5GAA Automotive Association

Enhanced Positioning Accuracy and Coherent Situational Awareness by Connected Sensors and Positioning as a Service

ConSens Work Item

5GAA Automotive Association
Technical Report

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Contents

1 Executive Summary

This report provides an overview of positioning technologies for Connected Intelligent Transport Systems (C-ITS) and explores functions where positioning solutions work together to improve their functions. Furthermore, the Work Item ConSens (Connected Sensors) aims to explore possibilities for improving where technologies can exchange information in a cooperative manner to establish new and better localization techniques. ConSens defines a new service which allows traffic participants to request positioning improvement services from the 5G network and infrastructure. The methodology of how the service should be triggered and used is described in conjunction with the 'digital twin' approach for Advanced Driver Assistance Systems (ADAS). The report also provides implementation examples of such services and systems, and it assesses associated business models.

2 Introduction

The evolution of Vehicle-to-Everything (V2X) is pivotal in realizing the vision of smart, connected transportation systems. In the dynamic landscape of automotive technology, the integration of 5G capabilities with V2X communication systems is a cornerstone for revolutionizing road safety and traffic efficiency. At the core of this evolution is the enhancement of positioning accuracy, which is fundamental to improving the safety, efficiency, and reliability of vehicular operations. Precise positioning enables vehicles to navigate complex traffic environments, communicate effectively with other road users, and execute safe maneuvers, thereby reducing the risk of accidents and optimizing traffic flow. Thus, 'Enhanced Positioning Accuracy and Coherent Situational Awareness by **Con**nected **Sens**ors and Positioning as a Service' aims to leverage the robust 5G-V2X ecosystem to foster unprecedented levels of situational awareness and positioning precision for various road users. This Technical Report (TR) outlines the objectives, methodologies, and anticipated outcomes of the project, known by its acronym ConSens.

Positioning accuracy and situational awareness are critical components in ensuring the safety and efficiency of road users, from pedestrians and cyclists to motor vehicles. Inaccurate or delayed positioning information can lead to severe consequences, including the increased likelihood of accidents and traffic inefficiencies. ConSens addresses these challenges by proposing an innovative integration of existing and emerging technologies to create a cohesive system that enhances the reliability and accuracy of situational data.

The proposed approach is not merely about improving individual technological components; it is about synergizing them into a comprehensive service that can be offered to all stakeholders in the traffic system, including Vulnerable Road Users (VRUs) who are often the most affected by positioning inaccuracies. By creating a digital twin of the road environment and employing advanced sensor fusion techniques, ConSens aims to provide a real-time, accurate, and reliable positioning service, called **Positioning as a Service** (PaaS).

The real-time requirement of the connected automobile in some cases requires a very high speed, low latency connection between two vehicles, or higher bandwidth. In some cases, there may not be enough bandwidth in a typical 5G-V2X direct system to allow for many vehicles to simultaneously share information. ConSens will outline a method for establishing wide-band system connection requiring high throughput or bandwidths.

Several examples of these bandwidths and throughputs are the real-time sharing of:

- Digital Twin Information
- Raw Camera Information
- UWB Ranging Information

A high-precision ranging system, such as GNSS RTK and/or UWB technologies, meets the accuracy requirements.

Through detailed analysis and collaboration across multiple working groups within

5GAA, this report delves into the technical requirements, exploring the challenges, potential solutions, and the broader implications of deploying such technology. It serves as a **blueprint for the future of connected road safety**, setting the stage for a significant leap forward in our journey towards smarter, safer roads.

3 Abbreviations

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

ACAS	Galileo Assisted Commercial Authentication Service
ADAS	Advanced Driver Assistance System
AoA	Angle of Arrival
APDU	Application Protocol Data Unit
BSM	Basic Safety Messages
BLE	Bluetooth Low Energy
CAM	Cooperative Awareness Messages
CHIMERA	Chips Message Robust Authentication
CRPA	Controlled Reception Pattern Antennas
CSAE	China Society of Automotive Engineers
E2E	End-to-End
ESA	European Space Agency
GNSS	Global Navigation Satellite System
HD CPM	High-Definition Cooperative Perception Messaging
HID	Human Interface Device
IDMS	Identity Management System
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
IMU	Inertial Movement Unit
IOO	Infrastructure Owner Operators
ITS	Intelligent Transportation System
KPI	Key Performance Indicator
LHCP	Left-Hand Circular Polarization
MEC	Mobile Edge Computing
NDS	Navigation Data Standard
NLOS	Non-Line-of-Sight
OOB	Out-of-Band
OSNMA	Open Service Navigation Message Authentication
PaaS	Positioning as a Service
PNT	Position, Navigation and Timing
PVT	Positioning, Velocity and Timing
ProSe	Proximity Services
RAN	Ranging Area Network
RHCP	Right-Hand Circular Polarization
RQ	Request
RS	Response
RSU	Roadside Unit

RTK	Real-Time Kinematic
RTT	Round-Trip Time
RU1	Road User 1
RU2	Road User 2
SDO	Standards Development Organization
SDSM	Sensor Data-Sharing Message
SLR	Service Level Requirement
SP App	Service Provider Application
SPAKE2+	Simple Password Authenticated Key Exchange
SPAT	Signal Phase and Timing
SSM	Sensor-Sharing Messages
TDoA	Time Difference of Arrival
ToA	Time of Arrival
UE	User Equipment
URSK	UWB Ranging Secret Key
UWB	Ultra-Wideband
V2I	Vehicle-to-Infrastructure
V2N2X	Vehicle-to-Network-to-Everything
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VIN	Vehicle Identification Number
VIR	Vehicle Intention Request
VRU	Vulnerable Road Users

4 Objectives and Scope

The rapid evolution of connected vehicle technologies is transforming how we think about road safety and transportation systems. As Vehicle-to-Everything communications become increasingly integrated into road infrastructure, the need for highly accurate positioning and situational awareness becomes even more critical, especially when it comes to protecting Vulnerable Road Users, such as pedestrians, cyclists, and motorcyclists who face greater risk in traffic environments and more challenges in being detected and accounted for by traditional traffic systems.

The ConSens Work Item is a forward-looking initiative designed to leverage the full capabilities of the 5G-V2X ecosystem to enhance positioning accuracy and situational awareness for all road users. Positioned at the intersection of technology and mobility, the project's objectives are multidimensional, focusing on technological advancement which improves road safety and traffic efficiency.

ConSens is working to harness the power of connected sensors and advanced communication technologies, delivering a more coherent and accurate depiction of the vehicular environment. The Work Item's focus extends beyond mere technical advances; it seeks to integrate these technologies into a unified system that offers Positioning as a Service. This service promises to revolutionize how vehicles perceive their surroundings by providing high-fidelity, real-time positioning data essential for *safety-relevant* driving decisions.

ConSens addresses several key challenges in the current V2X landscape, including the variability in sensor accuracy and the latency in data transmission, which can undermine the effectiveness of safety measures. By improving the quality and reliability of positioning information, ConSens seeks to create a safer road environment for all users, particularly VRUs in urban settings.

The next chapters outline the importance of enhanced positioning systems in the broader context of vehicular communications and introduce the objectives of the ConSens Work Item. As we delve deeper into the specifics of the implementation and use cases in subsequent chapters, we will explore how ConSens is set to fulfill its ambitious goals within the rapidly-evolving 5G-V2X ecosystem.

4.1 Technology Review and Past Experiences

In previous demonstrations, the importance of V2X for VRU protection has been highlighted. However, the user experience was often marred by imprecise positioning, leading to false warnings. These false warnings were not only frustrating but also hindered the potential for mass deployment. ConSens is addressing these issues by enhancing positioning accuracy and reliability, while also relying on past 5GAA assets such as previous Work Items.

The TR also tries to assess each existing technology from the point of view of enhancing it to provide PaaS. The goal is to identify which technologies are best fitted to improve the localization of 5G connected vehicles.

Central to the ConSens work is the goal to significantly improve the accuracy of positioning information available to vehicles. The Work Item seeks to achieve this through the innovative use of connected sensors that collect, process, and disseminate data more effectively. ConSens integrates multiple data sources including local sensors like GNSS RTK, cameras, lidar, and radar, as well as remote sensors provided by other vehicles and infrastructure.

4.2 Development of Positioning as a Service

An innovative aspect of ConSens is the conceptualization and development of Positioning as a Service. This model is envisioned as a shared infrastructure utility that vehicles and other road users can tap into for accurate, real-time positioning data either obtained locally, at the edge, or from the cloud. PaaS promises to be a transformative approach, enabling a scalable solution that can be integrated across different segments of road traffic management, from individual vehicles to broader traffic control systems.

4.3 Digital Twin and Reliable Situational Awareness

ConSens is working toward a robust framework for coherent situational awareness. This involves creating a digital twin of the vehicular environment that updates in real time, reflecting dynamic changes and providing a comprehensive view of potential hazards. By ensuring high fidelity in the replication of the physical environment, ConSens supports advanced decision-making capabilities in autonomous and semi-autonomous vehicles, enhancing their ability to respond to unexpected situations.

A key challenge in achieving reliable situational awareness is conflict resolution. For example, if two systems share their independently-collected digital twin information, the location of objects may not be perfectly correlated. ConSens addresses this by enabling a system to share digital twin information in real time such that such conflicts can be resolved.

Several challenges need to be addressed to realize the objectives of ConSens:

- **Identity Management:** Ensuring that the identities of all road users and their devices are accurately managed and authenticated.
- **Positioning Mismatch:** Resolving discrepancies in positioning data from different sources.
- **Prioritization:** Prioritize the critical road user whose position and motion could lead to a collision.
- **Classification/Content Mismatch:** Harmonizing different types of data and

classifications to ensure consistency.

- **Timing Mismatch:** Synchronizing data from various sources to ensure accurate and timely information dissemination.
- **Real-Time Data Sharing:** Identifying a method for sharing data which is beyond the capabilities of existing V2X system. This may include the Out-of-Band (OOB) method to share in real time (at very low latency) between two entities, and which includes a method for improving positional information.

By tackling these challenges, ConSens is working to create a cohesive system that enhances the overall functionality of the 5G-V2X ecosystem.

4.4 Implementation Options for Positioning as a Service

There are many alternative deployment options for ConSens services, depending on the involved ecosystem stakeholders, communication technologies, and end-user V2X applications. Guidelines will be laid down in this document as well as links to other industrial standards and 5GAA recommendations such as the V2N2X application layer architecture described in 'Vehicle-to-Network-to-Everything (V2N2X) Communications: Architecture, Solution Blueprint, and Use Case Implementation Examples' [8].

ConSens also serves up concrete technology examples where 5G-V2X is combined with other (OOB) technologies to provide PaaS. These include lidar, radar, camera, Ultra-Wideband (UWB) and many other sensors available in the vehicle. Many of these systems provide extensive data sets which may need to be shared between vehicles. In the US, V2X direct systems are limited to 30 MHz bandwidth. Much of this is used in sharing lower bandwidths of data to solve many existing use cases. In some situations, such as UWB, this OOB sensing needs to be cooperative between two entities, so a link between these two entities is needed to enable more precise sensing, and the ConSens framework provides a viable solution to such a cooperative framework.

An alternative ConSens example will also be defined to show how a cloud-based service can be utilized in pursuit of the same goals. An example could be to combine Global Navigation Satellite System (GNSS) + Real-Time Kinematic (RTK) systems. When integrating RTK into the base localization system onboard bases on GNSS, different factors must be taken into account. The ConSens approach can provide a framework for interaction between these platforms.

5 Use Cases

This chapter delves into the practical applications of the ConSens Work Item within the framework set by Working Group 1 (WG1). It outlines the use cases pivotal to understanding how the project enhances situational awareness and positioning accuracy in real-world settings. Notably, these use cases do not aim to redefine existing scenarios but to enrich the information flow and integration within the 5G-V2X ecosystem.

