau_l'|$ is greater than 1/B, where τ denotes the LOS delay between ISAC Tx, sensing target and ISAC Rx, and B denotes the bandwidth allocated for the ISAC sensing operation.
- **Doppler resolution:** Two objects are distinguished if their Doppler difference $|\nu_l - \nu_l'|$ is greater than $1/(T \times T_s)$, where ν denotes the doppler shift associated to the propagation path, T denotes the number of allocated sensing symbols and T_s is the symbol duration.
- **Angular resolution:** Two objects are distinguished if the difference in azimuth angle $|\theta - \theta'|$ is greater than $2/N$, where θ denotes the azimuth angle of object from ISAC Rx frame of reference, where N is the number of $\lambda/2$-spaced antenna elements.

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[1] With frequencies between 10 kHz -100 GHz which are referred to as radio frequencies (RF). In an ISAC context, depending on the level of integration, the frequency band used for the ISAC-sensing operation can be a licensed band.

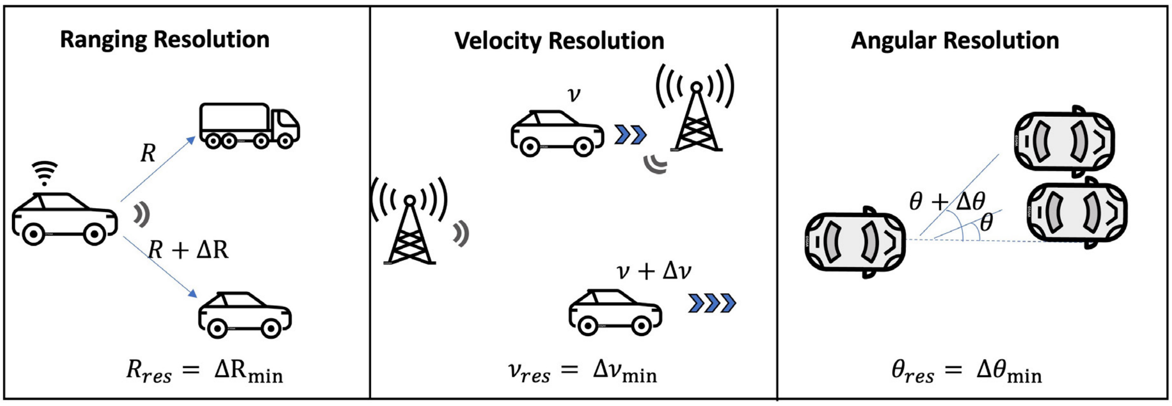


Figure 6. Domains for sensing resolution

If the received sensing signal is resolved in one domain (i.e. delay/doppler/angle difference is above the sensing resolution), then the objects appear resolved as two separate objects in the ISAC Rx. From the above descriptions, deployment parameters of ISAC systems that directly influence the sensing resolution can be described by the following rules of thumb [20]:

- **Wider bandwidths lead to better range resolution.** In this direction, currently the FR2 band in 5G-A has 800MHz as licensed spectrum [21]. More licensed spectrum is expected to be available for the evolution of 5G towards 6G across a wide variety of frequency bands [22], including the reuse of C-band employed for communication. For instance, technologies such as 3GPP NTN are expected to use frequency bands (e.g. Ku-band which spans from 12-18GHz) [23] where a significant amount of bandwidth is available. IMT bands have also seen the addition of new frequencies in the upper-mid band such as 7.125-10.5GHz in WRC-27 which will co-exist with UWB [24]. More frequency bands are expected to be studied and analyzed for automotive purposes, given the new communication and sensing requirements envisioned for IMT.
- **Higher carrier frequencies lead to better velocity resolution.** Typically, the doppler domain has been exploited by state-of-the-art automotive radars (e.g. using FMCW @ 77GHz). In this direction, the (sub) THz bands (e.g. from 275-450GHz) are being explored for communication in industry, academia, and by ETSI [25].
- **Larger arrays lead to better angular resolution.** Current and future communication systems are increasing the antenna aperture which further improves the angular resolution. The same trend is occurring in automotive MIMO radar to support automotive driving functions with higher levels of automation. The lower angular resolution is enabling imaging radar techniques to obtain point clouds of the environment at a much lower cost than LIDAR and provide robustness against bad weather conditions [26].

Current automotive radar systems typically operate in a mono-static configuration and can estimate the state of moving passive objects in its frame of reference with significant levels of accuracy [19]. Typically, these radars operate at 26GHz or 76-81GHz mm-W frequency bands [27]. These frequencies allow antenna elements to fit in or on, for example, the front or rear bumper of a vehicle. Complementary to current automotive radar systems, several carrier frequencies – e.g. those being considered for 6G that include the 7.125-24.25GHz band range discussed at the World Radiocommunication Conference 2023 (WRC-23) [22] and elsewhere or current FR2 band – can provide a good balance between size of antenna arrays, large bandwidths and sufficiently high carrier frequencies for energy efficiency and sensing coverage. [20] The required sensing resolution could come from increased antenna aperture while keeping antenna size sufficiently small.

6.1.2 Relation to 3GPP Positioning

There are several differences between ISAC sensing and 3GPP positioning for automotive uses [28], where the target is an active device (e.g. a vehicle-mounted UE) with fixed antenna elements. Fundamentally, 3GPP positioning is an **estimation problem**, where the active target's position is unknown but its presence is known due to its communication capabilities. In contrast, ISAC sensing is a **detection and estimation problem**, because the sensing targets are passive and the amount of sensing targets and environmental objects are not known a priori. [20] This fact is relevant for the different use cases identified in Chapter 5 Use Case Implementation Descriptions with Integrated Sensing And Communication (e.g. see Intersection Movement Assist UCID) where the density of sensing targets and environmental objects depends on the use case scenario. 3GPP positioning has, however, several parallels to bi-static sensing since transmitter and receiver are located at or on different entities in both cases. 3GPP positioning is typically based on separating the line-of-sight path from the non-line-of-sight paths to estimate the active target's position, whereas in bi-static sensing the propagation paths may correspond to sensing target(s) and different environmental objects. With enough sensing resolution, the clutter and propagation paths corresponding to the sensing target(s) can be separated.

6.2 ISAC Deployment Considerations for Automotive

6.2.1 ISAC Sensing Topologies/Deployment Scenarios

Types of Sensing Technique

There are two types of sensing techniques determined according to the location of the sensing Tx and the sensing Rx. The technique is considered "mono-static sensing" if the sensing Tx and Rx are co-located. If the sensing Tx and Rx are not co-located, the sensing technique is called "bi-static sensing".

One of the main differences between the two sensing types is the service coverage. In the communication cell planning, the SNR measured at the edge of the cell is important to determine the cell coverage or cell size. Theoretically, the "pathloss" of the communication signal is proportional to the square of the distance between the transmitter and the receiver.

The sensing service coverage can also be determined by the SNR of the signal received by the sensing Rx. Different from the communication case, the pathloss in the mono-static sensing case is proportional to the fourth power of the distance (D) between the sensing node (operating as both sensing Tx and sensing Rx) and the object, due to the reflection by the object backward to sensing node.

$$Pathloss_{monostatic} \propto D^4 \qquad (1)$$

The received power of the mono-static sensing signal is expressed as follows:

$$P_{r,monostatic} = \frac{G_t G_r \sigma \lambda^2}{(4\pi)^3 D^4} P_t \qquad (2)$$

where $P_{r,mono\text{-}static}$ is the received power (W), P_t is the transmit power (W), G_t is the transmit antenna gain, G_r is the receive antenna gain, σ is the radar cross section, λ is the wavelength of the sensing signal, and D is the distance between sensing node and object.

Based on the pathloss equation above, the sensing service coverage shrinks much faster than the communication coverage according to the distance. For example, if an object is located at the cell edge of the communication network, the received sensing signal power becomes too low for the sensing node to detect the object in mono-static sensing. As a result, the sensing coverage is much smaller than that of the communication, as depicted in Figure 7.

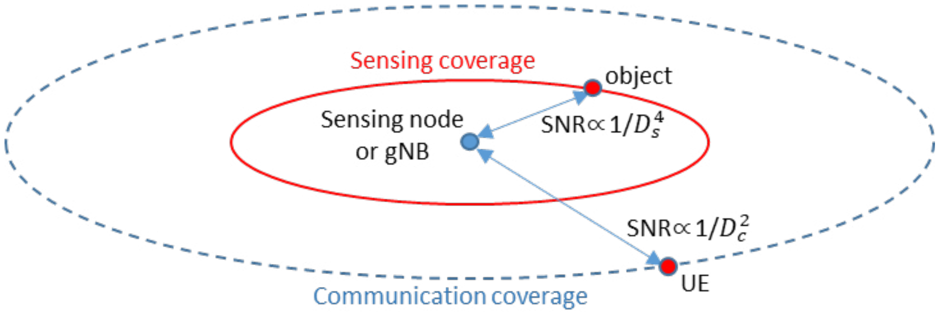


Figure 7. Illustration of communication and sensing coverage for mono-static sensing

The pathloss in bi-static sensing is proportional to the product of the squared distance between sensing Tx and the object ($D_{Tx\text{-}obj}$), and the squared distance between the object and sensing Rx ($D_{obj\text{-}Rx}$).

$$Pathloss_{bistatic} \propto D_{Tx-obj}^2 \cdot D_{obj-Rx}^2 \qquad (3)$$

The received power of the bi-static sensing signal is expressed as follows:

$$P_{r,bistatic} = \frac{G_t G_r \sigma \lambda^2}{(4\pi)^3 D_{Tx-obj}^2 D_{obj-Rx}^2} P_t \quad (4)$$

where $P_{r,bi\text{-}static}$ is the received power (W), P_t is the transmit power (W), G_t is the transmit antenna gain, G_r is the receive antenna gain, σ is the radar cross section, λ is the wavelength of the sensing signal, $D_{Tx\text{-}obj}$ is the distance between the sensing Tx and the object, and $D_{obj\text{-}Rx}$ is the distance between the object and the sensing Rx.

If one of the two distances ($D_{Tx\text{-}obj}$ and $D_{obj\text{-}Rx}$) is much larger than the other, the pathloss in the bi-static sensing becomes almost proportional to the square of that larger distance. For example, in Figure 8, if an object is located near the cell edge of the communication network, and the sensing Rx is close to the object, $D_{Tx\text{-}obj}$ is much larger than $D_{obj\text{-}Rx}$ and, the pathloss almost proportional to the square of $D_{Tx\text{-}obj}$ becomes similar to that of the communication. Different from the mono-static sensing case, the received signal power (sufficient for the object detection) can be obtained even at the edge of the communication network coverage in bi-static sensing. That is, bi-static sensing can provide comparable coverage to the communication.

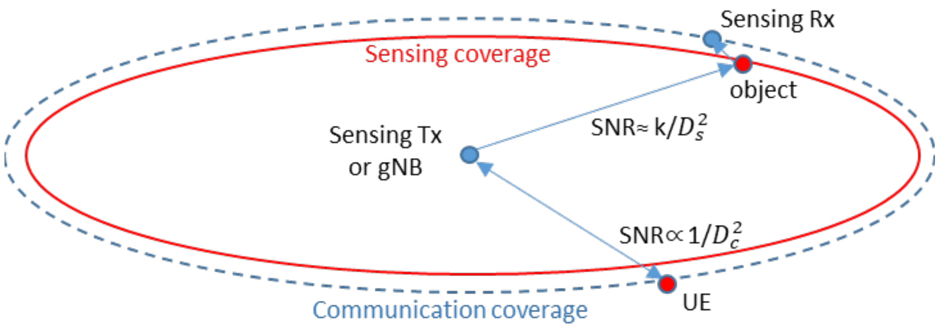


Figure 8. Illustration of communication and sensing coverage for bi-static sensing

Considering the analysis above, as ISAC integrates the sensing function with the communication, bi-static sensing is more beneficial than mono-static from the sensing service coverage point of view. What is more, bi-static sensing does not require complex hardware for full duplex operation, which is the mandated feature of the sensing node in mono-static sensing.

Bi-static sensing does, however, require synchronization between the sensing Tx and sensing Rx. This requirement is key when there is no LOS ray between the sensing Tx and sensing Rx. Any timing offset will degrade the distance measurement performance. The other technical issue is that the communication link may be needed for the sensing Rx to report its measurement to the sensing result calculation entity.

Possible Sensing Modes

Based on the type of the sensing Tx and Rx, six sensing modes emerge. Depending on each sensing mode, a TRP transmission and reception point (TRP) of a base station or user equipment (UE) can thus be the sensing Tx or the sensing Rx.

There are three sensing modes where TRP operates as the sensing Tx, as shown in Figure 9.

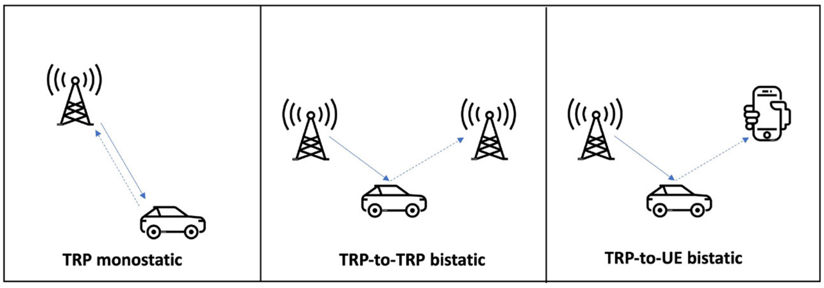


Figure 9. TRP transmission-based sensing modes

1. TRP mono-static sensing mode

This is the sensing mode where the same TRP operates as both sensing Tx and sensing Rx. Due to the reflection, this mode significantly reduces the sensing service coverage compared to the communication service coverage.

2. TRP-to-TRP bi-static sensing mode

This is the sensing mode where one TRP operates as the sensing Tx, and the other TRP as the sensing Rx. If more than one TRP operate as the sensing Tx or the sensing Rx, it can be called a "TRP-to-TRP multi-static sensing mode". This sensing mode does not solve the reduced sensing coverage issue due to the fixed and large distance between the neighboring TRPs.

3. TRP-to-UE bi-static sensing mode

This is the sensing mode where the TRP operates as the sensing Tx, and UE as the sensing Rx. If more than one TRP operate as the sensing Tx, and/or more than one UE as the sensing Rx, it can be called "TRP-to-UE multi-static sensing mode". This mode can provide sensing service coverage comparable to that of the communication service, if the target is much closer to one TRP or UE than the other.

There are three sensing modes where UE operates as the sensing Tx, as shown in Figure 10.

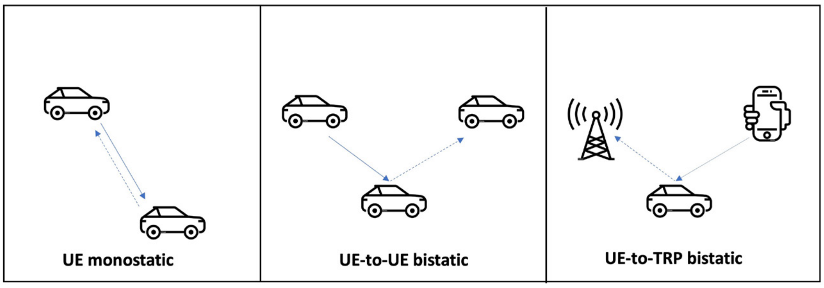


Figure 10. UE transmission-based sensing modes

1. UE mono-static sensing mode

This is the sensing mode where the same UE operates as both sensing Tx and sensing Rx. Because of the short sensing service coverage, this mode may be used for the detection of objects near UE.

2. UE-to-UE bi-static sensing mode

This is the sensing mode where one UE operates as the sensing Tx, and the other UE as the sensing Rx. If more than one UE operate as the sensing Tx or the sensing Rx, it can be called “UE-to-UE multi-static sensing mode”. As there are possibilities of pairing UEs with the suitable distance for sensing, this mode can provide a sensing service coverage comparable to that of the communication service.

3. UE-to-TRP bi-static sensing mode

This is the sensing mode where UE operates as the sensing Tx, and TRP as the sensing Rx. If more than one UE operate as the sensing Tx, and/or more than one TRP as the sensing Rx, it can be called “UE-to-TRP multi-static sensing mode”. Similar to TRP-to-UE bi-static sensing mode, this mode can provide a sensing service coverage comparable to that of the communication service, if the target is much closer to one UE or TRP than the other. On the other hand, this sensing mode may suffer coverage issues because of the low UE transmission power.

6.3 Key ISAC Technology Features for Automotive

5GAA’s C-V2X use cases and roadmap [29] include a variety of applications, such as Safety, Vehicle Operations Management, Convenience, Automated Driving, Platooning, Traffic Efficiency and Environmental friendliness, and Society and Community. Certainly, ISAC will provide further enhanced support to this roadmap by complementing existing (onboard) sensors in different ways. Fundamentally, the ISAC framework provides the possibility to enhance ADAS by enabling **tighter and better interaction** between two functions (sensing and communication), and extending the perception **beyond the view** of onboard sensors, to facilitate the creation and maintenance of accurate and real-time digital twins.

In order to provide a better picture of the “ISAC Technology for Automotive”, it is worth thinking not only in terms of the **key features** provided by ISAC, but also in terms of **other complementary technology components**, which make ISAC operation more robust and better.

Key Features/Benefits Provided by ISAC

The main features/benefits of ISAC for automotive include, but are not limited to, enhanced object detection and identification, range/velocity estimation, positioning, and tracking. Altogether, these features lay the ground for better and even augmented environment perception. In addition, the sensing and communication functions can complement each other. Sensing-assisted communications would enhance certain important functions, such as beam management, channel estimation, and resource allocation. Communication-assisted sensing could also help in sensing resource allocation and by enabling data/sensor-sharing. Thus, either by improving communication, sensing, or both, ISAC provides a rich and flexible framework to support the automotive use case groups mentioned before.

Another important feature of ISAC is the potential in terms of modularity, sustainability, and cost reductions. These come fundamentally from the possibility to re-use certain hardware elements (e.g. antennas) and the compatibility/fit with automotive trends, such as virtualized functions, distributed antenna systems, and general-purpose/high-performance onboard computing.

Complementary Technology Components

There are several other technology components necessary to exploit the full potential of ISAC. These include new antenna/array concepts, techniques for multiple antennas, e.g. holographic multiple input multiple output (HMIMO), artificial intelligence and machine learning (AI/ML), reconfigurable intelligent surfaces (RIS), advanced/full duplex schemes, technologies to enable operation at mmW and (sub)THz levels, among others.

Challenges

Among the most important challenges for ISAC in the automotive context include compliance and regulatory aspects, computing/processing power, data volumes, interference management, energy efficiency, peak-to-average power ratio (PAPR) reduction, security and trust, architectures for distributed antennas, distributed/cooperative schemes and protocols, high-quality data collection, multi-modal data sensing, standardization, business models, consistent simulation and performance assessment, among others. These aspects are summarized in Figure 15.

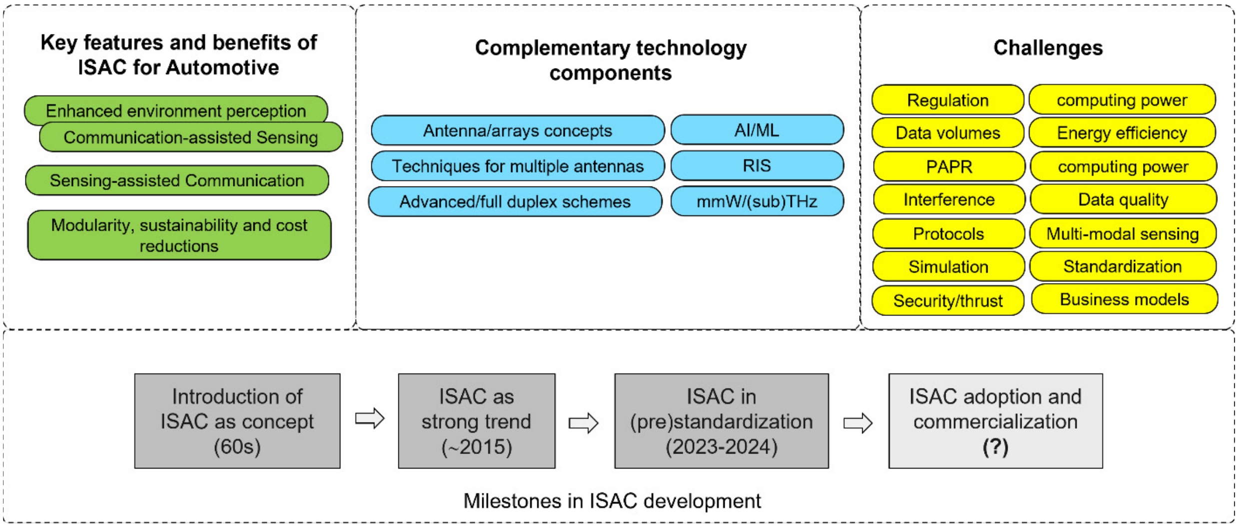


Figure 11. Summary of key ISAC technology features for automotive

6.3.1 ISAC Levels of Integration

ISAC levels of integration refer to how integrated the communication system and sensing system are within an entity. In this case system means the hardware components (e.g. antennas, processors, etc.) and software components (e.g. software/firmware) that perform a certain function: either communication or sensing. In the automotive context, the entity in question mostly refers to an automotive vehicle, however, some considerations may be applicable to roadside units and base stations. ISAC, depending on the level of integration, has different benefits and considerations that need to be taken into account with respect to automotive vehicles, e.g. in terms of cost reduction and space etc. Other considerations that need to be taken into account are the expected benefits and impacts of the C-V2X connectivity ecosystem, the vehicles' ADAS and roadside perception from an IOO perspective. Accordingly, we identify and elaborate on possible ISAC levels of integration to gain a better understanding of the most suitable levels of integration for the automotive domain. The taxonomy of different ISAC levels of integration could be developed in line with **many other/different criteria**, but in this report we mainly focus on the reuse/sharing of **hardware** and **spectrum.** We define the following ISAC levels of integration from the automotive perspective:

1. Higher-layer integration
2. Spectrum-level integration
3. Hardware-level integration
4. Full integration

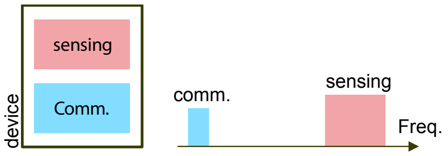
Higher-layer integration

Refers to the integration level in which the communication system and sensing system use their own spectrum and hardware and both exchange higher-layer information with each other. Higher-layer information refers to either application-layer information (e.g. sensing result obtained from sensing system) or higher-layer information (e.g. medium access control layer information from communication or sensing information encapsulated with proprietary protocol/software module). Sensing information from the sensing system is sent to the communication system as higher-layer information. In this integration level, there is no potential for hardware reuse, however there is no spectral resource overhead or interference from the sensing operation on the communication system. This ISAC level of integration can enable sensing-assisted communication, where sensing can provide “side information” to improve communication functions (e.g. beam steering, alignment, refinement, tracking, fast hand-over, etc.).