5.1 Awareness of the Presence of VRUs Near Potentially Dangerous Situations

User Story

In the existing scenario, a vehicle Road User (RU) and a VRU, such as a pedestrian or cyclist, are equipped with connected devices that support interaction within an Intelligent Transportation System (ITS).

1. Connectivity and Data Sharing:
    - Both RU and VRU actively broadcast their locations using GNSS technology, shared through ITS message containers designed to communicate pertinent traffic information across the network.
2. Automated Warning System:
    - As the two users approach each other, the system evaluates their relative positions and motions. If a potential collision trajectory is detected, automated warnings are issued to both parties, prompting them to take preventive action.

Identified Limitations

- The reliance on GNSS for positioning can lead to inaccuracies due to signal degradation in urban settings, multipath interference, and inherent positioning errors, resulting in false alarms which undermine the effectiveness and trustworthiness of the system.

Enhanced User Story Extension

To enhance accuracy and reduce false alarms, the following improvements are proposed:

- Improve GNSS by using RTK:
    - Using RTK data for GNSS augmentation to mitigate atmospheric and other aspects will result in much better baselines for the positioning engine.
- Refined Data Exchange Mechanism:
    - Maintain initial connectivity protocols but introduce a unicast

communication session between RU and VRU for more direct and precise data exchange as they converge.

- Integration of Multi-modal Positioning Technologies:
    - Activate additional positioning technologies such as Ultra-Wideband (UWB), Sidelink positioning, Bluetooth Low Energy (BLE), radar, and lidar. These technologies offer finer resolution and reduced latency in data processing, providing a more accurate real-time position estimation.
- Dynamic Warning Verification:
    - Utilize the enriched data from these diverse technologies to recalibrate the risk assessment algorithms continuously. This dynamic verification process significantly enhances the accuracy of the warning system, ensuring that alerts issued to RU and VRU are based on the most reliable data available.

Proposed Enhanced User Story Extension – UWB/BLE Infrastructure Activation:

Infrastructure Readiness:

- The roadside infrastructure is equipped with UWB and Bluetooth Low Energy (BLE) beacons, which are calibrated precisely and well-documented for optimal functionality.

Enhanced Operational Flow:

1. Continuous Data Interaction:
    - As RU and VRU near each other, the system activates the infrastructure beacons. These beacons supplement the positioning data by providing additional reference points, which are especially useful in Non-Line-of-Sight (NLOS) conditions where GNSS may fail.
2. Infrastructure-Aided Position Calibration:
    - The beacons work in conjunction with onboard sensors to refine the data used for calculating the relative positions of RU and VRU. This integration helps in making the situational analysis more robust against environmental and technical variations.
3. Accurate Alert Mechanisms:
    - With improved data accuracy, the system reassesses potential collision threats and adjusts the warning signals accordingly. This method ensures that alerts are only issued when genuinely required, minimizing unnecessary driver or pedestrian stress and enhancing overall traffic safety.

Forward-Looking Challenges

- **Hybrid Communication Strategy:** Implementing a dual strategy that incorporates both unicast for precision and broadcast for broader communication presents technical and logistical challenges, including network load management and data synchronization. This requires assessment of the data bandwidth and selection of the appropriate communication method, either in-band or OOB.

- **Advanced Sensor Integration:** The extended exchange capabilities require sophisticated data management systems that can handle increased volumes and varieties of sensor data, necessitating substantial upgrades to existing traffic management infrastructures.

5.2 High-Definition Sensor Sharing

Current Scenario

This use case begins with Road User 1 (RU1), typically a vehicle, approaching an intersection where the Roadside Unit (RSU) is actively involved in traffic management.

1. Basic Intersection Services:
    - As RU1 approaches, the RSU broadcasts SPAT (Signal Phase and Timing) and MAP (intersection geometry) information as part of its default service set, which helps vehicles navigate intersections more safely and efficiently.

Proposed Enhanced User Story Extension

To advance beyond the basic services and significantly enhance the intersection management capabilities, the following extensions are proposed:

1. Announcement of Enhanced Services:
    - The RSU announces the availability of High-Definition Cooperative Perception Messaging (HD CPM) services for the area. This service includes details on available resolution, accuracy, sensor types, and other relevant specifications.
2. Request for HD CPM Service:
    - RU1, upon receiving the announcement, sends a request to the RSU to subscribe to the HD CPM service, indicating its specific data needs for the upcoming intersection crossing.
3. Detailed Data Requests:
    - RU1 sends detailed specifications of the desired data, which may include:
        - Moving objects detected within the intersection (using CPM and SDSM).
        - Identification of free spaces that can be safely navigated.
        - Locations of potential conflict areas (possibly detailed in MAP messages).
        - Alerts about detected hazards or warnings (DENM).

4. Data Provision and Integration:
    - The RSU accepts the service request and confirms the provision of data, choosing between groupcast or unicast depending on the situation.
    - It then sends comprehensive data at the maximum refresh rate, providing RU1 with a dynamic and detailed map of the intersection area, including real-time movements of all objects.
5. Feedback Loop and Data Sharing:
    - RU1 provides feedback and additional sensor data back to the RSU, enhancing the data pool.
    - The RSU integrates this data to construct a more detailed situational awareness map, which it can share on request not only with RU1 but also with other road users approaching the intersection.

Proposed Extended Capabilities and Challenges

- **Active Data Requests:** RU1 actively requests high-definition data from the RSU, requiring robust service architecture to handle dynamic data needs and ensure timely delivery.
- **Construction of Enhanced Situational Awareness:** Both the RSU and possibly a Mobile Edge Computing (MEC) platform work together to process and integrate data from multiple sources, creating a comprehensive environmental model that is continuously updated.
- **Data Sharing and Sensor Integration:** The RSU not only processes its own sensor data but also incorporates data received from RU1 and other vehicles. This collective sensor integration helps improve the overall environmental perception, covering potential blind spots and enhancing decision-making for all road users.

Innovative Aspects and Addressing State-of-the-Art Challenges

- The use of high-definition sensor data and cooperative perception significantly advances intersection management capabilities.
- The system addresses constraints such as data latency, processing capacity, and the accuracy of environmental models, setting new benchmarks for real-time traffic management and vehicle communication technologies.

6 Technologies and Methodologies

6.1 Positioning Technologies

This section summarizes and extends insights from the ‘Evaluation of Radio-Based Positioning Enhancements for Automotive Use Cases’, or EPOS, Work Item [9] by the 5G Automotive Association (5GAA), showcasing the integration and implementation of advanced positioning technologies within the automotive sector.

While network-based, sidelink, and UWB positioning technologies offer substantial benefits, they also present unique challenges including ensuring interoperability among diverse systems, scalability across different geographic and operational contexts, and security of direct and network-mediated communications. Addressing these challenges through robust standards, interoperable protocols, and secure communication frameworks is essential. The focus of ConSens is to utilize the strengths of the different technologies and combine them within the 5G-V2X ecosystem.

5G Network-Based Positioning

5G network-based positioning leverages the capabilities of the cellular network infrastructure to determine the position of user equipment (UE) with precision. This positioning method makes use of advanced techniques such as Round-Trip Time (RTT), Time of Arrival (ToA), and Angle of Arrival (AoA). These techniques are supported by the dense deployment of 5G networks, which is a critical factor influencing their effectiveness. As highlighted in the EPOS Work Item from the 5GAA, the performance of network-based positioning largely depends on the specific deployment characteristics of the 5G network infrastructure. The density and configuration of cell towers significantly impact the accuracy and reliability of the positioning, particularly in urban environments where buildings and other structures can obstruct or reflect signals.

5G Sidelink Positioning

5G sidelink positioning, introduced in 3GPP Release 18, offers direct communication between User Equipment (UE) without the need for network infrastructure. This feature, known as Vehicle-to-Everything, utilizes sidelink channels to enhance vehicular positioning and safety applications. Sidelink positioning employs advanced techniques, such as Proximity Services (ProSe), and allows vehicles to share their positional information directly. This capability is crucial for scenarios where immediate proximity detection is vital, such as in dense traffic conditions or emergency situations.

The technology facilitates a variety of positioning methods, including Time Difference of Arrival (TDoA) and AoA, which significantly improve the accuracy of position estimation compared to traditional GNSS systems alone. By leveraging direct inter-vehicle communication, sidelink positioning enhances the reliability of vehicular location services, particularly in environments where GNSS signals are obstructed or reflected, such as urban canyons.

The effectiveness of sidelink positioning, as explored in the EPOS Work Item, depends heavily on the available bandwidth and the penetration rate. Adequate bandwidth ensures that a large volume of data can be transmitted quickly and reliably, which is crucial for maintaining the accuracy and timeliness of positional information shared between vehicles in dynamic traffic situations.

Ultra-Wideband Positioning

Ultra-Wideband technology is recognized for its high accuracy in indoor positioning and is increasingly being explored for automotive applications. UWB operates by sending a wide spectrum of frequencies, which allows for precise measurement of the time it takes for a signal to travel from the transmitter to the receiver. This precision makes UWB exceptionally suitable for critical applications requiring centimeter-level accuracy.

In the context of V2X communications, UWB complements traditional positioning systems by providing highly accurate distance measurements between vehicles and between vehicles and infrastructure. This is particularly beneficial for complex driving maneuvers and in environments where GNSS reliability is compromised. The integration of UWB in automotive applications supports functionalities such as automated parking, collision avoidance systems, and precise asset tracking.

UWB's ability to provide accurate positioning data offers a significant advantage over other radio technologies. Its resilience to multipath interference, combined with low power consumption, makes it an ideal candidate for enhancing vehicular safety and navigation systems.

Global Navigation Satellite System Positioning

Due to its ubiquity, GNSS is a natural candidate for providing accurate and reliable Position-Velocity-Time (PVT) solutions applied to various applications. However, GNSS signals are vulnerable to different types of disturbances that can degrade or disrupt the service quality. In this section, we review some of the common sources of GNSS signal interference and the possible mitigation techniques that can be implemented within the GNSS receiver in order to try and answer whether a solution based only on GNSS is sufficient.

While GNSS operation can be degraded by physical effects, such as signal propagation through the atmosphere and environmental effects, a GNSS solution architecture comprised of a proper antenna and receiver design and augmented by correction services – e.g., Precise Point Positioning (PPP), Real-Time Kinematic (RTK), Satellite-Based Augmentation System (SBAS) or Differential GNSS (DGNSS) and, in the future, Galileo High Accuracy Service (HAS) – can mitigate these effects and meet the accuracy requirements for most applications.

However, GNSS has vulnerabilities that may still impact its serviceability. In this regard, the most challenging signal disturbances are caused by NLOS and signal blockage, spoofing, and jamming.

The following subsections explain these disturbances and describe possible mitigation techniques that may be implemented within the GNSS receiver itself and do not involve additional sensors or technologies.

GNSS NLOS and Signal Blockage:

NLOS and signal blockage are dominant sources of errors, especially in dense urban environments. In this scenario, the signal can either be blocked at the receiver or it has a longer propagation path, which causes errors in the *pseudorange* (estimated distance between satellite and receiver) and rate estimations, leading to Position, Navigation and Timing (PNT) solution errors. Compared to a multipath case, where the Line-of-Sight (LOS) signal is also available at the receiver end; in this case the receiver does not have sufficient information to properly estimate the range just from the signal itself, therefore errors are introduced regardless of the receiver implementation.

NLOS mitigation can be performed in the presence of non-NLOS signals. When the receiver is capable of processing multiple frequencies and multiple GNSS constellations, there is a good chance that some signals have LOS components. The receiver can identify the proper signals by examining the properties of each signal independently or collectively.

When performing independent analysis, the receiver is looking at the statistical range and rate errors and the signal polarization in order to point out the NLOS signals, assuming that signals have higher error deviations and Left-Hand Circular Polarization (LHCP), compared to Right-Hand Circular Polarization (RHCP) observed with LOS signals. Then, it uses signals with higher LOS probability to calculate the PVT solution.