From a use case perspective, sensing-assisted communication helps the C-V2X vehicular communication system to meet communication SLRs under the 5GAA use cases [2] [3] [4] (which are technology agnostic), to achieve a high degree of availability for automotive functions. Moreover, this ISAC level of integration also enables communication-assisted sensing, where data from different sensing systems spanning multiple entities can be readily fused to improve the accuracy/reliability of sensing results. The higher-layer integration is summarized as follows:

1. Different systems and different bands – higher-layer integration

- The two systems operate using their own spectrum and hardware
- They communicate to assist each other in achieving certain functions, i.e. LIDAR sensor assisting mmWave beam steering for communications
- This level of integration enables sensing-assisted communication (with exchange of higher-layer data) among communication and sensing systems, and, communication-assisted sensing, e.g. where multiple sensing data from different sensing systems spanning multiple entities can be readily fused.



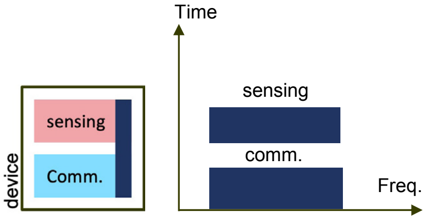
Spectrum-level integration

Refers to the integration level in which the communication system and sensing system share the spectrum, yet use their own dedicated hardware. The systems do not simultaneously use the spectrum resources (e.g. frequency or space domain), but rather communication and sensing signals are multiplexed exclusively in the time domain, similar to time division duplex (TDD) systems. Since the communication Tx and sensing Tx use different dedicated hardware, it is not possible to incorporate sensing signals in the communication baseband processing chain (i.e. include sensing signals in the inverse fast Fourier transform (IFFT) operation when generating the composite OFDM time-domain signal).

In this level of integration, hardware components such as RF chains and/or antennas can be re-used, which translates into some levels of cost and space reduction. The challenge is to accommodate different communication and sensing requirements using the same RF. From the communication and sensing operation perspective, channel aging and high delay may be limiting factors to meet communication and sensing requirements. In addition, depending on the time resource needs (e.g. time slots dedicated to the sensing operation), the “virtual sensing overhead” on the communication system must be studied. The spectrum-level integration is summarized as follows:

2. Different systems with shared bands – spectrum-level integration

- The spectrum for both systems are multiplexed in the time domain
- Sensing and communication mostly use different hardware, but they may share some digital baseband chains, RF chains or antennas etc.
- Using mmWave communication and sensing in a licensed band
- Split between communication and sensing operation is done in time domain (TDD-like)
- Using the same or parts of the same hardware reduces cost and space, but it is challenging to accommodate different requirements using the same RF
- Antenna topology could be re-used for the communication and sensing operation



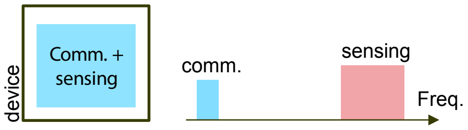
Hardware-level integration

Refers to the integration level in which the communication and sensing system share the hardware, yet use their own dedicated spectrum. In this scenario, the communication operation can, for example, use a licensed frequency band for communication and the sensing operation can use a frequency band for automotive radar (e.g. 77GHz) while reusing hardware components. The hardware components shared by communication and sensing may include baseband and some RF components. It is considered that this level of integration may be implemented with a reduced dependency on 3GPP technical standards.

As the communication and sensing operation use their own dedicated spectrum, the sensing waveform can be more flexible because it will not be limited by the communication resource format or numerology. Moreover, as the difference in carrier frequency for the communication and sensing operation may be large (e.g. sub-6GHz for communication and 28GHz for sensing), there is less potential to re-use the RF antennas. The hardware-level integration is summarized as follows:

3. Same system with different bands – hardware-level integration

- Spectrum used for sensing and for communication are different, e.g. licensed spectrum for communication and 77GHz for sensing
- Hardware module can be shared for cost and space reduction
- Baseband can be shared for the two systems
- Sharing of other hardware components, e.g. RF, may be possible but would be dependent on implementation options
- Sensing and communication may or may not use the same waveform
- Communication waveform may be used for both communication and sensing
- Using a different waveform for sensing, e.g. FMCW, should also be feasible



This scenario describes a high integration level with communication and sensing systems sharing the same hardware and spectrum. We note that this integration is described from a “communication-centric” perspective in the sense that the sensing functionality is integrated into the communication system.[2] With this integration level, the communication and sensing operation are multiplexed in the time, frequency and space domains. This level of integration offers the most benefits thanks to the re-used hardware components (e.g. baseband, RF components, antennas, etc.) which translates into potential significant cost and space reductions. We consider the generation of the communication and sensing signal should remain independent as both functions have different application-layer needs in automotive settings. For example, automotive sensing in most cases needs to be “always-on” or “always available” in order to satisfy situational awareness requirements, whereas communication is driven by active application layer data patterns.

Full integration

Automotive sensing may demand a large bandwidth for range-related sensing SLRs and potentially require large beamwidth or beam-sweeping to cover desired sensing FoV, etc. Moreover, if a single transmission for both communication and sensing operations is used, that transmission compromises the performance of both (e.g. sub-optimal beam direction, unnecessary bandwidth and resources used for the transmission, reduced power, etc.).

To exploit the benefits of **full integration**, several challenges remain such as: coordination of the resources to meet QoS in terms of sensing and communication while managing cross-interference between communication and sensing signals, to minimize sensing signal resource consumption while achieving desired sensing performance.

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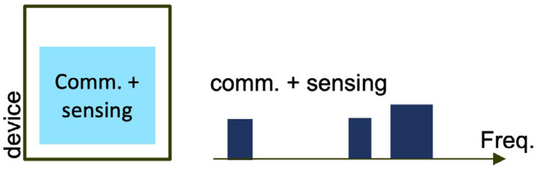
[2] The alternative to this approach is “radar-centric”, where communication functionality is added to the sensing system.

Other challenges related to implementation include coexistence implications with different sensing waveform choices. One option is that communication and sensing use the same digitally-modulated waveform (e.g. OFDM) where sensing signals are specified as a reference signal or they are dynamically assigned. Another option is that a different waveform is used for sensing, where a given parameter selection would ensure compatibility with the resource format and numerology of the communication system.

4. Same system with same band – full integration

- One approach is to use a communication waveform (e.g. OFDM, DFT-s-OFDM, …) and add sensing functionality via a "comms-centric approach" – obvious choice for communication systems
- Another approach is to use optimized new waveforms (e.g. enhancement of existing waveforms (DFT-s-OFDM / OFDM variant, …)
- Sensing and communication signal transmissions are multiplexed and coordinated in time, frequency and space domain (i.e. TDM, FDM, or SDM)
- Sensing and communication signal generation may be independent



Other possible levels of integration exist, but due to the nature of sensing requirements in automotive applications, some levels of integration are not described. We summarize the ISAC levels of integration matrix with respect to their different advantages/disadvantages, implementation aspects, and open challenges from an automotive perspective:

Integration Level	Description	Disadvantage	Advantage	Implementation Aspects Beneficial to Automotive	Challenges to be Solved
Application-layer Integration	The two systems operate using their own separate spectrum and hardware	No potential for hardware reuse	Ease of implementation	Interface between communication and sensing system may integrate other non-3GPP sensors	Understand the performance benefits of sensing-assisted communication

Spectrum-level integration (different systems and same band)	Spectrum for both systems reuse the same frequency band on different hardware by multiplexing both functions in time domain (TDD)	Challenging to accommodate different requirements using the same RF/ MIMO antenna system	May share digital baseband chains, RF chains or antennas (no additional spectrum needed)	Antenna elements within vehicle (front bumper, rear bumper, side bumper etc.)	Understand sensing and communication performance with both signals multiplexed in the time domain
Hardware-level integration (same system and different bands)	Same system with different bands, where hardware module is shared for cost and space reduction	- Potentially more spectrum needs - Challenging to support common baseband and RF chains, antennas	- Possible baseband hardware reuse - More flexibility in choosing sensing waveform	Dedicated RF component for sensing may be needed to support full-duplex operation in UE mono-static sensing	RF can be shared but dedicated RF component for sensing may be needed to support full-duplex operation
Full integration (same system and same band)	- Same system with same band - Coordination of radio resources used for sensing signal and communication signal transmission, e.g. TDM, FDM, SDM	Understand aspects of backward compatibility, co-existence and spectrum sharing	Highest level of hardware reuse	If using communication waveform (e.g. OFDM), flexibility to generate independent communication and sensing signal generation due to different needs and characteristics (digitally modulated over a OFDM waveform)	- Meeting automotive sensing and communication requirements, with the considerations of waveform and multiplexing options - To understand performance, implementation complexity, coexistence implication with different waveform choices - Minimize sensing resource consumption while meeting requirements

6.3.2 Technical Considerations for Automotive

ISAC sensing for automotive has unique requirements that need to be addressed in system design and implementation. Among them, system design that meets automotive sensing requirements with reasonable resource consumption is fundamental for the integrated system to prosper; antenna design and placement at or on UE is also critical given the different configurations and installations in the automotive domain.

6.3.2.1 Considerations on System Design for Low Resource Consumption

Automotive sensing is required to meet very stringent key performance indicators (KPIs) typically related to performance requirements for speed, range, and angle in sensing target detection. To be more specific, sensing in the ISAC system should work properly with maximum possible relative speed between ISAC Tx/Rx and sensing target (max. velocity), as well as distinguish targets travelling at different speeds relative to ISAC Tx/Rx (velocity resolution); it should be able to detect targets far enough in advance to enable a proper reaction and maneuver (max, range), and distinguish targets that have different distance to ISAC Tx/Rx (range resolution); it should also be able to distinguish targets in different directions (angular resolution) within sensing FoV. Moreover, for automotive applications, it is important that the sensing operation is performed continuously to keep track of sensing targets, which implies periodic sensing of Tx/Rx operations by the ISAC system (i.e. refresh rate).

On the one hand, stringent KPI requirements may imply high resource consumption in sensing signal transmission. For example, to meet the desired maximum range and range-resolution requirements, the sensing signal should have sufficient bandwidth and frequency; for maximum velocity and velocity resolution, the sensing signal should maintain sufficient duration and “occupancy”; angular resolution requirements imply the need for beam sweeping in the sensing area of interest. Together with periodic Tx/Rx sensing, the overall resource consumption for sensing can be high, especially when the sensing design follows a conventional FMCW approach.

On the other hand, it is important to keep sensing resource consumption at a reasonable level in an ISAC system. Firstly, ISAC sensing in real-world deployments needs to provide sufficient capacity to accommodate the sensing load in the network; lowering sensing resource consumption is thus important as more sensing operations can be accommodated in the system. Secondly, ISAC sensing may be performed in a frequency band shared with communication, e.g. through the spectrum-level integration or full integration ISAC options; an ISAC system design with low-sensing resource consumption would then benefit communication.

As a result, a system design that achieves desired sensing performance while at the same time maintains a reasonable resource consumption level is crucial for the automotive sector. Multiple techniques can be used to achieve the goal.

Comb-structure sensing signal

Following the design principles of communication standards (e.g. in 3GPP), the signal used for sensing in the ISAC system may be specified in the form of a “reference signal” (RS). Design of the sensing RS takes into consideration both automotive-sensing requirements and sensing-resource consumption.

A widely used technique for reducing RS overhead is a comb-structure design. For comb-structure in time, the sensing RS is transmitted using a fraction of the time resources, e.g. in a subset of OFDM symbols when the system is based on this is a similar waveform convention. For automotive, the sensing RS needs to last long enough to achieve the desired velocity resolution requirement. By leveraging “comb-structure in time”, resource consumption for a single sensing RS transmission can be significantly reduced. Details of the duty cycle for sensing RS symbols and the duration of a sensing RS transmission needs further study, taking into consideration velocity resolution and maximum velocity requirements for different use cases. Depending on waveform options, resources may also be reduced using comb-structure in the frequency settings. For example, if an OFDM waveform (or similar) is used for the sensing RS, only a fraction of the subcarriers may be needed for transmitting the sensing RS.

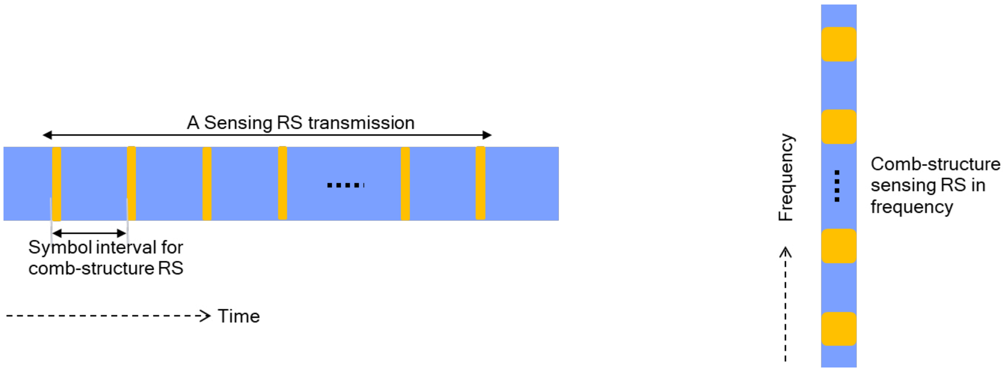


Figure 12. Comb-structure sensing RS in time (left) and frequency (right)

With a comb-structure sensing RS design, resource consumption for sensing can be reduced. The comb-structure also facilitates TDM/FDM of different sensing RS transmissions (e.g. from different transmitters) and/or TDM/FDM of sensing RS transmission and communication signal transmission.

Spatial multiplexing of sensing and communication

For some of the sensing modes, e.g. UE mono-static sensing or UE-to-TRP bi-static sensing, UE transmits sensing RS with beam directions within the sensing FoV (the beams are formed in azimuth to cover the desired FoV and usually have a zero-degree elevation). This is different from communication and the difference can be exploited in the ISAC system design to facilitate the SDM of sensing and communication, and thus to reduce the system-level sensing resource consumption in an ISAC system. The figure below illustrates the different beam directions for sensing and for communication.

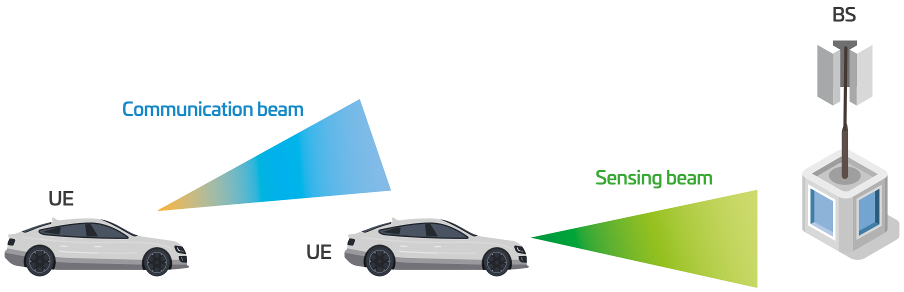


Figure 13. An example of vehicle UE transmitting in UL for communication and for sensing (communication beam may always have a positive elevation while sensing has a zero-degree elevation)

Multi-stage sensing for automotive

Different from positioning, sensing can be used for an unequipped object (sensing target), an object by itself having no wireless transmission/reception capability. Sensing unequipped objects implies somehow detecting the "presence" of the objects, and thus an "always-on" or "always-available" operation for situational awareness in automotive is envisaged. For a detected target, sensing is also required to estimate related KPIs. This suggests that sensing solves a detection and estimation problem, as outlined in Chapter 6.1 ISAC Fundamentals.

It should be noted that requirements for detection and estimation are different. For detecting the presence of sensing targets, sensing requirements can be relaxed if the desired KPIs are "estimated" because they are only needed if a sensing target is detected. This suggests that separated and sequential operations of detection and estimation (e.g. performed at different stages) have the potential to reduce sensing resource consumption.

A specific example is two-stage RS sensing:

- The first-stage RS sensing is to detect the presence of targets. It may transmit for only a short duration, occupy less bandwidth (in the frequency), and employ potentially wider beams (less beams are needed). As a result, less resources will be needed for sensing RS per transmission.
- The second-stage RS sensing RS is to estimate KPIs for detected sensing targets. It is needed only if sensing targets are detected. Statistically, second-stage sensing RS can be transmitted much less frequently in comparison to first-stage sensing RS.

It should also be noted that in two-stage sensing, the first stage can be leveraged in terms of sensing KPI estimation (e.g. for max. velocity), and resource consumption for second-stage sensing RS transmission can thus be reduced, e.g. in comparison to a conventional single-stage sensing operation. This implies that even in a worst-case scenario that sensing targets are detected in all beams, two-stage sensing can still significantly reduce sensing RS resource consumption.

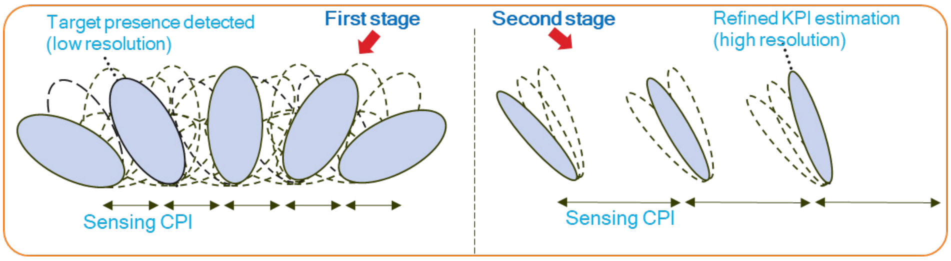


Figure 14. An example of two-stage sensing

6.3.2.2 Considerations on Vehicle UE Antenna Design and Placement

Conventionally, an antenna or module used for communication is located on the vehicle's rooftop, while antenna for radar sensing (front-facing direction) is on the front grill. In the automotive context, depending on integration options, one of the major benefits of ISAC is to reduce hardware cost (and potentially space) by at least partially reusing hardware, e.g. a single antenna panel at, on or in the UE for both sensing RS transmission and communication signal transmission. For this "tight" integration of communication and sensing, it is desirable to have a common antenna panel placement that is suitable for both communication and sensing.

The following figure shows an example of roof-top antenna placement for ISAC which has the potential to meet both sensing and communication requirements. The two-panel design shown in the illustration is an example for full-duplex operation in sensing; it may not be needed in bi-static sensing.

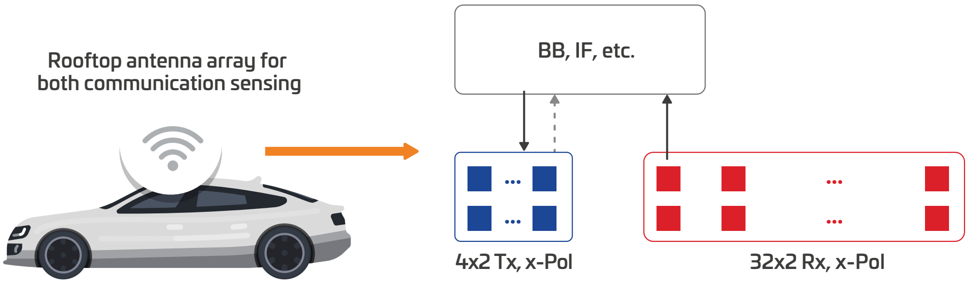


Figure 15. An example of antenna placement at/on/in the UE for automotive ISAC

7 Conclusions

The aim of this Technical Report is to describe use cases, technologies and features for Integrating Sensing and Communication Systems into the ecosystem of automotive services. ISAC features, cases and technologies identified in this text are based on the analysis and consensus of the automotive and telecommunication industry represented by 5GAA. This document should be considered as an initial ISAC applicability assessment for automotive applications. The authors have developed automotive implementation descriptions based on 5GAA's use cases and roadmap, as the basis for respective sensing SLRs. The authors formulated an ISAC automotive concept and vision where a gradual adoption of ISAC systems for automotive purposes is expected towards 5G-A and 6G, including vehicle-based and infrastructure-based ISAC sensing. An initial set of key ISAC technology features, together with technical and non-technical challenges, were duly identified.

The key takeaways of the report are:

Automotive ISAC Use Cases and Requirements

- For a better understanding of 5GAA use cases (and "sensing roadmap"), 5GAA developed and followed an established methodology to define an initial set of use case implementation descriptions with ISAC-sensing functionality in vehicles and in/on infrastructure (i.e. network and/or roadside). The augmented template describes detailed steps focused on the ISAC-sensing operation as well as different sensing targets, sensing topologies, frequency bands, etc. associated with each use case. Nevertheless, 5GAA use cases will need to be further developed once ISAC technology matures.
- To fully capture the sensing requirements from an automotive perspective, the authors defined a sensing SLR table as well as derived the respective sensing SLRs per developed use case, including ranging-, speed- and angle-related sensing KPIs. This analysis was focused on the "state estimation" of sensing targets, however, further considerations related to the identification of sensing targets may be considered.
- The document describes physical characteristics (size, material, velocities) of sensing targets (e.g. e-scooter in the vulnerable road user use case) of the different use cases and feeds this information into the current work towards ISAC in 3GPP RAN1 for ISAC channel modelling and definition of deployment scenarios. The authors expect that further interaction will be needed to align automotive requirements, consistent ISAC automotive simulations and implementation aspects with SDOs.

Automotive ISAC Concept

- As ISAC has different applicability to several domains/verticals, it is important to articulate an automotive ISAC concept. ISAC unifies two automotive functions that have been independent up to this point: telematics and ADAS. From a vehicle point of view, in the short-to-medium term, ISAC is expected to complement existing automotive onboard sensors (with vehicle and infrastructure ISAC sensing) and in the long-term, there will be more and more integration between 3GPP and non-3GPP sensors. From an infrastructure point of view, ISAC-capable infrastructure (e.g. network and/or roadside infrastructure), together with ISAC-capable vehicles, will support multiple sensing modes in any V2X communication scenario of the connected mobility ecosystem. To date, 5GAA has only considered communication-related aspects (including 3GPP positioning), however it has become crucial to consider sensing-related aspects for the connected mobility ecosystem.