Alternatively, the receiver can use multiple signal combinations to calculate the solution, then perform comparisons among the solutions and remove those that are inconsistent. When a solution is determined to be valid, filtering algorithms such as extended Kalman filter and vector tracking [4] can be used to predict and smooth the solution between subsequent valid satellite measurements.

GNSS Jamming and spoofing:

The fact that the GNSS received signals are very weak (-158 dBW is the nominal power level for GPS L1C/A, for example) makes them susceptible to interference. A jammer can either block the GNSS signal or degrade the carrier-to-noise-density ratio (C/N0), causing errors.

In this situation, a 1 W device can disrupt GNSS service within a range of 10 km or more.

Nowadays, jammers and spoofing technologies are very accessible, allowing not only government authorities but also private players to interfere with GNSS operation.

Multiple reports show a high increase in jamming and spoofing incidents, making GNSS service already unreliable in some regions of the world, and experts predict that attacks on GNSS services are going to grow in the future.

Examples of jamming signal types are continuous wave, chirp, frequency-modulated noise, wideband noise, modulated signals, pulsed signals, power ramps. Jamming can also be caused by unintentional interference from equipment operating near GNSS frequencies.

Jamming signals can be detected from the increase of signal-to-noise ratio by the receiver. Mitigation tries to suppress the interference. Interference removal methods include applying dynamic filters and Controlled Reception Pattern Antennas (CRPA), which utilize multiple antenna elements coupled with signal processing techniques to nullify the interference signals.

In the case of spoofing, the attacker tries to deceive the receiver by sending fake GNSS signals. These can be either self-generated or replay signals. The receiver interprets the false signals as authentic and uses them to calculate the PVT solution, leading to errors. Spoofing implementation is more complicated than jamming. There are three types of spoofing attacks: asynchronous, synchronous, and meaconing.

In an asynchronous spoofing, the attacker performs jamming first in order to make the receiver lose the satellites, then transmits a false signal with slightly higher power than the true signal, causing the receiver to lock on the false signal.

In a synchronous attack, the spoofing signal initially is aligned (in code phase and Doppler characteristics) with the true signal, such that the tracking algorithms in the receiver cannot distinguish between them. Sophisticated spoofing systems may even use multiple transmission points to simulate different directions of arrival. A multipath environment, such as a dense city, increases the chance of a successful attack, as it may confuse the receiver even more, since it cannot distinguish between a true reflected signal and a false one. Once tracked by the receiver, the false signal power is increased to become the dominant one, and the victim receiver adapts it for the PNT calculation.

In meaconing, the true signal is captured and retransmitted, causing the receiver to lock onto the delayed or modified (amplified) signal.

Mitigation methods include comparisons and consistency checks among signals from multiple frequencies and constellations.

Algorithms that are looking for signal anomalies – such as variable power, same angle of arrival, and Doppler shifts – and performing consistency checks for these properties, can help the receiver identify and suppress the false signals, or exclude them from the solution algorithm.

Cryptography for authentication and integrity of the navigation data and signal can prevent non-replay attacks. In this context, new public services, such as Open Service Navigation Message Authentication (OSNMA), are being deployed by the European Space Agency (ESA) and Galileo Assisted Commercial Authentication Service (ACAS) to be used for spreading code authentication is in planning. As for GPS, Chips Message Robust Authentication (CHIMERA) with similar security objectives is planned to be deployed in the next generation GPS satellites (GPS block IIIF), starting 2026.

It is important to note the progress that industry is making in both infrastructure and commercial devices towards more robust GNSS equipment. Lab and field experiments demonstrate good performance in some scenarios, while other scenarios such as synchronous spoofing are still not addressed well [5]. Moreover, different road users have different requirements and constraints for GNSS solutions.

Real-Time Kinematic

RTK is a differential GNSS technique that provides centimeter-level positioning accuracy by correcting signal errors using fixed base stations or reference networks. It significantly improves accuracy in both open and semi-obstructed environments. RTK enables low-latency updates essential for dynamic V2X interactions involving VRUs [3].

Core Capabilities:

- Centimeter-level positional accuracy.
- Low latency for high-speed mobility scenarios.

- Works well in clear sky conditions with base station connectivity.

Limitations:

- Susceptible to GNSS signal degradation in urban canyons or tunnels.
- Infrastructure-dependent (e.g., base stations).
- Limited global availability. [6]

6.2 Sensor Data Collection, Sharing and Fusion

Sensor fusion combines data from multiple sensors – such as lidar, cameras, radar, IMU, and GNSS – to create a more accurate, coherent view of the environment. It compensates for individual sensor limitations and provides situational awareness where GNSS signals may be unreliable [5].

Core Capabilities

- Effective in GNSS-challenged environments (e.g., urban canyons).
- Real-time object classification and trajectory prediction.
- Onboard and edge-processing capable.

Limitations

- Higher computational requirements.
- Expensive hardware (lidar, radar).
- Potential data privacy concerns. [7]

6.2.1 Overview of Sensor Data-Sharing Message

The Sensor Data-Sharing Message (SDSM) is specified by the SAE V2X Vehicular Applications Technical Committee, under SAE J3224 'V2X Sensor-Sharing for Cooperative and Automated Driving', published on 17 August 2022. The SDSM plays a critical role in facilitating the exchange of sensor data among vehicles and infrastructure to enhance cooperative and automated driving.

Note that for Europe, a similar service exists called the Collective Perception Message (CPM) specified in ETSI TS 103 324.

Concept of Operation

The SDSM encompasses various aspects:

- **System Overview:** Provides a comprehensive system overview, including use cases, security measures, and user privacy considerations.
- **Application Protocol:** Defines the structure of the message, requirements for message generation, and transmission guidelines.
- **Other Requirements:** Specifies requirements related to positioning, timing, and security.

Message Structure

The SDSM is structured to include several key components:

- **Management and Host Data:** Includes message count, source ID, equipment type, timestamp, reference position, position accuracy, and optional position confidence.
- **Detected Object Data:** Lists detected objects with common data (e.g., object type, ID, position, speed, heading) and type-specific data (e.g., vehicle-specific or VRU-specific information).

Message Generation and Dissemination Rules

- **Transmission Rate:** Standard rate of 10 Hz, with no transmissions when nothing is detected.
- **Object Inclusion Rule:** Excludes vehicles transmitting BSMs.
- **Object Age (Delay Budget):** Maximum information age is typically around 100 ms, not exceeding 200 ms.

Comparison with Other Regional Specifications

Compared to ETSI CPM, the SDSM features a simpler message structure and generation rules, enhancing interoperability and efficiency.

6.2.2 Overview of Sensor-Sharing Message in CSAE 157-2020

The Sensor-Sharing Message (SSM) under CSAE 157-2020 is another critical message type supporting C-ITS. It is part of the standards developed by the China Society of Automotive Engineers (CSAE) for enhanced traffic safety and efficiency.

Concept of Operation

The CSAE 157-2020 standard includes the following:

- **Communication Modes:** Supports various communication modes including V2V, V2I, P2I and V2P, using PC5 as the access layer.
- **Application Scenarios:** Encompasses safety, efficiency, traffic management, and advanced intelligent driving scenarios.

Message Structure

The SSM under CSAE 157-2020 is structured to include:

- **Transmitter Data Set:** Includes data such as Vehicle Intention Request (VIR) and SSM.
- **VIR Message:** Contains vehicle intention, request messages, and current behavior details. The VIR message is optional depending on the UE implementation.
- **SSM Message:** Contains detected object data, including traffic participants, obstacles, and traffic events.

Main Components of SSM

- **Management and Host Data:** Includes message count, temporary vehicle ID, timestamp, position, detected participants, and obstacle data.
- **Detected Object Data:** Similar to the SDSM, it includes detailed information about detected objects, their type, position, speed, heading, and other relevant data.

Generation and Dissemination Rules

- **Transmission Rate:** Data communication frequency is 10 Hz with a communication distance of at least 200 meters.
- **Application Layer Latency:** End-to-end latency is within 100 ms, ensuring timely data exchange.
- **Horizontal Accuracy:** Ensures accuracy within 1 meter.

Application Scenarios

The SSM is designed for multiple scenarios, such as:

- **Vehicle Sensing:** Vehicles with sensing and communication capabilities share perception data with other vehicles.
- **RSU Sensing:** Roadside Units (RSU) detect and share information about nearby traffic conditions, improving safety and efficiency.

Implications for ConSens

The adoption of both SDSM and SSM within the ConSens framework offers several advantages:

- **Interoperability:** Simplified structures and rules enhance compatibility across different systems and stakeholders.
- **Efficiency:** Streamlined message generation reduces computational overhead and improves real-time data exchange.
- **Accuracy:** Regular updates and inclusion of precise positioning data improve overall situational awareness and positioning accuracy.

6.2.3 Vehicle Intention Request Message

The VIR message is a critical component in the CSAE 157-2020 standard, designed to facilitate communication about a vehicle's intended actions and requests for cooperation from other road users or infrastructure. This message is essential for enhancing cooperative driving and ensuring efficient and safe navigation through complex traffic environments.

Structure of VIR Message

The VIR message includes the following key elements:

- **Message Count (msgCnt):** Tracks the number of messages sent.
- **Temporary Vehicle ID:** A unique identifier for the vehicle sending the message.
- **Timestamp:** The time at which the message is generated.

- **Position3D:** The current three-dimensional position of the vehicle.
- **Vehicle Intention and Request:** Detailed information about the vehicle's current and intended actions, such as path planning and specific requests.
- **Current Position:** The vehicle's current location.
- **Path Planning:** Information about the vehicle's planned route and maneuvers.
- **Current Behavior Sequence:** A sequence of actions the vehicle is currently executing.
- **Request ID:** A unique identifier for the request.
- **Status of the Request Message:** Indicates whether the request is pending, approved, or denied.
- **Priority of the Request Message:** The priority level of the request, which can influence how other road users or infrastructure respond.
- **Temporary IDs of Target Vehicle and RSU:** Identifiers for the target vehicle or RSU involved in the request.
- **Request Message Types:** Includes various types of requests such as lane change, road clearing, signal priority, station entry, and sensor information sharing.

Application in Use Cases

The VIR message is pivotal in several ConSens use cases, enhancing the cooperative aspects of V2X communication.

Below are examples of how the VIR message is applied:

Use Case I: Awareness of the Presence of VRUs Near Potentially Dangerous Situations

In this scenario, a vehicle (EV-1) may use the VIR message to request priority passage or lane changes when approaching areas with high VRU activity, such as crosswalks or school zones. By communicating its intentions and receiving confirmation or adjustments from nearby vehicles (EV-2) and infrastructure (RSU), the vehicle can navigate more safely and efficiently, reducing the risk of accidents involving VRUs.

Use Case II: High-Definition Sensor Sharing

In this use case, vehicles approaching an intersection use VIR messages to share their intended actions with the RSU and other vehicles. This communication ensures that all parties are aware of each other's intentions, facilitating smoother and safer intersection crossing. The RSU can use this information to manage signal phases and provide real-time guidance to vehicles, enhancing overall traffic efficiency and safety.

Benefits of VIR Message

- **Enhanced Communication:** VIR messages enable vehicles to communicate their intentions clearly, reducing misunderstandings and conflicts on the road.
- **Improved Safety:** By coordinating actions and requests, vehicles can avoid potential collisions and navigate complex traffic situations more safely.

- **Increased Efficiency:** Efficient communication and coordination help optimize traffic flow, reduce delays, and improve the overall efficiency of the transportation system.
- **Support for Cooperative Driving:** VIR messages are essential for the implementation of cooperative driving scenarios, where vehicles and infrastructure work together to achieve safer and more efficient traffic management.

By integrating VIR messages into the ConSens framework, it can significantly enhance the cooperative aspects of V2X communication, leading to improved safety and efficiency in various traffic scenarios.

6.3 Identity Management

Identity management is a critical component in the ConSens Work Item, ensuring that each road user – whether a vehicle, pedestrian, cyclist, or other – is uniquely identified and authenticated within the 5G-V2X ecosystem. Effective identity management facilitates reliable communication, accurate positioning, and enhanced situational awareness across diverse road users with varying capabilities.