Key ISAC Technology Features: Opportunities and Challenges

- Based on a unified ISAC automotive concept, 5GAA envisions ISAC will contribute to the realization of C-V2X use cases and its roadmap thanks to tighter and better-integrated application of sensing (including 3GPP and non-3GPP sensing) and communication systems. ISAC sensing complements onboard sensors (in terms of enhanced and extended perception) and communication systems (in terms of more reliable communication functions) with vehicle-based and infrastructure-based ISAC sensing. A key opportunity and motivation for vehicle OEMs in terms of sustainability and modularity is the potential to reduce costs by re-using hardware and spectrum depending on the level of integration between the sensing (e.g. radar) and communication (i.e. telematics) systems.
- To have an initial understanding of some of the different options to integrate sensing and communication systems in automotive contexts, the Technical Report describes different levels of integration attending to hardware and spectrum reuse. The integration levels are: higher-layer integration (higher-layer service provided by sensing system to communication system, and vice versa, i.e. no hardware reuse), spectrum-level integration (different hardware and same band), hardware-level integration (same hardware and different band), and full integration (same hardware and same band). Certainly, full integration brings the most potential in terms of sustainability and cost-reduction due to maximum hardware, antenna and spectrum reuse, as well as flexibility to allocate resources between the sensing and communication systems. Several challenges to realize full integration were identified, such as a common antenna panel placement (or a majority of antenna elements) suitable for both communication and sensing. Moreover, it is crucial for the automotive sector to achieve a desired sensing performance while at the same time maintaining reasonable/conservative resource consumption in order to minimize the impact on the communication system and accommodate more sensing operations.
- To capitalize on the different ISAC technology features and opportunities for automotive applications/services, there are several challenges that need to be addressed: implementation aspects such as architectures for distributed antennas, standardization, business models, consistent simulation and performance assessment aspects, compliance and regulatory aspects, computing/processing power, data volumes, interference management,

energy efficiency, peak-to-average power ratio (PAPR) reduction, security and trust, among others.

The goal is to build upon these outcomes by further studying implementation aspects/applicability, and to interact with standardization organizations to ensure the automotive sector can take advantage of the opportunities of ISAC technology as well as guide the development of ISAC tailored for the identified requirements. Accordingly, future studies on ISAC in 5GAA will focus on:

1. Implementation aspects, challenges, opportunities, and potential benefits
    - Implementation aspects of different device types (automotive vehicle, roadside infrastructure, network infrastructure)
    - Understand impact of ISAC signals for automotive applications
    - Understand relationship with vehicular distributed antenna systems (DAS); understand if different scope and trustworthiness
    - Revisit integration levels in more detail
    - Touch regional- and global-level spectrum aspects related to sensing (e.g. privacy) for automotive applications, as a basis for implementation aspects/frequency bands
    - Identify what is the regulatory gap that should be changed, and the regulatory constraints
    - More detailed use case implementation descriptions, e.g. based on sensing-assisted communication

2. Assessment/Refinement of reference scenarios of automotive ISAC simulations:
    - Link/refine reference/canonical scenarios from 3GPP to defined 5GAA ISAC use cases in ISAC-I WI.
3. Applicability and usage of ISAC channel models and/or validation with measurements from 5GAA members:
    - More detailed evaluation/calibration of proposed reference and deployment scenarios for automotive applications.
4. Assess the value for car OEMs/tier-1 OEMS/MNOs including VRUs as well as business perspectives per stakeholder in C-V2X ecosystem

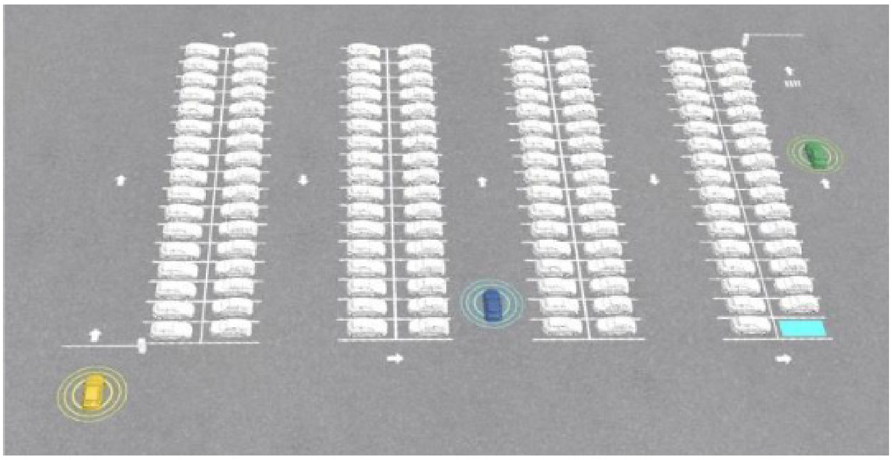
Annex A: Modified Use Case Descriptions from Sensing Perspective

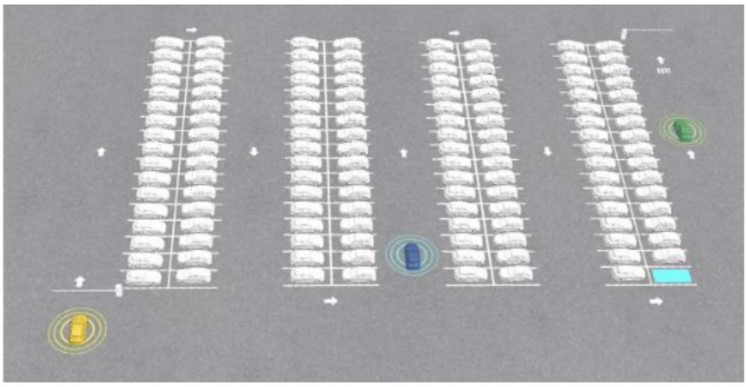
A.1 Modified Use Case Descriptions of Selected ISAC-Applicable Use Cases

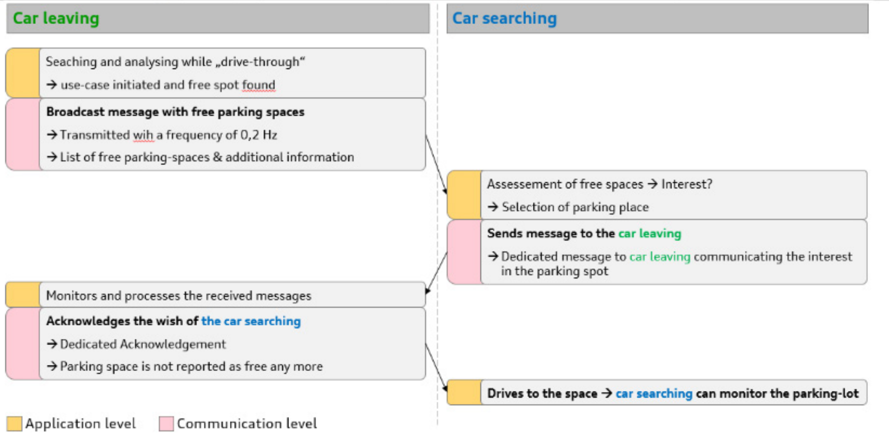
The present annex outlines the extended and modified ISAC-applicable use cases defined by 5GAA in Vol I, II and III [2] [3] [4] from a sensing perspective.

A.1.1 Sensing for Parking-lot Management

Use case name	Sensing for Parking-lot Management
User story	Searching for a parking spot in a big and crowded lot can take a lot of time and thus lead to stress for the driver and passengers. Especially big outdoor parking lots often lack adequate management-systems to allow an efficient assignment of free parking spots, which can lead to many cars driving through the parking lot searching for a free space. This causes higher congestion and consumes lots of time as well as fuel, and may cause incidents. Furthermore, the parking spaces found often do not match the requirements of driver and car (e.g. sufficient size or charging opportunity). All in all, the parking process is a huge challenge and searching for a free space especially on large parking lots can increase the discomfort for customers.
Category	Convenience, traffic efficiency, and environmental friendliness
Road environment	Parking lot (urban)
Short description	The use case is based on the communication between a car driving through the parking lot, scanning its surroundings, and searching for a free parking space. The car on the lot may activate its sensors (including ISAC- sensing function), if the parking density exceeds a set limit, and then scan its surroundings for free spaces and their characteristics (e.g. size). The gathered information is processed and shared with other cars nearby. Cars receiving the data can process it and select (by themselves or via user input) a parking space that suits their needs. The second car then sends a message to the reporting car to outline its interest. Upon reception, the reporting car acknowledges the interest of the searching car and thus the searching car may approach the space, while scanning the lot for free spaces for other participants.
Actors	Drivers (to select the parking space and drive), cars (equipped with communication- and sensor-systems)

Vehicle roles	To describe the mechanisms of the use case three roles are established. Car leaving (green): This role describes a car, which was parked on and is moving towards the exit of the parking lot. It can search for free parking lots and transmit the gathered information to others nearby.  Car approaching (yellow): The “car approaching” has not reached the parking lot yet, but already knows the driver’s intention to park there (because of vehicle input, navigation data, or similar). As soon as it is within proximity of the lot, it may report its interest in a certain parking lot (characteristics). The assignment of a free space early on can avoid having to search the lot and enable direct movement to the free space. Car searching (blue): The “car searching” is already driving through the parking lot searching for a free space. It can be guided to a spot through the reports of other cars and use its sensors to find free spaces, in which it has chosen not to occupy (e.g. because they are too small or offer no charging opportunity).
Road and roadside infrastructure	– No traffic signs – Different types of infrastructure sensors (radar, LIDAR, cameras), including sensors with ISAC-sensing capabilities, provide a complete picture of the dynamic road conditions (e.g. state of vehicles, pedestrians and cyclists)
Other actors’ roles	Cloud systems
Goal	To optimize the process of searching for an adequate/suitable parking space on large and chaotic parking lots.

Needs	– Sensors in the cars (everything from basic ultrasound parking sensors and ISAC sensors up to high-definition cameras) – Communication modules to transmit, receive and process the messages – Standardized communication architecture; message-data, network/ transport-protocol – User interface to start/end use case and select parking spaces – For future implementation; integration in overall “mobility system” to allow for a complete user solution for problems like “last-mile scenarios”
Constraints/ presumptions	▸ Parking sensors and space measuring capabilities; parking space can be sensed with ISAC infrastructure ▸ Communication and standards
Geographic Scope	Global
Illustrations	
Pre-conditions	▸ Communication capabilities ▸ “Wake up” connectivity module for parking list; “keep alive” vehicle role ▸ Car approaching (yellow): Must be within a 500m radius of the parking lot entry to avoid long reservation periods ▸ Car leaving (green): A completed protocol; car has left parking spot during quite high parking density situation (>= 80% measured during >= 15s time spend and >= 15m driven on the parking lot)

Main event flow	Connection lost: A free space is only assigned to a searching car, if the whole assignment process shown is fulfilled; otherwise a space is seen as unoccupied/ unreserved. Multiple interest messages for one free space: The first car transmitting its interest for the space to the reporting car receives the acknowledgement. Space occupied in the meantime: Other cars driving through the lot can check, whether reportedly free spaces are still free and communicate mistakes. If a car is already driving towards the now occupied space it may be redirected. Same space reported by different cars: To avoid the same parking lot being reported by different cars, and the responsibility to assign the space to a searching car is unclear, the cars should monitor the information of other cars. By monitoring the other messages sent, the probability of doubled information can be avoided. For future implementations a “responsibility hand-over” may be considered. 
Alternative event flow [3]	A keep-alive vehicle maintains the list during its parking action and enables future arriving vehicles to access parking spaces; this vehicle in turn becomes the keep-alive vehicle.
Alternative event flow [4]	Information is additionally sent into the cloud by surrounding intelligent systems such as cameras and other sensors (including those with ISAC-sensing capabilities) or by the vehicles themselves. Vehicles then approaching the area could retrieve the latest available information from the cloud.
Post-conditions	▸ Car approaching (yellow): Parked on the lot ▸ Car leaving (green): Left the parking lot ▸ Car searching (blue): Parked on the lot
Service-level KPIs	N/A
Information requirements	▸ New identifiers for parking lots needed to allow communication dedicated to a certain parking lot ▸ New data frames (similar to TIM frames) with different elements to describe the parking space and its additional features ▸ The protocol-infrastructure has to be defined to test and set performance-indicators