Challenges in Road User Identity Management

Heterogeneous Nature of Positioning Solutions

Different road users have distinct positioning and communication capabilities. For example, a pedestrian may only have basic GNSS capabilities through a smartphone, whereas an advanced vehicle may have multiple sensors and communication interfaces such as Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I). Managing identities across such a heterogeneous landscape is complex and requires a robust system to ensure interoperability and reliability.

Unique Identifiers

A fundamental question in identity management is whether globally or locally unique identifiers are needed for each road user. Globally unique identifiers ensure consistency and traceability across different regions and systems, while locally unique identifiers may suffice for smaller, contained environments. Both approaches have implications for privacy, security, and scalability.

Key Problems and Questions in Road User Identity Management

Mapping IDs to Road Users

One of the central challenges is accurately mapping an identifier (ID) to a specific road user. This mapping must be consistent and reliable to prevent misidentification, which can lead to incorrect positioning data and potentially dangerous situations.

Dynamic Assignment of IDs

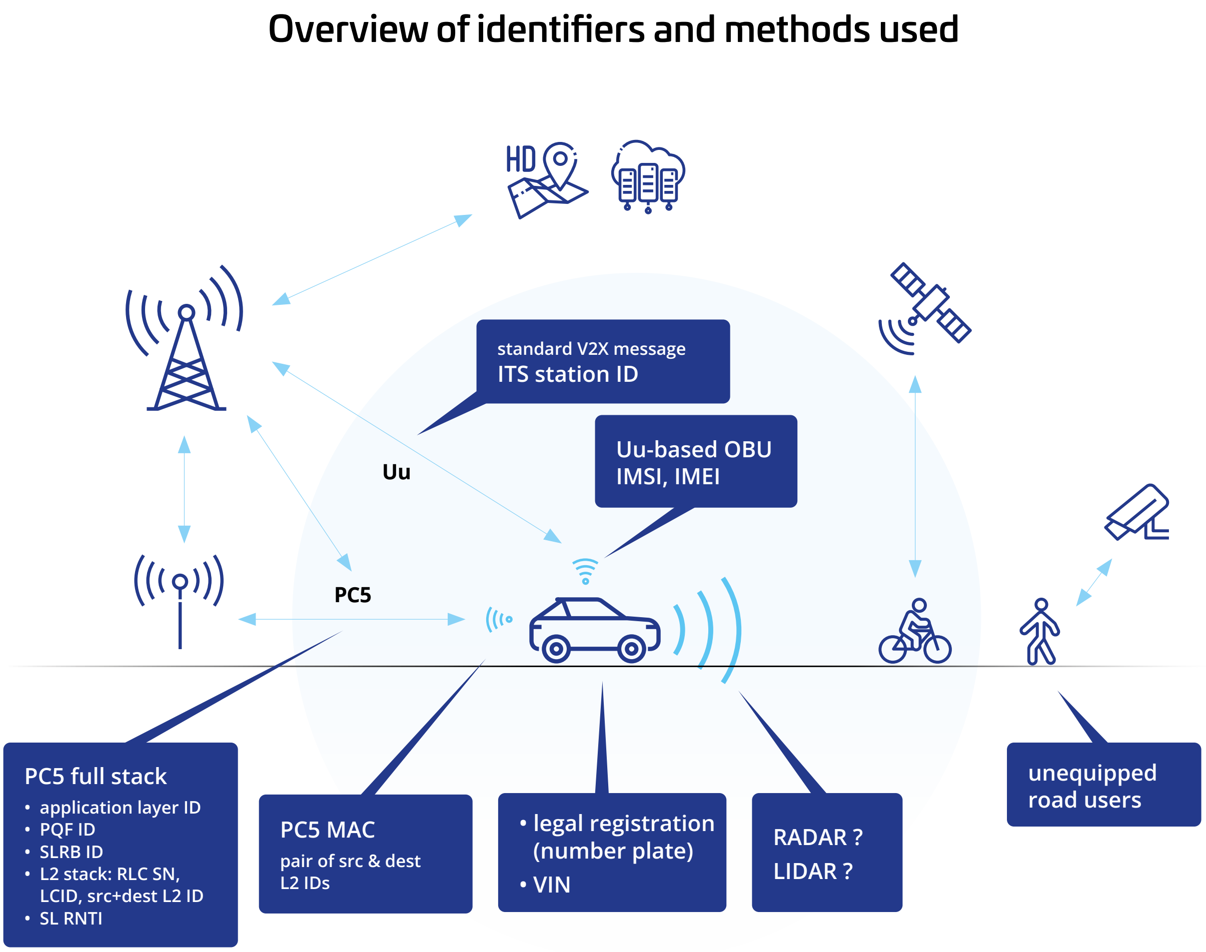
Dynamic assignment of IDs may be necessary for legal, technical and privacy reasons. This involves generating temporary identifiers that can change over time to protect user privacy while maintaining traceability for authorized entities.

Ownership and Hosting of Identity Management Systems

Determining who owns and manages the Identity Management System (IDMS) is crucial. The system could be centralized, managed by a single authority, or distributed, with multiple stakeholders sharing responsibility. Each approach has benefits and drawbacks:

- **Centralized IDMS:** Easier to manage and enforce standards but may pose privacy risks and single points of failure.
- **Distributed IDMS:** More resilient and privacy-preserving but harder to coordinate and standardize.

Possible User Identifiers



1. Figure: Overview of identifiers and methods used

Figure 1 illustrates the various identifiers associated with different types of road users. As pointed out above, the challenge is to unambiguously identify a road user based on the various types of identifiers associated with that single road user so that measured localization parameters can be associated with the unique identifier. For example, considering the vehicle in the figure, a potential choice could be the vehicle's globally unique Vehicle Identification Number (VIN) assigned by the manufacturer, or the vehicle's number plate. On the national level, while a vehicle registration number (i.e. number plate) may identify the vehicle in the legislative domain, neither the VIN nor the number plate are recognized as digital identifiers for use in data exchanges with other road users. If the vehicle in Figure 1 is equipped with a cellular modem, a plethora of new identifiers are added (or attached) to the vehicle. The (embedded) SIM for the network-based communication comes along with an International Mobile Subscriber Identity (IMSI) assigned by the network operator and an International Mobile Equipment Identity (IMEI) associated with the hardware module itself. For direct communication over the PC5 interface, several identifiers are used in different layers of the PC5 stack (e.g., PC5 application layer ID, PQF ID, SLRB ID, L2 stack: RLC SN, LCID, source & destination layer-2 ID, SL-RNTI).

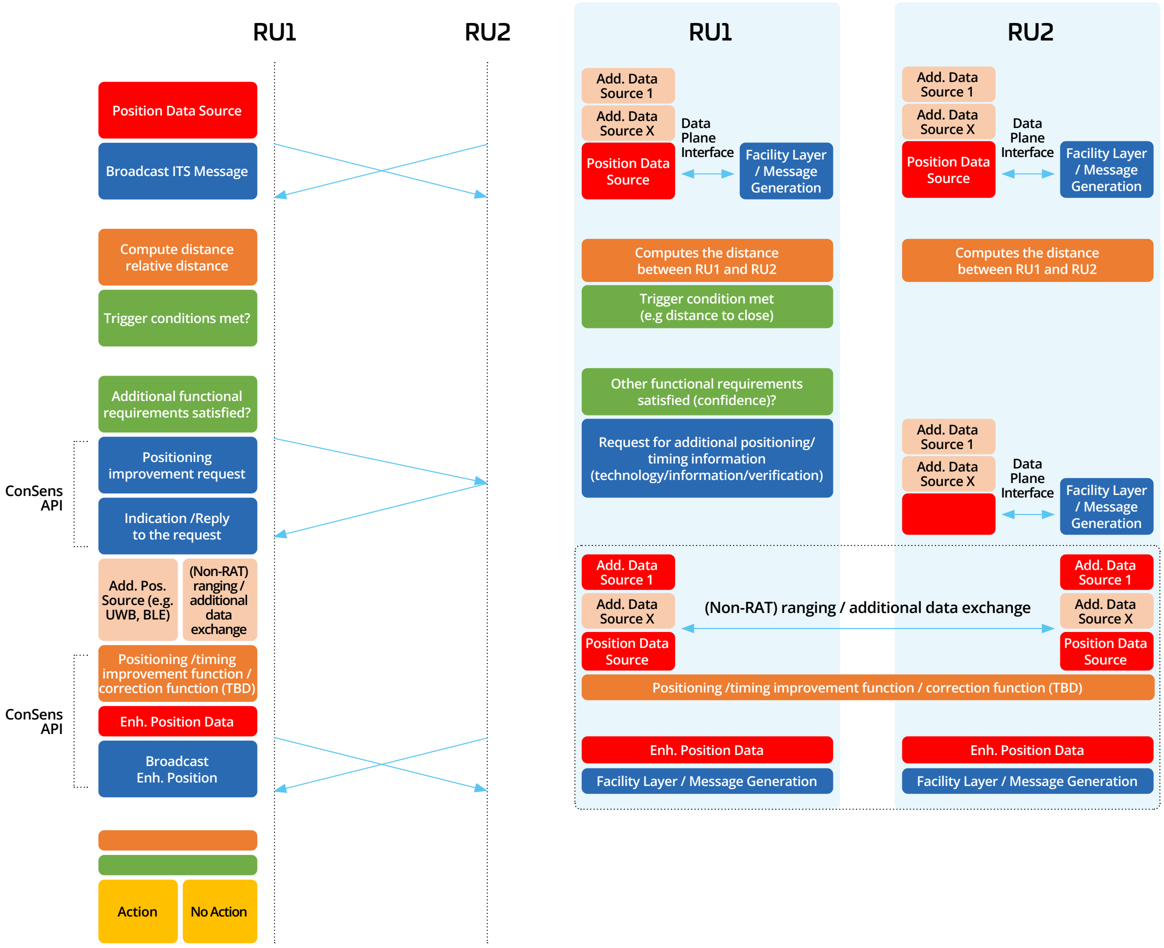
The objective of an identity management system is threefold: mapping of IDs to a specific road user, dynamic assignment of IDs and tracking of the IDs used in a scenario/application.

7 ConSens Service Description and Application Layer Functional Architecture

7.1 ConSens Service Description

ConSens provides on-demand service to the end user to improve the quality of positioning information of the ego entity and/or detected objects in a specific environment by leveraging inputs from different data sources. Such data sources include local positioning data source and/or remote positioning data. The end users of the ConSens service are V2X applications (e.g., VRU protection, collective perception, maneuver coordination) operating on positioning information with a certain level of quality requirements. ConSens thus improves the quality of the positioning information results in terms of precision, accuracy, timeliness, and trustworthiness, fulfilling the quality requirements of the end users, i.e., V2X applications.

Simple information flow between Road User 1 (RU1) and Road User 2 (RU2)



2. Figure: Simple information flow between Road User 1 (RU1) and Road User 2 (RU2)

Figure 2 illustrates the derivation of the ConSens architecture. This example is directly related to the previously discussed use case involving Road User 1 and Road User 2. In this context, RU1 is typically a vehicle, while RU2 represents a VRU, such as a pedestrian or cyclist.

The flow on the left side of the figure details a step-by-step process that outlines how RU1 and RU2 interact within the Intelligent Transportation System, aiming to prevent collisions and enhance road safety. The flow is as follows:

1. Position Data Source:
   - Imagine RU1, a vehicle, and RU2, a cyclist, both equipped with advanced connected devices. As they travel, they continuously broadcast their locations using GNSS technology. These broadcasts are encapsulated in ITS message containers, designed to relay crucial traffic information across the network.
2. Compute Relative Distance:
   - As RU1 and RU2 move closer to each other, the system calculates the distance between them based on their transmitted GNSS positions. This calculation is vital for understanding their relative positions and potential interaction.
3. Evaluate Trigger Conditions:
   - The system then evaluates whether certain trigger conditions are met. For instance, it checks if the distance between the vehicle and the cyclist falls below a predefined safety threshold, indicating a possible collision trajectory.
4. Test Additional Functional Requirements:
   - To ensure reliable operation, the system assesses whether additional functional requirements, such as the accuracy and confidence levels of the positioning data, are satisfied. This step is crucial to prevent false alarms and ensure trustworthiness.
5. Positioning Improvement Request:
   - If both the trigger conditions and additional functional requirements are met, the system issues a positioning improvement request. This request is a call to action for enhancing the accuracy of the positional data.
6. Indication/Reply to the Request:
   - The system sends an indication or a reply to the positioning improvement request, initiating the process of refining the positional information.
7. Additional Position Source (e.g., UWB, BLE):
   - To improve positioning accuracy, the system activates additional positioning sources. Technologies such as Ultra-Wideband and Bluetooth Low Energy are employed. These sources provide finer resolution and more reliable data, especially in challenging

environments where GNSS may falter.

8. Positioning/Timing Improvement Function/Correction Function:
   - The enhanced position data is further refined using positioning/timing improvement functions and correction algorithms. These processes aim to minimize errors and improve the overall reliability of the positional information.
9. Enhanced Position Data Broadcast:
   - The now refined and enhanced positioning data is broadcasted back to RU1 and RU2. This ensures that both users have the most accurate and up-to-date positional information available.
10. Action/No Action:
   - Based on the recalibrated data and updated risk assessment, the system then decides whether to issue collision warnings to RU1 and RU2. If a collision is deemed likely, warnings are sent out, prompting both the vehicle driver and the cyclist to take preventive actions. If no immediate threat is detected, no action is taken, allowing both users to continue their journey safely.

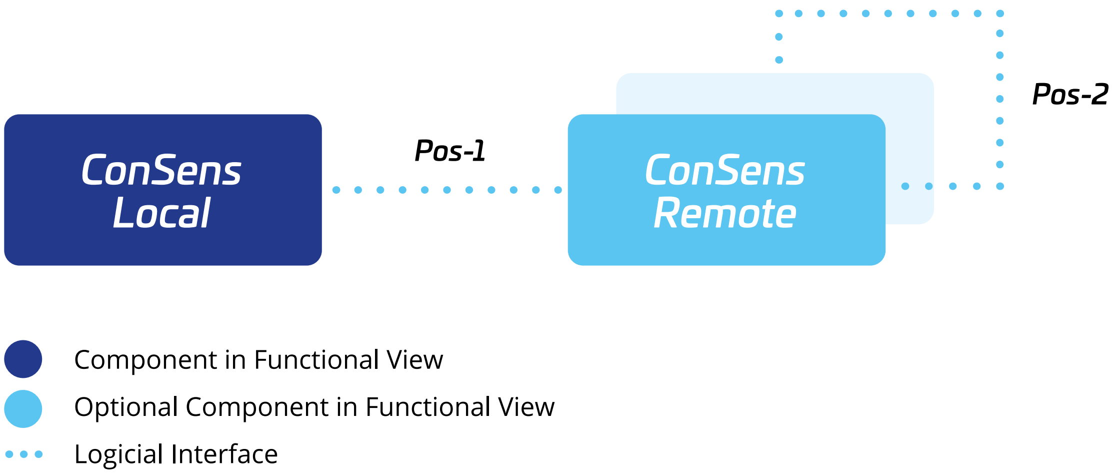
The right side of the figure details how the functional blocks from the left side can be deployed within the vehicle domains of RU1 and RU2. Each block represents specific components and processes within the vehicle infrastructure, facilitating the integration and operation of the ConSens architecture. The deployment scenario ensures that the enhanced data exchange mechanisms and positioning technologies are effectively utilized to improve the accuracy and reliability of collision warnings, thereby enhancing overall traffic safety.

In addition to the detailed functional flow and deployment scenario, the figure also depicts the ConSens API. This interface plays a crucial role in facilitating the communication and data exchange between RU1 and RU2, as well as integrating additional positioning technologies. In the subsequent sections of this report, we will discuss how the ConSens API integrates into the holistic Vehicle-to-Everything and Vehicle-to-Network-to-Everything (V2N2X) architecture. This integration is essential for ensuring seamless connectivity, precise positioning, and robust collision avoidance mechanisms, ultimately contributing to safer and more efficient transportation systems.

7.2 ConSens Application Layer Functional Architecture

A ConSens system consists of two basic functional components – namely ConSens Local and ConSens Remote – which jointly execute the ConSens service, as shown in Figure 3.

ConSens application layer functional architecture



3. Figure: ConSens application layer functional architecture

ConSens Local:

ConSens Local provides improved positioning information to end users; V2X applications, such as VRU protection, collective perception, maneuver coordination, etc., which need positioning information fulfilling a certain level of quality requirements. ConSens Local provides the improved positioning information based on different data, including local inputs (e.g., from local sensors or GNSS) and/or remote inputs provided by ConSens Remote on demand.

Local positioning data sources that a ConSens Local can utilize include localized GNSS devices, sensors (camera, lidar, radar), digital maps (map-matching), and processed positioning data based on received V2X messages (e.g., CAM, BSM, CPM, SDSM)[1], etc. In this architecture, ConSens Local is responsible for the quality of the local positioning data sources. The interfaces between ConSens Local and localized data sources are not part of the current Work Item.

ConSens Local may request remote positioning data from sources using the Pos-1 interface to ConSens Remote (see below 'ConSens Remote').

[1] In this work, positioning data based on received V2X messages is considered 'local data', providing they are not received via from the ConSens Remote via the Pos-1 interface.

The ConSens Local performs the necessary processing of data from local and/or remote data sources (e.g., data validation, data fusion, etc.) to ensure that the required quality requirements of the end users (V2X applications) are met in the final positioning results.

ConSens Remote (optional):

ConSens Remote is an optional functional component, which supports ConSens Local in the overall ConSens service offer by providing on-demand remote data inputs to ConSens Local over the Pos-1 interface for the purpose of improving positioning results. However, ConSens Remote does not provide the final positioning results to the end users, i.e., V2X applications. ConSens Remote may utilize the local positioning data source and/or remote positioning data source provided by other ConSens Remote functions over the Pos-2 interface.

Local positioning data sources that a ConSens Remote can utilize include local GNSS devices, local sensors (camera, lidar, radar), digital maps (map-matching), processed positioning data based on received V2X messages (e.g., CAM, BSM, CPM, SDSM), etc. In this architecture, ConSens Remote is responsible for the quality of the local positioning data sources and the positioning data it shares using the Pos-1 and/or Pos-2 interfaces. Again, the interfaces between ConSens Remote and its local data sources are not part of the current work.

The ConSens Remote function may perform the necessary processing (e.g., data validation, data fusion, etc.) of data from its local and/or remote data sources, before providing the positioning data to ConSens Local via the Pos-1 interface, or to other ConSens Remote components via the Pos-2 interface.

ConSens Pos-1 interface

Pos-1 interface connects ConSens Local with ConSens Remote to enable positioning data communications and ConSens signaling communications.

ConSens Pos-2 interface

Pos-1 interface connects two ConSens Remote functions to enable positioning data communications and ConSens signaling communications.

Note: The definitions of ConSens Local and ConSens Remote are based on the application layer functionality of the components, which is independent of the implementation and deployment. This means ConSens Local and ConSens Remote can be implemented across separate physical entities (e.g., end user device, vehicle, infrastructure, etc.), or collocated in the same physical entity. For the latter case, the Pos-1 interface may not be visible (e.g., implemented as an internal interface or API). In the service deployment, ConSens Local and ConSens Remote are often implemented on separate physical entities, or by different vendors. To ensure that ConSens service is interoperable, the interfaces Pos-1 and Pos-2 – including the messages and protocols as well as the implementation profiles – need to be agreed among the stakeholders or standardized by the respective Standards Development Organization (SDO).

8 Digital Twin

8.1 Digital Twins Used for ITS

A digital twin in this Work Item's context is a digital representation of the environment which shows all objects relevant to the roadway. In a broader sense, the term digital twin means a digital representation (partial copy) or a real environment (e.g., an animation of a goal in football can be considered as a digital twin of the field). In ITS, this technology is used on the infrastructure side and within the vehicles themselves for various purposes. Digital twins can operate at several different layers and, as such, update at various rates.

At the lowest update rate, the digital twin represents the static world of fixed objects and roads (and their fixed properties). The update rate for this level is the rate at which new buildings are built, at which new trees grow/are planted, and the rate at which new roads are constructed. This rate is relatively long, such as yearly, so the database that keeps track of such data can be updated fairly irregularly.

The next data layer would store map (road) properties that change at a much faster rate. A good choice for a next layer could be information that requires more frequent updates (i.e., for roadworks). According to navigation data, such digital twin maps of road properties are updated weekly.[2] Another example could be a flood where water is over a road.

The next could be daily, such as when roads are closed due to construction, or hourly for events such as a highway wreck or temporary road closure. Events like stationary vehicle information or traffic jams are usually updated every minute or even faster.

Lastly, the digital twin may need to be continually updated with real-time information, including 'dynamic object' tracking, such as other vehicles, VRUs, wildlife (e.g., a deer crossing the road), or trash/litter that may be obstructing the road/highway. Such information must be updated within a few seconds as its validity lasts usually only between one and 10 seconds.

Digital twins could exist in several different environments; the first being a high definition (HD) map which contains relatively static objects that could be downloaded periodically; and the second could be a digital twin inside an RSU monitoring an intersection, for example. The most critical digital twin is likely to be found inside the vehicle, used by the navigation unit to help avoid collisions. In general, the more frequent the update, the closer it needs to be to where the information will be used; in our case that would mean vehicle control, so the closest location is the vehicle's computing unit.

The primary purpose of a digital twin is the vehicle's need to navigate the road system. Secondary uses might be to monitor road conditions, e.g., municipalities working to improve traffic flow. Other needs might be for an emergency vehicle to plan an optimal route to a critical situation, and for the authorities to clear the roads for the emergency vehicle.

[2] https://www.here.com/docs/bundle/sdk-for-android-navigate-developer-guide/page/topics/offline-maps-update.html

The digital twin in the HD map may not be real time. With high-speed download systems, it could be updated very quickly to keep up with changes in the roadway environment, down to the hourly level or possibly more frequently.

The digital twin in the vehicle must be a near-real time system (sub-second update rate). It will rely on the HD map for static objects or semi-persistent ones, such as parked cars. However, it must monitor the roadway in the path it intends to go through in order to monitor real-time movement of objects. This may include radar, lidar, or camera systems.

One of the next levels of operation is the sharing of digital twin information by vehicles to improve the information available to the vehicle in making better decisions. The HD map is the first level of information-sharing. Additional examples can occur as vehicles share digital twin information between themselves, or share digital twin information with infrastructure. One reason for sharing information is to detect objects that might otherwise be hidden from the vehicle or driver's view.

8.1.1 ADAS/ADS Support

Automated Driver Assistance Systems use sensor data to help human drivers. Current systems provide support such as 'blind-spot detection', 'adaptive cruise control', 'lane-following', and many others. In all cases, the driver must remain aware and ready to take over if there are any issues with support systems. For example, the lane-following system would warn the driver to take over if the road stripes and/or edges are no longer visible.

One of the important inputs of ADAS is the digital map – a digital twin of the road system that helps the human driver navigate the road network. These map systems have been extended to provide proposed navigation routes for the human to follow. These are displayed on a display or Human Interface Device (HID).

In more advanced ADAS applications, such a road-following, the HD maps may contain information about stripes on the highway and the number of lanes so the vehicle can safely perform the task.

Information Reliability and Sourcing

The different elements of the digital twin are constructed by merging and layering information from different sources with varying reliability and trust. Information used for automated control functions is traditionally low latency and sourced within the vehicle by the onboard sensors (short-range V2X is potentially the second-best option).