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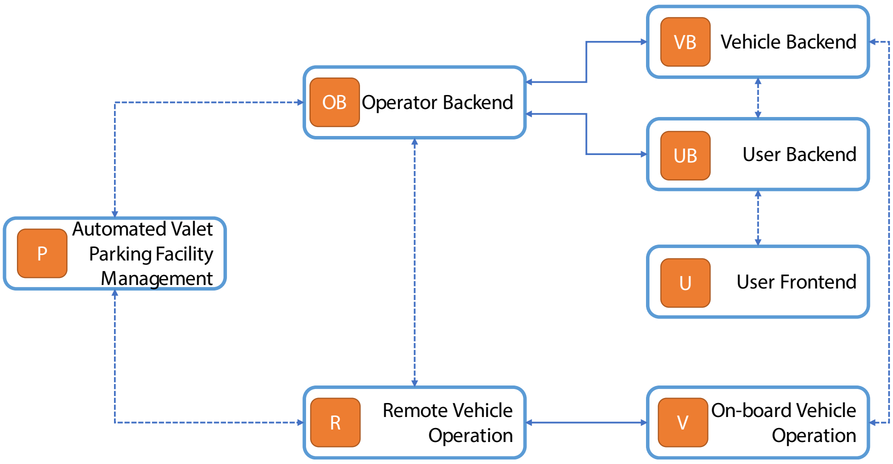
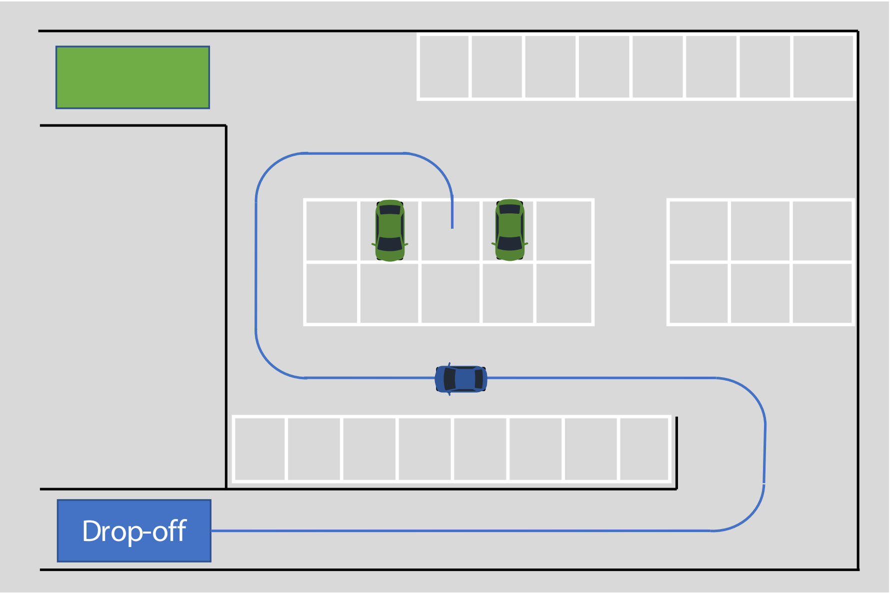
[3] Alternative event flows in this document are not intended as replacements for the main event flow; they are intended to represent different possible flows.

[4] Alternative event flows in this document are not intended as replacements for the main event flow; they are intended to represent different possible flows.

A.1.2 Sensing for Automated Valet Parking

Use case name	ISAC for Automated Valet Parking
User story	When a vehicle arrives at the designated hand-over zone [4], the driver leaves the vehicle, and the vehicle is parked by using the vehicle's own ISAC function or it is operated by an ISAC infrastructure-assisted Automated Valet Parking System (AVPS) after being authorized by the driver.
Category	Vehicle operations management, convenience, autonomous driving, traffic efficiency, and environmental friendliness
Road environment	Urban, rural, parking area (indoor or outdoor)
Short description	▸ A vehicle arrives at the hand-over zone ▸ The driver hands the vehicle over to the AVPS ▸ The vehicle is parked (in an automated manner using ISAC) at the destination parking spot operated by the AVPS ▸ The user may request a "pick-up" request to receive its vehicle in the same manner, again managed by the AVPS
Actors	Vehicle, driver (user), AVPS (of Type 1, 2 or 3)
Vehicle roles	Host vehicle (HV) represents the parking vehicle.
Road and roadside infrastructure roles	Connectivity to HV is provided via wireless communication enabling the "Use Case Preparation (Wake-up)" and valet parking operation. Depending on the AVP type, see below, sensing performed by infrastructure (e.g. RSU) and computing capabilities are provided.
Other actors' roles	▸ AVPS of either – Type 1 – Remote destination assignment: AVPS provides MAP and destination to the vehicle in order to drive in an autonomous manner (L4) to the available/reserved parking spot – Type 2 – Remote motion guidance: AVPS provides "safe time" sync and motion guidance to the vehicle in order to steer the automated vehicle remotely to the designated parking spot – Type 3 – Remote route guidance: AVPS provides the route/proposed path and destination to the vehicle in order to drive in an autonomous manner (L4) to the available/reserved parking spot ▸ Remote vehicle operation subsystem constructs an accurate surroundings environment model (of the HV) through the information received from sensors, control units and communication units, and provides the driving paths and/or maneuver instructions for the HV. The sensors have ISAC sensing capabilities. ▸ The AVP Management Subsystem provides, for example, a high-definition map of the parking area (interior), and sensor information including results acquired using ISAC sensing inside the parking lot. It is connected to the Parking Facility Management System. ▸ The OEM backend system is connected to HV and validates AVP requests while collecting driving data directly from the vehicle. The OEM backend is connected to the Automated Valet Parking Management System to authorize all actions that take over vehicle control (hand-over, motor start, etc.). ▸ The AVP Management System is connected to the valet parking subsystems to monitor them. The Parking Facility Management System manages access to the garage and manages parking slot reservations and assignments. It also incorporates information from the AVPS for parking spot availability. ▸ AVPS uses ISAC capabilities to obtain parking spot availability.
Goal	Using the sensing function by ISAC to enable the parking of HV through AVP without the presence of driver and passengers.

Needs	HV enables automated valet parking driving functionality and communicates with AVP Management Subsystems. The parking area provides accurate and timely environmental information inside the parking area by internal equipment, e.g. high-resolution camera, LIDAR, ISAC sensors, etc. to operate and supervise the AVP mission.
Constraints/ presumptions	HV provides the capability (either Type 1 or 2 or 3) to enable AVP driving functionality. Depending on the type of AVP, HVs have ISAC capabilities. The Parking Facility Management System provides data to identify free parking spots and their location. It is connected to AVP subsystem to coordinate parking reservations and AVP parking, as well as ad-hoc parking of AVP.
Geographic scope	Anywhere
Illustrations	 Logical AVP System Architecture (according to [4]); Key 1 Operator Interface, Key 2 Management Interfaces  AVPS Operation

Pre-conditions	AVP Type 1 and 3 only: - HV enables highly accurate positioning - HV vehicle must be able to autonomously drive based on the provided path - HV vehicles have ISAC capabilities and can exchange sensing information with road infrastructure and other vehicles
Main event flow	HV arrives at the “pick-up/drop-off” area. The user requests to hand over the driving authority to the AVP system. AVP Type 2: - Destination assignment, route planning, object and event detection, pose estimation, trajectory calculation is done by the AVPS’s Remote Vehicle Operation Subsystem. - ISAC-sensing infrastructure in the parking lot performs ISAC sensing to obtain environmental information around HV and provides results to AVPS Remote Vehicle Operation Subsystem. - Path or trajectory information, i.e. motion guidance (like “forward 10m”), and estimation are transferred to HV. For “command mode”, the path can also be sent for the whole parking maneuver and just the velocity is adapted continuously through cyclic commands. Steering is done in the vehicle based on the location sensed by the infrastructure and the target path. - Vehicle motion control, according to the motion guidance received, is performed by HV’s Onboard Vehicle Operation Subsystem. All AVP types: - AVP system provides the current state and position to the user. - Owner/user may make a pick-up request.
Alternative event flow	HV arrives at the “pick up/drop off” area. The user requests to hand over the driving authority to the AVP system. AVP Type 1: - A high definition map of the AVP parking facility is provided to HV’s Onboard Vehicle Operation Subsystem, as well as the driving destination (parking spot). - Route planning, object and event detection, localization, trajectory calculation as well as vehicle motion control is performed by HV’s Onboard Vehicle Operation Subsystem. - HV performs ISAC to acquire local environmental information and provides sensing results to HV’s Onboard Vehicle Operation Subsystem. - AVP system provides the current state and position to the user. - Owner/user may make a Pick-Up request.

Alternative event flow [2]	HV arrives at the "pick-up/drop-off" area. The user requests to hand over the driving authority to the AVP system. AVP Type 3: ▸ Destination assignment and route planning is done by the AVPS Remote Vehicle Operation Subsystem. ▸ HV performs ISAC sensing to acquire local environmental information and provides results to HV's Onboard Vehicle Operation Subsystem. ▸ Sensing infrastructure in the parking lot performs ISAC to obtain environmental information around HV and provides the results to AVPS Remote Vehicle Operation Subsystem. ▸ Object and event detection is a shared task between HV's Onboard and AVPS' Remote Vehicle Operation Subsystem. ▸ Localization, trajectory calculation and vehicle motion control is performed by HV's Onboard Vehicle Operation Subsystem. ▸ AVP system provides the current state and position to the user. ▸ Owner/user may makes a pick-up request.
Post-conditions	HV has reached its destination and successfully parked at the destination (place) or has returned to the hand-over zone.
Service level requirements	▸ Service level latency ▸ Service level reliability ▸ Information requested/generated ▸ Vehicle velocity ▸ Vehicle density ▸ Positioning accuracy ▸ Accuracy of positioning estimate by sensing (horizontal and vertical) ▸ Accuracy of velocity estimate by sensing (horizontal and vertical) ▸ Sensing resolution (range resolution and velocity resolution) ▸ Max detection range ▸ Max detection velocity
Information requirements	▸ Type 1 only: High-definition map inside the parking area ▸ Estimation of position ▸ Time synchronization, heartbeat ▸ HV information (e.g. type, size, height, turn radius) ▸ HV's state information

SLR Title	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	Min. 100	---
Information requested/ generated	Quality of information / Information needs	0.2Mbps HV to AVPS; Up to 0.2Mbps AVPS to HV; Up to 2Mbits/s AVPS to HV (Type 2)	---
Service level latency	[ms]	40	---
Service level reliability	[%]	99.9%	---
Velocity	[m/s]	8.3	---
Vehicle density	[vehicle/km^2]	100	Include considerations NOTE: Density of target objects for ISAC sensing
Positioning accuracy	[m]	N/A	Depends on target performance of AVPS (e.g. how close to park vehicles to each other)
Interoperability/regulatory/ standardization required	[yes/no]	Yes/Yes/Yes	---