Automated Driving Support

In the Society of Automotive Engineers' highest level of vehicle automation – a Level 5 Autonomous Vehicle (AV) – the onboard autonomous system must be 100% 'aware' of the surroundings and make motion decisions based on that information.

However, the term 'autonomous' taken to its furthest extent would be a vehicle that is totally stand-alone. That is, it does not obtain or share information with other entities. The first examples of self-driving vehicles were totally autonomous and thus proved difficult to manage, so the industry started implementing information-sharing methods to improve these systems. While we may continue to call these systems autonomous today, they are in reality semi-autonomous.

One of the key functions of the autonomous system is to determine the needed trajectory of the vehicle and provide motion control to maintain that trajectory. A second key function is to track surrounding moving objects and their trajectory to ensure a collision does not happen. The autonomous system must provide route prediction for all key objects of interest.

If the trajectory of the key object is constant, then this task is straightforward, however if the object changes its trajectory without warning, then this becomes more challenging, and a very fast reaction time is needed. One solution is to use inter-vehicular communications; a vehicle signals its intent to change trajectory so another vehicle can anticipate and respond to the change. Examples include 'lane-changing' and 'emergency-braking' actions.

Vulnerable Road Users are a key focus in this context as they are involved in many traffic fatalities each year. Communication systems can greatly improve this situation through the sharing of sensor data. In this case, the sensors are tuned to detect a VRU, such as a pedestrian or a cyclist, and warn the driver if a trajectory change is needed to avoid an accident.

Communications Support

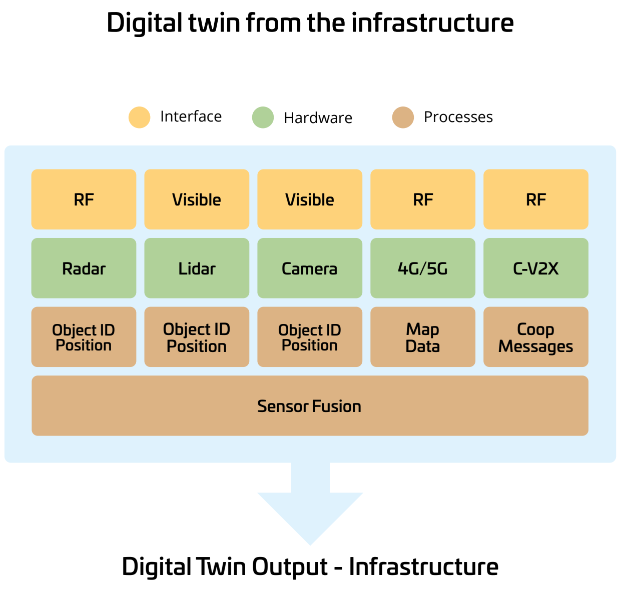
A vehicle that needs to share information requires technology to do so. C-V2X systems provide for communication between vehicles and/or with infrastructure to share information. The addition of external communications allows this system to share sensor information with other systems, thereby improving the overall system quality. There are many systems proposed to assist with this process:

- V2X – BSM/CAM messages with position information
- V2X – Sensor-sharing
- V2N2X – Intersection sensor systems
- V2N2X – Pedestrian tracking
- V2N2X – Network positioning systems
- V2X + UWB – Relative positioning system

8.1.2 Digital Twin Components – Infrastructure

One goal of an infrastructure-based system is to deploy more complex systems with higher visibility than can be achieved in a vehicle, thereby providing higher accuracy and broader coverage at a lower cost. One example is an intersection where there are many vehicles maneuvering through a relatively small area. Such a system would provide sensor fusion to integrate information from a variety of inputs including radar, lidar, and camera systems. In addition, it could collect C-V2X broadcast information, such as Cooperative Awareness Messages and Basic Safety Messages (CAM/BSM), to provide another level of visibility. The addition of Kalman filter to track the trajectory of objects would add a level of prediction on traffic flow. All of these inputs could be collected into a single digital twin of the intersection.

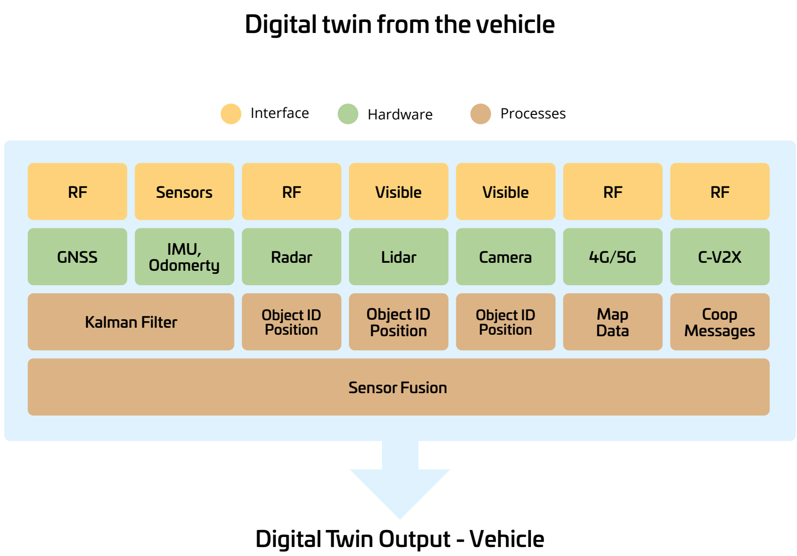
There are many infrastructure systems which could benefit, e.g., intersection management, automated valet parking.



4. Figure: Digital twin from the infrastructure

8.1.3 Digital Twin Components – Vehicle

The vehicle is based on a system similar to the infrastructure but has a major difference in that the vehicle is moving, thus the low latency layers are in a 'relative coordinate' system. The digital twin in this system must contain a method for tracking the real-time location of the vehicle in order to fuse the 'absolute coordinate' system layers with the relative one. However, control functions are usually based on a relative – egocentric – representation. This requires a GNSS system, Inertial Measurement Unit (IMU) and odometry followed by a Kalman filter to track the position in real time. The output is then fed into the sensor fusion to merge all objects detected into one representation, as shown below.



5. Figure: Digital twin from the vehicle

8.1.4 Coordinate system considerations

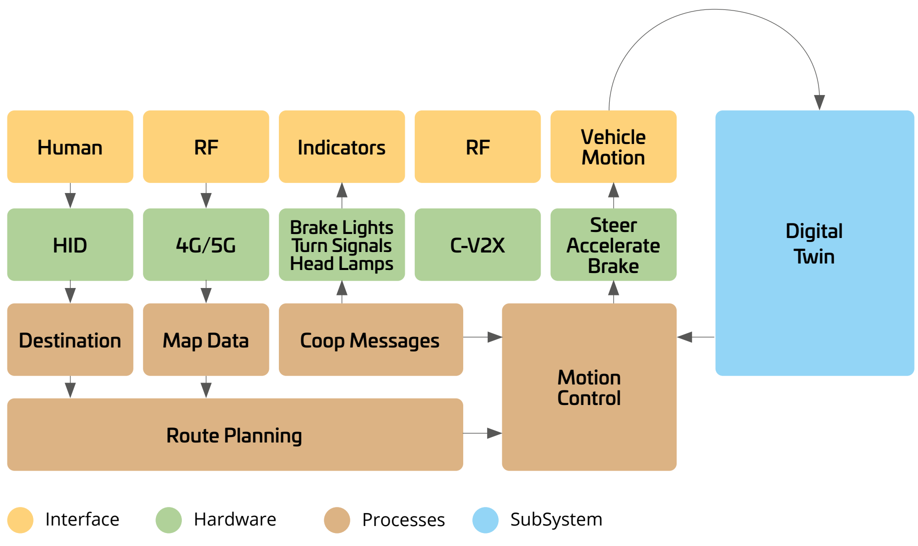
As previously mentioned, most real-time digital twin layers are implemented using relative coordinate systems because the safety application relies on an egocentric point of view. For C-ITS, and more specifically for the exchange of information between different actors, this exchange of a digital twin between two entities (e.g., a smart sensor RSU providing information on detected VRUs around the intersection via a CPM/SDSM to a vehicle nearby) is done in most cases using at least one absolute coordinate, and it references relative objects from that absolute coordinate. Alternatively, all objects can be represented using absolute coordinates for a considerable message size increase. The agreed data type for C-ITS is WGS84 as the absolute coordinate system.[3] The exchange of maps and road-related digital twins (e.g., based on nodes and joints) use yet again different data representations.

8.1.5 Autonomous System

The heart of the Autonomous Vehicle is the autonomous system, which controls the motion of the vehicle. Accurate understanding of the position and timing are critical when making decisions about the motion of the vehicle in a safe manner, especially in the presence of pedestrians and cyclists.

The autonomous system has three major components: route planning, digital twin, and motion control. The route planning typically uses positional information as the starting point and HD maps to plan the route. Once the route is planned, the motion control system takes control to navigate along the route. Periodic updates may occur as new information makes a different route more efficient (such as a traffic accident).

Feedback loop of the digital twin

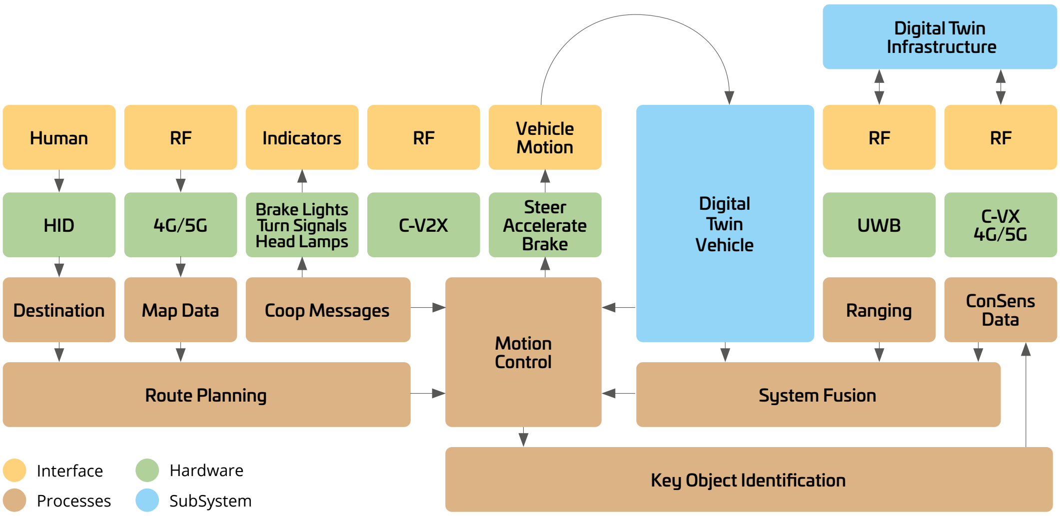


6. Figure: Feedback loop of the digital twin

[3] See EN 302 890-2

The problem with this system is that it does not use the cooperative information available to other sources. One additional key feature needed is to identify key objects and gather additional information about those objects from external sources. One example might be as the vehicle approaches an intersection, the system identifies the intersection as a key object and then requests the intersection to share its digital twin information. Another example is when the vehicle wants to change lanes or merge into an adjacent lane, it might want to start a UWB session with the key vehicle to more accurately know the position of those vehicles, as shown on 7. Figure.

Extended view of the digital twin data exchanges

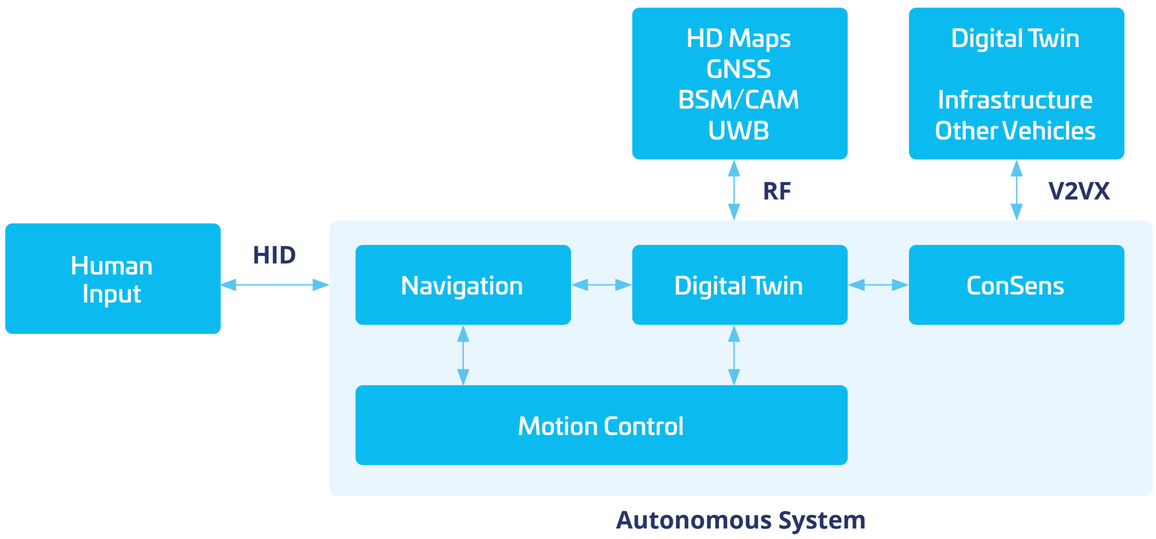


7. Figure: Extended view of the digital twin data exchanges

8.2 High-level View

Figure 8 shows the high-level interaction of the many systems. The vehicle has three major subsystems – the autonomous system, the digital twin, and the ConSens system – for sharing sensor information.

High-level architecture of the autonomous vehicle system, illustrating interactions between the autonomous system, digital twin, and other sensors



8. Figure: High-level architecture of the autonomous vehicle system, illustrating interactions between the autonomous system, digital twin, and other sensors

8.3 Considerations for the Exchange of Digital Twins

External digital twins will always need to be fused with the local representation, which introduces challenges due to inaccuracies and information conflicts, regardless of the fact that they are based on absolute or relative coordinate systems. Also, data age (the latency from capturing the sensor measurement to the time it arrives via a digital twin representation – e.g., a CPM – to the recipient vehicle) impacts fusion accuracy as the local digital twin might be several cycles ahead of the incoming update (new information).

Error propagation is also a huge challenge when relative and absolute objects, and event representations are transferred, especially if the information source is in a different coordinate system.

8.3.1 Use of Digital twins for the Work Item

The first use case, called 'Awareness of the presence of VRUs near potentially dangerous situations' (see [10]) focuses on providing a unicast relative distance measurement potentially available for both participants, thus digital twins are not exchanged, the location assessment is done on the Ego Vehicle itself and the update of the twin is done by the Ego System.

The second use case, 'High-definition Sensor Sharing' (according to [10]) defines the roadside system to exchange digital twins using e.g. V2X sensor sharing messages as a carrier of a digital twin data representation.

8.3.2 Privacy Aspects

The two main aspects to consider for privacy are the storage of data and the transmission of information to external locations. A vehicle or roadside station can remain a digital twin without storing past information; because it is storing only currently valid values, and all past values of a parameter (e.g., location information) are overwritten or removed. This way, information is only held until it is absolutely necessary. The transmission of information must also be considered because regional rules (e.g., GDPR[4]) are quite strict when it comes to sending object locations to non-local entities (e.g., the cloud). However, further privacy aspects are out of scope of the current Work Item and shall be done on a use case basis.

8.3.3 Coherent Situational Awareness and the Role of the Digital Twin

Each digital twin in the traffic system (vehicle or infrastructure) is expected to be slightly different, as updates (changes to the digital twin) are continuous and partially asynchronous. However, using techniques such as versioning and timestamping, coherence can and should be aimed for. This means that all systems want to be aligned and reach a common conclusion about the state of the environment (i.e., each system will try to update itself to the most recent information in an effort to be mostly – if not always completely – coherent).

Another aspect of coherence is the continuous update of the vehicle's digital twin layers. As described before, a digital twin is updated continuously by internal or external sensor data and other information sources. In most cases these updates will not completely replace the existing information onboard, but rather provide an update to a small fraction of the twin. By incorporating new information into the twin, a harmonization is required using fusion, prediction and other methods in order to allow all information in the digital twin to be coherent as a layer (each part coherent with the full layer).

The role of the digital twin is to allow higher layer applications to make decisions, e.g., decide to make a maneuver based on the known objects around or activate various warnings or alerts to the driver if a dangerous situation is identified. However, correct situation assessment requires sufficiently precise data; if the information (e.g., position accuracy of a given object) is not precise enough, the decision to warn cannot be made accurately, making false positives or negatives more probable. To overcome

[4] The General Data Protection Regulation (GDPR) is a European Union law focused on data privacy and security.

this problem, the ConSens system can be used to request an improvement of the positioning data of the Ego Vehicle and its surroundings to improve the situation assessment. The digital twin is the reference to which the higher layer vehicle systems will turn to when identifying the area or object needing improvement. Objects or locations are selected by the applications which are then provided to the ConSens interfaces for interaction.

9 ConSens Use Case Implementation Examples

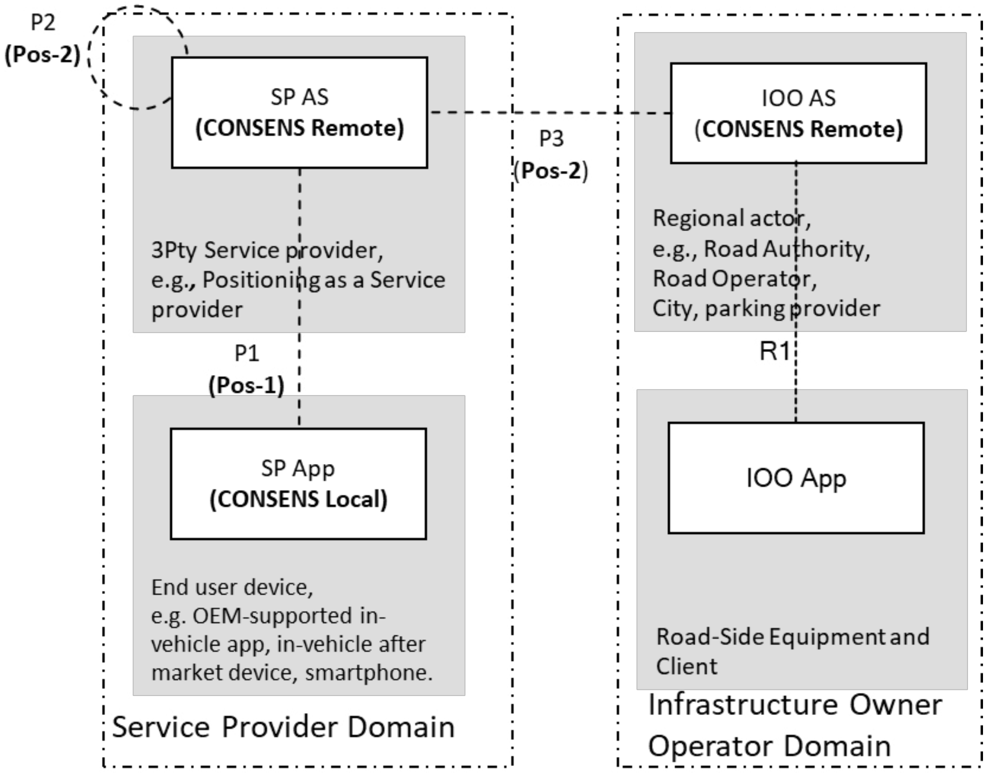
This chapter provides implementation examples for different ConSens use cases using the V2N2X application layer architecture described in Annex A: V2N2X application layer architecture [8]. More details about the V2N2X architecture and deployment options can be also found in [10]. In reality, there are many deployment options for ConSens services depending on the involved ecosystem stakeholders, communication technologies, and end-user V2X applications using the final positioning results. The purpose of this chapter is not to provide all possible ConSens deployment options, but to illustrate typical examples that may inspire further deployment options leveraging the functional components – ConSens Local, ConSens Remote and interfaces Pos-1 and Pos-2 – shown in Figure 7. Each implementation example contains the description of the use case, the prerequisites of the implementation, and end-to-end data flow of the service execution step.

9.1 Use Case I: Enhanced Positioning Service for V2X Applications Using Remote Positioning Data Source(s) from Infrastructure

In this use case, a Road User (ConSens Local) provides improved positioning service to V2X applications utilizing positioning data sourced from the infrastructure over the Pos-1 interface. The V2X applications can be, for example, VRU Protection, HD Coherent Awareness, Maneuver Coordination Services, etc., which have a certain level of requirements in terms of the precision and trustworthiness of the positioning results.

9.1.1 Implementation Option Using Interface P1 (See Annex A)

The deployment architecture of ConSens UC-I using P1 interface is shown in Figure 9.



9. Figure: ConSens UC-I deployment architecture using P1 interface

Use Case Deployment Solution Description

Prerequisites of the implementation:

(a) The ConSens Local is implemented as a Service Provider Application (SP App) from a SP providing Positioning as a service. The ConSens Local is implemented on end user devices e.g., OEM-supported SP App[5] installed on OEM infotainment system, aftermarket device, or smartphones, to support V2X applications on such device.

(b) The SP has implemented ConSens Remote as SP AS, usually hosted at the backend of the SP.

(c) The SP has established a trust relation with Infrastructure Owner Operators (IOOs), which also provides provide ConSens services by acting as ConSens Remote. Secure connection has been established between SP AS (ConSens Remote) and IOO AS (ConSens Remote) over the P3 interface.

(d) SP App (ConSens Local) is connected to the SP AS (ConSens Remote) via the SP proprietary interface P1.

(e) Prior to sharing any positioning information and data, all components in this system have taken necessary measures to ensure the compliance to personal data protection regulation, if applicable.

[5] See Section 7.2 in [10] for the definition of 'OEM-controlled App', 'OEM-Supported SP App', 'OEM-independent SP App'.

UC execution steps:

1. SP App (ConSens Local) receives request from V2X Application (e.g., VRU Protection) requiring positioning data associated with certain requirements, e.g., precision, timeliness, trustworthiness. SP App (ConSens Local) prepares the positioning results using local positioning data but cannot fulfill the requirements. SP App (ConSens Local) sends ConSens service request to SP AS (ConSens Remote) containing the location (and area) information of SP App (ConSens Local) and the associated requirements via the P1 (Pos-1) interface.
2. Upon the request from SP App (ConSens Local), the SP AS (ConSens Remote) checks its local positioning data source matching the location and area in the request.
    a. If the local positioning data source(s) of SP AS (ConSens Remote) fulfill the requirements from SP App (ConSens Local), the SP AS (ConSens Remote) starts sharing the positioning data with SP App (ConSens Local).

    Note: SP AS (ConSens Remote) may establish a communication session with SP App (ConSens Local) if periodical updates of the positioning data are needed.

    b. If the local positioning data source(s) of SP AS (ConSens Remote) do not fulfill the requirements from SP App (ConSens Local),
        i. The SP AS (ConSens Remote) forwards request to other SP AS(s) (ConSens Remote) and/or IOO AS(s) (ConSens Remote) or via the P2 and/or P3 interfaces (Pos-2 interface).
        ii. Upon reception of the ConSens request, the connected SP AS(S) (ConSens Remote) and/or IOO AS(s) (ConSens Remote) share positioning data source(s) via the P2 and/or P3 interfaces (Pos-2 interface), if they have data source(s) fulfilling the requirements.

    Note: SP AS (ConSens Remote) may establish communication sessions with other SP AS(s) (ConSens Remote) and/or IOO AS(s) (ConSens Remote) if periodical updates of the positioning data are needed.

        iii. Upon any positive feedback from other SP AS(s) (ConSens Remote) and/or IOO AS(s) (ConSens Remote), the SP AS (ConSens Remote) provides the positioning data sourced from other SP AS(s) (ConSens Remote) and/or IOO AS(s) (ConSens Remote) to the SP App (ConSens Local) via the P1 interface (Pos-1 interface).