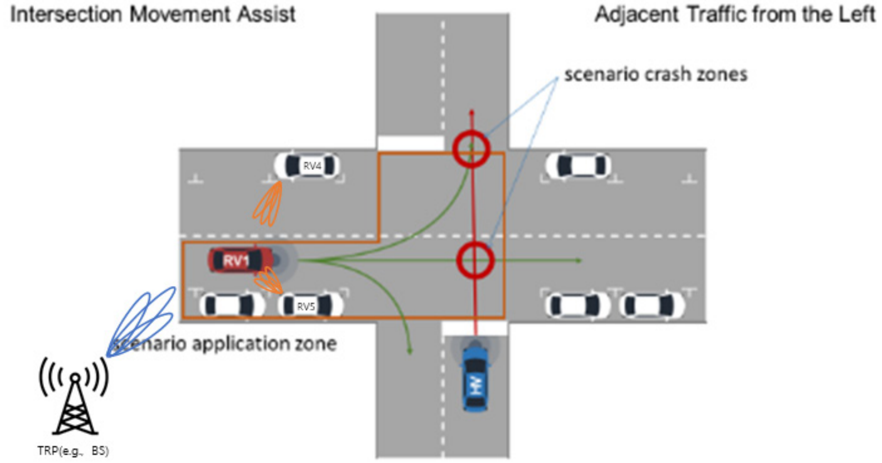
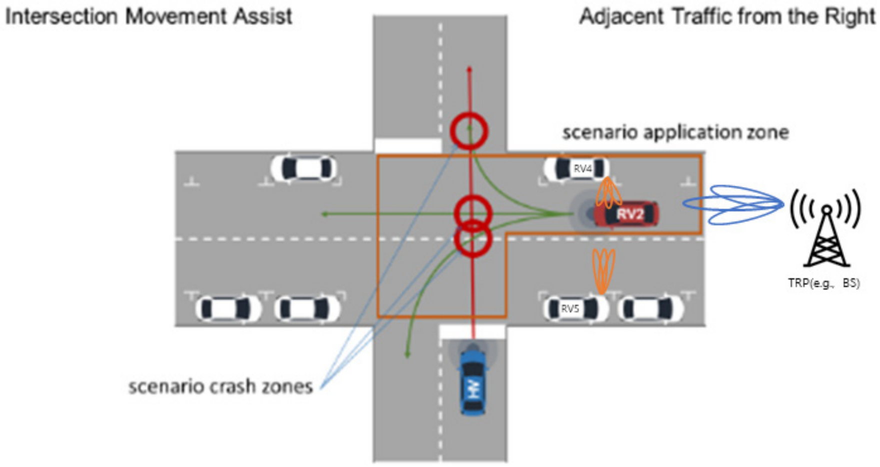
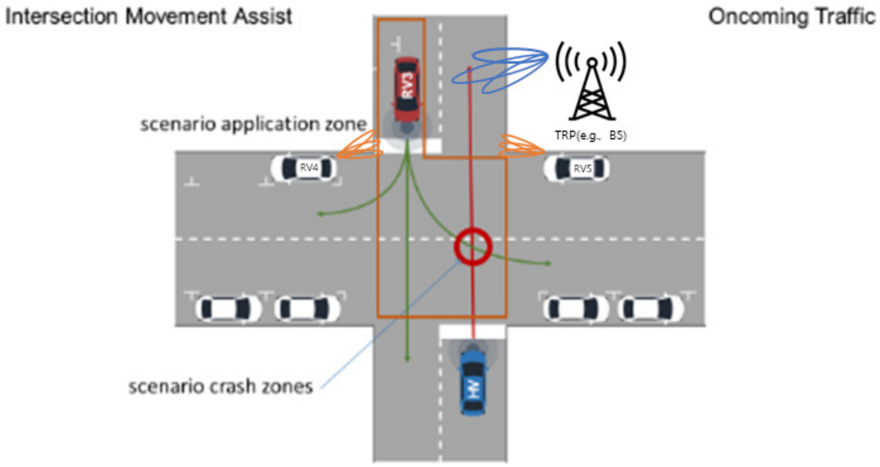
A.1.3 Sensing for ADAS

The UCID corresponds to a new defined use case.

A.1.4 Sensing for Intersection Movement Assist

Use Case Name	ISAC for Intersection Movement Assist.
User Story #2	Stationary HV proceeds straight from stop at an intersection. HV is alerted if it is unsafe to proceed through the intersection. Unconnected RVs trajectories are detected and estimated by using (ISAC) sensing.
Category	Safety.
Road Environment	Intersections.
Short Description	▸ Alerts HV that is stopped and intending to proceed straight through the intersection of: – Approaching cross-traffic from the left – Approaching cross-traffic from the right – Oncoming traffic intending to turn left
Actors	▸ Host vehicle (HV). ▸ Remote vehicle 1 (RV1). ▸ Remote vehicle 2 (RV2). ▸ Remote vehicle 3 (RV3). ▸ Remote vehicle 4 (RV4). ▸ Remote vehicle 5 (RV5).
Vehicle Roles	▸ HV represents the vehicle stopped at intersection. ▸ RV1 represents unconnected cross-traffic vehicle approaching from the left. ▸ RV2 represents unconnected cross-traffic vehicle approaching from the right. ▸ RV3 represents unconnected oncoming-traffic vehicle. ▸ RV4 and RV5 represents the vehicles with (ISAC) sensing capability.

Road & Roadside Infrastructure Roles	▸ Roads are defined by their lane designations and geometry. ▸ Intersections are defined by their crossing designations and geometry. ▸ Traffic lights and stop signs control right of way traffic flow through an intersection (if available). ▸ Local Traffic laws and rules control right of way through three-way stops, four-way stops and unsigned intersections. ▸ Different types of infrastructure sensors (RADAR, LIDAR, cameras) including sensors with ISAC sensing capabilities provide a complete picture of the dynamic road conditions (e.g., state of vehicles, pedestrians and cyclists).
Other Actors' Roles	Not applicable.
Goal	▸ Avoid a lateral collision between HV and RV1. ▸ Avoid a lateral collision between HV and RV2. ▸ Avoid an oncoming collision between HV and RV3.
Needs	▸ HV needs to know if there is a risk of collision with RV1 approaching from the left. ▸ HV needs to know if there is a risk of collision with RV2 approaching from the right. ▸ HV needs to know if there is a risk of collision with an oncoming RV3.
Constraints/ Presumptions	▸ The acceleration of HV from stopped must be assumed. ▸ RV1's intended direction through the intersection is known. ▸ RV2's intended direction through the intersection is known. ▸ RV3's intended direction through the intersection is known. ▸ Even though RV1, RV2 and RV3 are not connected, they and their states are detected and estimated by using sensors (e.g., RADAR, LIDAR, camera, ISAC sensing capabilities) of other road users (RV4 and RV5) or infrastructure.
Geographic Scope	▸ Global

Illustrations	  

Pre-Conditions	▸ HV is stopped at an intersection. ▸ The “Adjacent Traffic from the Left” scenario application zone is determined from: – HV’s location – lane designations and geometry – intersection geometry – posted speed limits – Road conditions (if available) ▸ The “Adjacent Traffic from the Right” scenario application zone is determined from: – HV’s location – lane designations and geometry – intersection geometry – posted speed limits – Road conditions (if available) ▸ The “Oncoming Traffic” scenario application zone is determined from: – HV’s location – lane designations and geometry – intersection geometry – posted speed limits – Road conditions (if available)

Main Event Flow	▶ RV1 is in the “Adjacent Traffic from the Left” scenario application zone. ▶ If RV1 has the right of way: – RV1’s trajectory through the intersection is estimated using: – RV1’s location and dynamics – RV1’s turn signal state – Lane designations and geometry – Intersection geometry – HV’s trajectory through the intersection is estimated using: – HV’s location – HV’s estimated acceleration – Lane designations and geometry – Intersection geometry – If there is a risk of collision based on the estimated trajectories of HV and RV1 then: – HV is warned of a risk of collision with RV1 approaching from the left ▶ Otherwise if HV has the right of way: – RV1’s stopping distance is estimated using: – RV1’s location and dynamics – Lane designations and geometry – Intersection geometry – Road conditions (if available) – If there is a risk that RV1 cannot stop before the intersection: – HV is warned of a risk of collision with RV1 approaching from the left

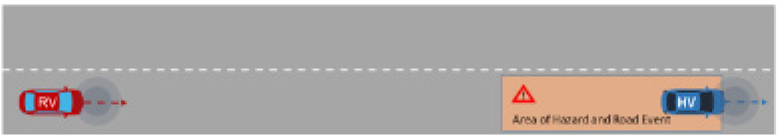
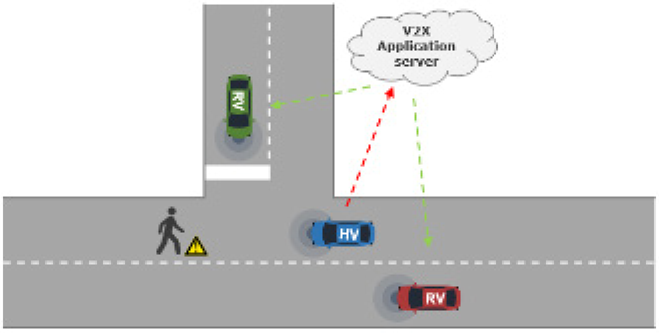
Alternative Event Flow	▸ RV2 is in the “Adjacent Traffic from the Right” scenario application zone. ▸ If RV2 has the right of way: – RV2’s trajectory through the intersection is estimated using: – RV2’s location and dynamics – RV2’s turn signal state – Lane designations and geometry – Intersection geometry – HV’s trajectory through the intersection is estimated using: – HV’s location – HV’s estimated acceleration – Lane designations and geometry – Intersection geometry – If there is a risk of collision based on the estimated trajectories of HV and RV2 then: – HV is warned of a risk of collision with RV2 approaching from the right ▸ Otherwise if HV has the right of way: – RV2’s stopping distance is estimated using: – RV2’s location and dynamics – Lane designations and geometry – Intersection geometry – Road conditions (if available) – If there is a risk that RV2 cannot stop before the intersection: – HV is warned of a risk of collision with RV2 approaching from the right

Alternative Event Flow	▸ RV3 is in the "Oncoming Traffic" scenario application zone. ▸ If RV3 has the right of way: – RV3's trajectory through the intersection is estimated using: – RV3's location and dynamics – RV3's turn signal state – Lane designations and geometry – Intersection geometry – HV's trajectory through the intersection is estimated using: – HV's location – HV's estimated acceleration – Lane designations and geometry – Intersection geometry – If there is a risk of collision based on the estimated trajectories of HV and RV3 then: – HV is warned of a risk of collision with oncoming RV3 ▸ Otherwise if HV has the right of way: – RV3's trajectory and stopping distance is estimated using: – RV3's location and dynamics – RV3's turn signal state – Lane designations and geometry – Intersection geometry – Road conditions (if available) – If there is a risk that RV3 cannot stop before the intersection: – HV is warned of a risk of collision with oncoming RV3
Post-Conditions	▸ HV is aware of a risk of collision with RV1 approaching from the left. ▸ HV is aware of a risk of collision with RV2 approaching from the right. ▸ HV is aware of a risk of collision with oncoming RV3.
Service-Level KPIs	▸ Location accuracy. ▸ Information age. ▸ Communication range. ▸ Accuracy of positioning estimate. ▸ Accuracy of velocity estimate. ▸ Sensing Resolution. ▸ Max Detection Range. ▸ Max Detection Velocity. ▸ Reliability of Sensing Result. ▸ Vehicle Density.

Information Requirements	▸ HV's location. ▸ HV's turn signal state. ▸ HV's estimated acceleration from stopped. ▸ RV1's location and dynamics. ▸ RV1's turn signal state. ▸ RV2's location and dynamics. ▸ RV2's turn signal state. ▸ RV3's location and dynamics. ▸ RV3's turn signal state. ▸ Lane designations and geometry. ▸ Intersection geometry. ▸ Traffic stop signs. ▸ Traffic light signal phase and timing. ▸ Traffic rules and laws for three-way stops, four-way stops and unsigned intersections. ▸ Current road conditions (if available).

A.1.5 Sensing for Hazard Information and Road Event for AV

Use Case Name	Vehicle Collects Hazard Information and Road Events for AV
User Story	Vehicles collect information on hazards and road events based on vehicle sensor data. They share the resulting relevant information as processed data.
Category	Safety.
Road Environment	Intersection, urban, rural, highway
Short Description	Whenever a vehicle detects a hazard or road event based on its own sensor data, the corresponding information (including hazard or event location) is collected for the purpose of sharing with other vehicles, especially AVs and V2X AS.
Actors	Host Vehicle (HV), Remote Vehicle (RV).
Vehicle roles	HV represents the vehicle that detects hazard and events based on its own sensor data during the driving; the RV, which is typically an AV, receives information collected by the HV.
Road/Roadside Infrastructure Roles	Optionally, a roadside infrastructure role can provide processed information derived from sensor data to RVs or in another way by receiving information from the HV and providing it to other RVs.
Other Actors' Roles	Optionally, a V2X application server (IOO/OEM/SP AS) role may be involved in the use case for receiving information from HV and forwarding it to the RV.
Goal	Share hazard, road, traffic, and weather event information detected by vehicles, so that the information horizon of the AVs (and other vehicles) is extended.
Needs	AVs (and other vehicles) need and benefit from prior information about the road, traffic and weather to improve their trajectory planning and motion control.
Constraints/ Presumptions	Assumptions will be required for the following information: The HV is able to detect hazards, road, traffic and weather events based on its sensor data. Different types of HV/infrastructure sensors (RADAR, LiDAR, cameras) including sensors with ISAC sensing capabilities provide a complete picture of the hazards on road. The HV is able to communicate the detected hazards and events
Geographic Scope	Global.

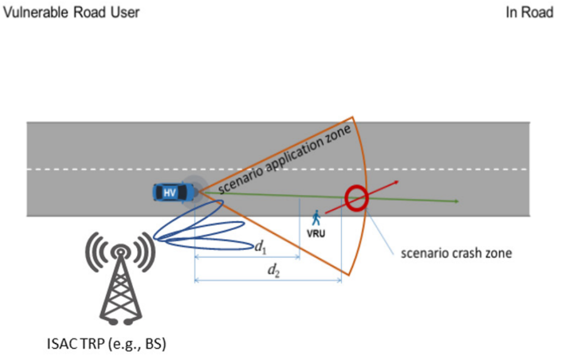
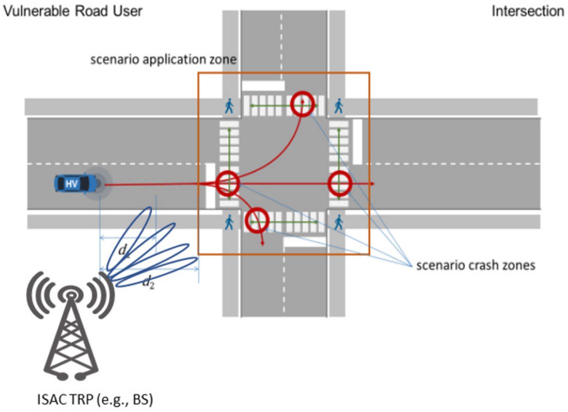
Illustrations	Scenario 1  Scenario 2 Vehicle collects hazard event and send it to the V2X AS 
Pre-Conditions	The HVs/Roadside Infrastructure are/is equipped with sensors (e.g., ISAC sensing, RADAR, Cameras, LiDAR) and they can share detected hazards and events. The vehicles e.g. AVs that receive the information can use the information to adapt their driving accordingly.
Main Event Flow	The HV/Roadside Infrastructure detects a hazard or a hazardous event (road, traffic, weather, etc.) The HV/Roadside Infrastructure sends out corresponding information of the detected hazard / event The RV is approaching the scenario application zone and receives the information directly from the HV/Roadside Infrastructure
Alternate Event Flow	The HV detects a hazard or a hazardous event (road, traffic, weather, etc.) The HV sends out corresponding information of the detected hazard or event to the V2X application server (e.g., IOO/OEM/SP AS) The application server gathers and redistributes the hazard / event information to the concerned RVs The RV is approaching the scenario application zone and receives the (warning) information from the V2X application server (e.g., IOO/OEM/SP AS)
Post-Conditions	Information on the detected hazard and road events are available and considered by the RV for driving decisions.
Information Requirements	HV’s sensor data Road conditions Car status (e.g. location, dynamics, etc.) Hazards and events detected by vehicles

User Story #1			
Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	300 m	Minimum range assuming the maximum speed in a highway and 4 seconds response time for AVs. Note in Scenario 2, this does not apply as it needs to reach an application server (AS).
Information Requested/ Generated	Quality of information/ Information needs	300 bytes/per message	The message sent from HVs to RVs or AS contains detected event types (barriers, road work, bad weather, etc.), location, priority, etc. And the message is sent by an event trigger. The maximum size of the message is assumed to be 300 bytes.
Service Level Latency	[ms]	20	Low end-to-end latency is needed for AVs to get hazard information in time to maintain safety levels.
Service Level Reliability	%	99.9	High reliability is needed for AVs to take action based on the hazard and road event message for other vehicles.
Velocity	[m/s]	Highway: 69.4	Maximum speed on highways is assumed to be 250 km/h.
Vehicle Density	[vehicle/ km^2]	12,000	The maximum assumed density in urban situations.
Positioning	[m]	1.5 (3σ)	AVs need pinpoint accuracy to estimate event locations and avoid collisions. Typical positioning accuracy is needed to confirm the traffic lane.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Scenario 1: Yes/ Yes/Yes Scenario 2: Yes/ Yes/Yes	Interoperability between different OEMs' vehicles is needed (Scenario 1), as well as between the HD map provider and different vehicles (Scenario 2). Regulatory oversight for safety related issues is needed. Standardisation is required in the sense that the format for sensor data exchange should be commonly understood by all involved vehicles.

A.1.6 Sensing for Vulnerable Road User

Use case name	Sensing for Vulnerable Road User
User story	Alert HV of approaching VRU on/along the road or crossing an intersection and warn of any risk of collision using (ISAC) sensing function.
Category	Safety
Road environment	Intersection, urban, rural, highway, other
Short description	Alert HV of approaching VRU on/along the road or crossing an intersection and warn of any risk of collision using (ISAC) sensing function.

Actors	▸ Vulnerable road user (VRU) ▸ Roadside unit with sensors (e.g. surveillance cameras, communication devices with ISAC-sensing capabilities, radar, LIDAR, ultrasonic) at traffic lights/crossings ▸ Host vehicle (HV) ▸ Remote vehicle (RV)
Vehicle roles	▸ HV represents the vehicle moving forward and has ISAC-sensing capabilities ▸ RV represents vehicle with (ISAC) sensing capabilities which has line-of-sight to VRU
Roadside infrastructure roles	▸ Roads defined by their lane designations and geometry ▸ Intersections defined by their crossing designations and geometry ▸ Traffic lights and stop signs control right-of-way traffic flow through an intersection (if available) ▸ Pedestrian crossings defined by their designations and geometry ▸ Different types of infrastructure sensors (radar, LIDAR, cameras) including sensors with ISAC-sensing capabilities provide a complete picture of the dynamic road conditions (e.g. state of vehicles, pedestrians and cyclists)
Other actors' roles	VRU represents pedestrian, bike, e-bike, motorbike, skateboard, etc. travelling along the road or intends to cross the road.
Goal	Avoid collision between HV and VRU.
Needs	▸ HV needs to be aware of VRU on the road and any risk of collision ▸ HV needs to be aware of VRU at an intersection and any risk of collision
Constraints/presumptions	Assumptions will be required for the following information: ▸ HV's safe stopping distance ▸ VRU's trajectory is constant ▸ Extent of scenario application zones
Geographic scope	Global.

Illustrations	  *d*1 =stopping distance of HV *d*2 =distance from HV to scenario crash zone

Pre-conditions	- HV is moving forward
	- Before establishment of line-of-sight, if any.
	- Known VRU is characterized (bike, pedestrian, motorcycle, etc.)
	- “In-road” scenario application zone is determined from:
	  – HV’s location and dynamics
	  – HV’s safe stopping distance
	  – Lane designations and geometry
	  – Road conditions (if available)
	- “Intersection” scenario application zone is determined from:
	  – HV’s location and dynamics
	  – HV’s safe stopping distance
	  – Intersection geometry
	  – Road conditions (if available)

Main event flow	- If VRU is in the “on-road” scenario application zone:
	  – HV or RSU (e.g. ISAC TRP) detects VRU moving in application zone using its sensing capabilities (ISAC-sensing, surveillance camera)
	  – If HV’s trajectory and VRU’s trajectory are on a collision course then warn HV of the risk, or otherwise caution HV about the approaching VRU

Alternative event flow	▸ If VRU is in the "intersection" scenario application zone: – RV or RSU (e.g. ISAC TRP) detects VRU moving in application zone using its sensing capabilities (ISAC sensing, surveillance camera) – If HV's trajectory and VRU's trajectory are on a collision course then warn HV of the risk, or otherwise caution HV about the approaching VRU
Post-conditions	▸ HV/Driver is aware of VRU's proximity and the risk of collision (Day 1-1.5) ▸ HV is aware of VRU's proximity and takes the necessary safety measures to avoid or mitigate collision (Day 3)
Service level requirements	▸ Positioning accuracy ▸ Information age ▸ Communications range
Information requirements	▸ HV's location and dynamics ▸ HV's safe stopping distance ▸ VRU's location and dynamics ▸ VRU's characterization (bike, pedestrian, motorcycle, etc.) ▸ Lane designations and geometry ▸ Intersection geometry ▸ Current road conditions (if available) ▸ Other vehicle sensor data

User Story	Detailed description, specifics and main differences to the user story in the main template
Awareness of the presence of VRUs near potentially dangerous situations	This VRU user story describes a scenario in which a presence warning at crossings and spots without line-of-sight (LOS), e.g. automatic detection of pedestrians waiting and/or crossing from infrastructure is intended. VRUs are monitored via infrastructure and/or vehicle support (i.e. surveillance cameras/wireless detection mechanisms, such as TRP or UE with ISAC-sensing capabilities) and/or they are equipped with mobile VRU devices (UE). Awareness notifications are shared with drivers, e.g. via roadside units/vehicles/monitoring system attached to a 3GPP system (potentially using MEC) sending messages to drivers or their C-ITS systems actively monitor VRUs equipped with a device.

Collision risk warning	The user story involves one or multiple vehicles and it assumes V2I and/or V2P connectivity. In this User Story a vehicle has entered an area in which VRUs are present: ► Area could be crossings (including cross-walks, zebra crossings) and spots without LOS ► VRUs monitored via infrastructure and/or vehicle support (i.e. surveillance cameras/wireless detection mechanisms, e.g. TRP or UE with ISAC-sensing capabilities) and/or equipped with mobile VRU devices (UE) ► Awareness notifications are shared with drivers, for example via: – Roadside units – Vehicles – Monitoring systems attached to 3GPP system* sending messages to drivers or vehicle's C-ITS system, and actively monitoring VRUs equipped with a device * Possible extension of user story, e.g. potentially using MEC
...	

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