    Note: SP AS (ConSens Remote) may establish a communication session with SP App (ConSens Local) if periodical updates of the positioning data are needed.

        iv. If the IOO AS (ConSens Remote) does not have data source(s) fulfilling the requirements, IOO AS sends ConSens Response with *Resp code=fail* to SP AS (ConSens Remote).

    v. If no positive feedback has been received before timeout, the SP AS (ConSens Remote) provides negative feedback to the SP App (ConSens Local) via the P1 interface (Pos-1 Interface).

  c. Upon positive feedback from the SP AS (ConSens Remote) the SP App (ConSens Local) provides the improved positioning results to the end user(s) i.e., the V2X Application(s), e.g., VRU protection.

    i. Either SP AS (ConSens Remote) or SP App (ConSens Local) can terminate the ConSens service session between SP AS and SP App.

    ii. Either IOO AS (ConSens Remote) or SP AS (ConSens Remote) can terminate the ConSens service session between IOO AS and SP AS.

3. If no positive feedback is received from the SP AS (ConSens Remote), the SP App (ConSens Local) declines the request from the end user, i.e., the V2X Application(s), e.g., VRU protection.

Protocol used:

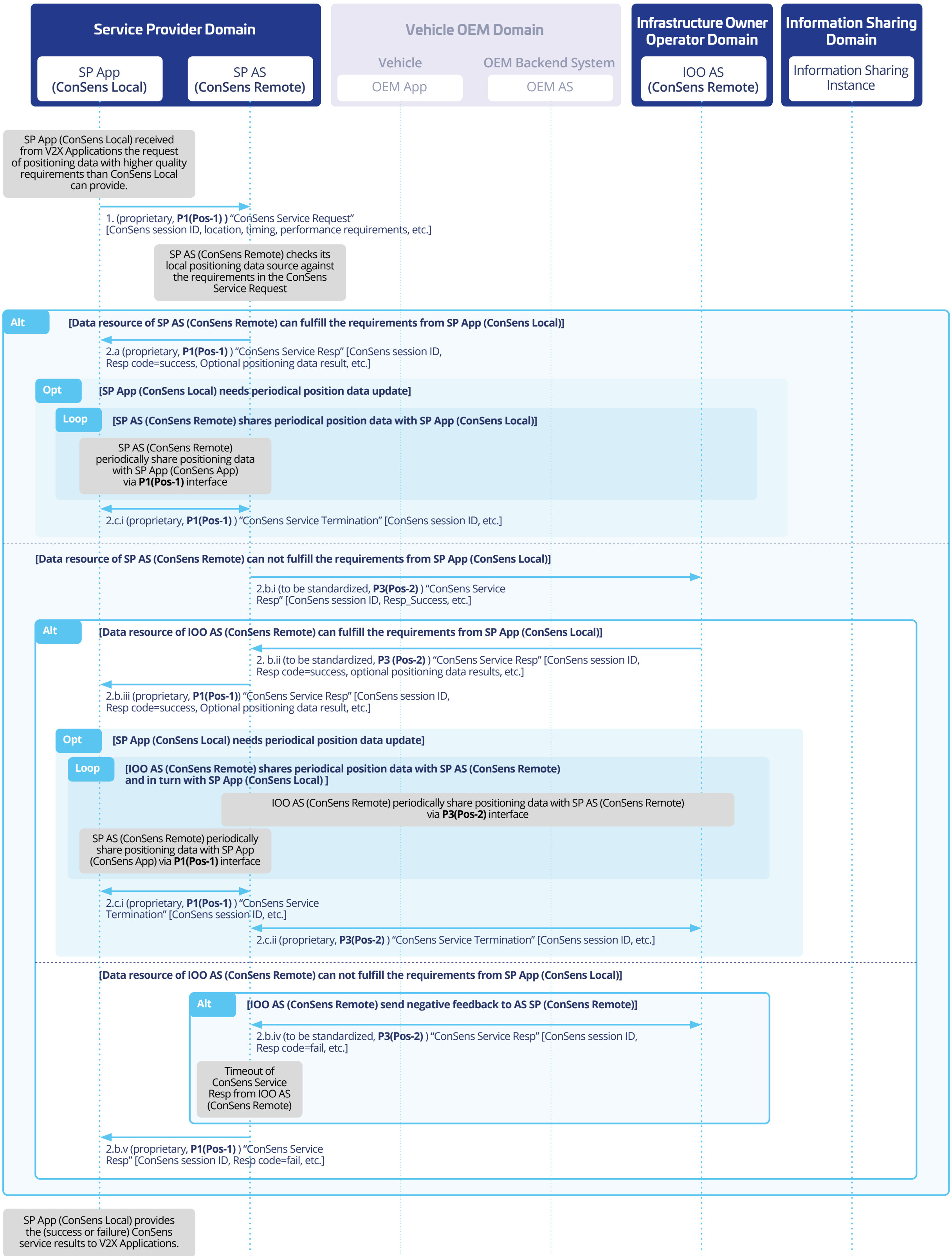
P1 interface: P1 interface (for Pos-1) is a SP proprietary interface. The SP can decide on the messages and protocols used on this interface.

P2 interface: P2 (for Pos-2) interface can be an inter-stakeholder domain interface, e.g., going cross the border of different SPs. For interoperability reason, messages and protocols used on this interface should be agreed among the SPs or standardized.

P3 interface: P3 (for Pos-2) interface is an inter-stakeholder domain interface, i.e., going cross the border of SP and IOO. For interoperability reason, messages and protocols used on this interface should be agreed between the connected stakeholder or standardized.

Sequence diagram:

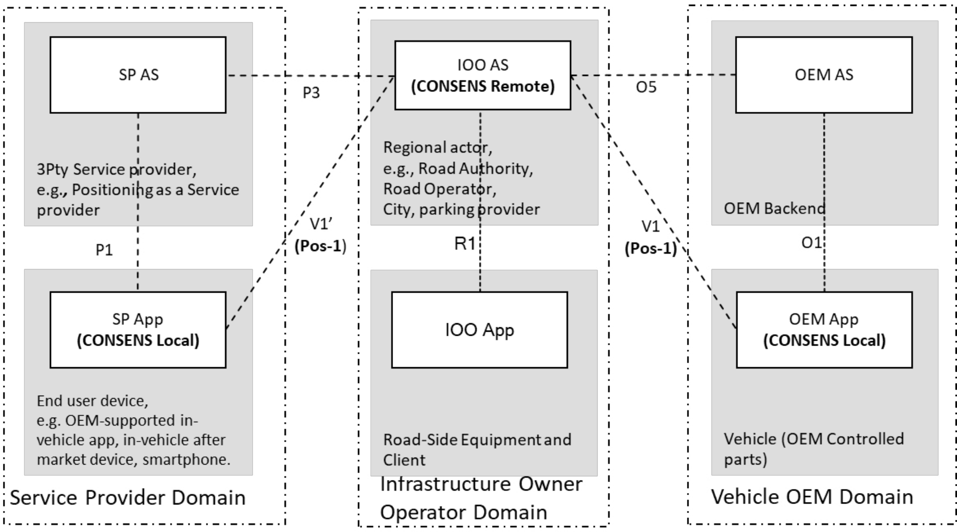
Message sequence of ConSens UC-I deployment architecture using P1 interface



10. Figure: Message sequence of ConSens UC-I deployment architecture using P1 interface

9.1.2 Implementation Option Using Interface V1 or V1' (See Annex A)

The deployment architecture of ConSens UC-I using V1 or V1' interface is shown in Figure 11.



11. Figure: ConSens UC-I deployment architecture using V1/V1' interface

Use Case Deployment Solution Description

Prerequisites of the implementation:

(a) The ConSens Local is implemented as a Service Provider Application (SP App) from a SP providing Positioning as a Service for the V1' implementation option, or as OEM App from a car OEM for the V1 implementation option. For SP App, the ConSens Local is implemented on end user devices e.g., OEM-supported SP App[6] installed on OEM infotainment system, after-market device, or smartphones, to support V2X applications on such device. For OEM App, the ConSens Local is implemented in the vehicle as OEM-controlled App.

(b) For the V1' implementation option, the SP has established trust relations with Infrastructure Owner Operators (IOOs) providing ConSens services by acting as ConSens Remote. Secure connection has been established between SP AS and IOO AS (ConSens Remote) over the P3 interface. For the V1 implementation option, the OEM has established trust relations with IOOs. Secure connection has been established between OEM AS and IOO AS (ConSens Remote) over the O5 interface.

(c) For the V1' implementation option, SP App (ConSens Local) is connected to the SP AS via the SP interface P1. For the V1 implementation option, OEM App (ConSens Local) is connected to the OEM AS via the interface O1.

(d) Prior to sharing any positioning information and data, all components in this system have taken necessary measures to ensure their compliance with personal data protection regulations/provisions, if applicable.

[6] See Section 7.2 in [8] for the definition of 'OEM-controlled App', 'OEM-Supported SP App', 'OEM-independent SP App'.

Use case execution steps:

Note: The following process describes the steps for the V1' implementation option. Nevertheless, the general process and the sequence diagram in Figure 12 still hold, substituting SP App with OEM App, SP AS with OEM AS, and V1' with V1.

1. SP App (ConSens Local) receives request from V2X Application (e.g., VRU Protection) requiring positioning data associated with certain requirements, e.g., precision, timeliness, trustworthiness. SP App (ConSens Local) prepares the positioning results using local positioning data source but cannot fulfill the requirements. SP App (ConSens Local) sends ConSens service request to SP AS containing the location (and area) information of SP App (ConSens Local) and the associated requirements via the P1 interface.
2. Upon the request from SP App (ConSens Local), the SP AS send ConSens request to IOO AS(s) (ConSens Remote) connected to it.
3. Upon reception of the ConSens request, if the position data source matches the request, the connected IOO AS(s) (ConSens Remote) acknowledges the SP AS with positive feedback, and exchanges with SP AS the security credentials for establishing the V1' (Pos-1) interface over the P3 interface.
4. If the SP AS receives any positive feedback from IOO AS (ConSens Remote), it forwards the address and security credentials for establishing the V1' (Pos-1) interface to SP App (ConSens Local) via the P1 interface.

   Note: The SP AS may generate credentials on behalf of the SP App for the mutual authentication on the V1' (Pos-1) interface.
5. Upon reception of the IOO AS (ConSens Remote) and necessary security credentials, the SP App (ConSens Local) establishes the connection to IOO AS (ConSens Remote) over the V1' (Pos-1) interface and start receiving position data source from the IOO AS (ConSens Remote).

   Note: SP App (ConSens Local) may establish communication sessions with other IOO AS(s) (ConSens Remote) if periodical updates of the positioning data are needed.
6. After receiving the positioning data source, SP App (ConSens Local) provide final positioning results to the end users, i.e., the V2X Application(s), e.g., VRU protection.

   Note: Either SP App (ConSens Local) or IOO(s) (ConSens Remote) can terminate the ConSens service session.
7. If IOO AS (ConSens Remote) cannot provide data source fulfilling the requirements of SP App (ConSens Local), IOO AS sends negative ConSens Service Resp with '*Resp code=fail to SP AS via the P3 interface*'.
8. Upon reception of ConSens Service Resp with *'Resp code=fail'* from IOO AS (ConSens Remote), SP AS forward the negative response to SP App (ConSens Local).
9. If no positive feedback is received from the SP AS, the SP App (ConSens Local) declines the request from the end user, i.e., the V2X Application(s), e.g., VRU protection.

Protocol used:

P1/O1 interface: P1/O1 interface is a SP/OEM proprietary interface. The SP/OEM can decide on the messages and protocols used on this interface for discovering IOO AS(s) (ConSens Remote) and exchange the address and security credential information needed for establishing the V1'/V1 (Pos-1) interface.

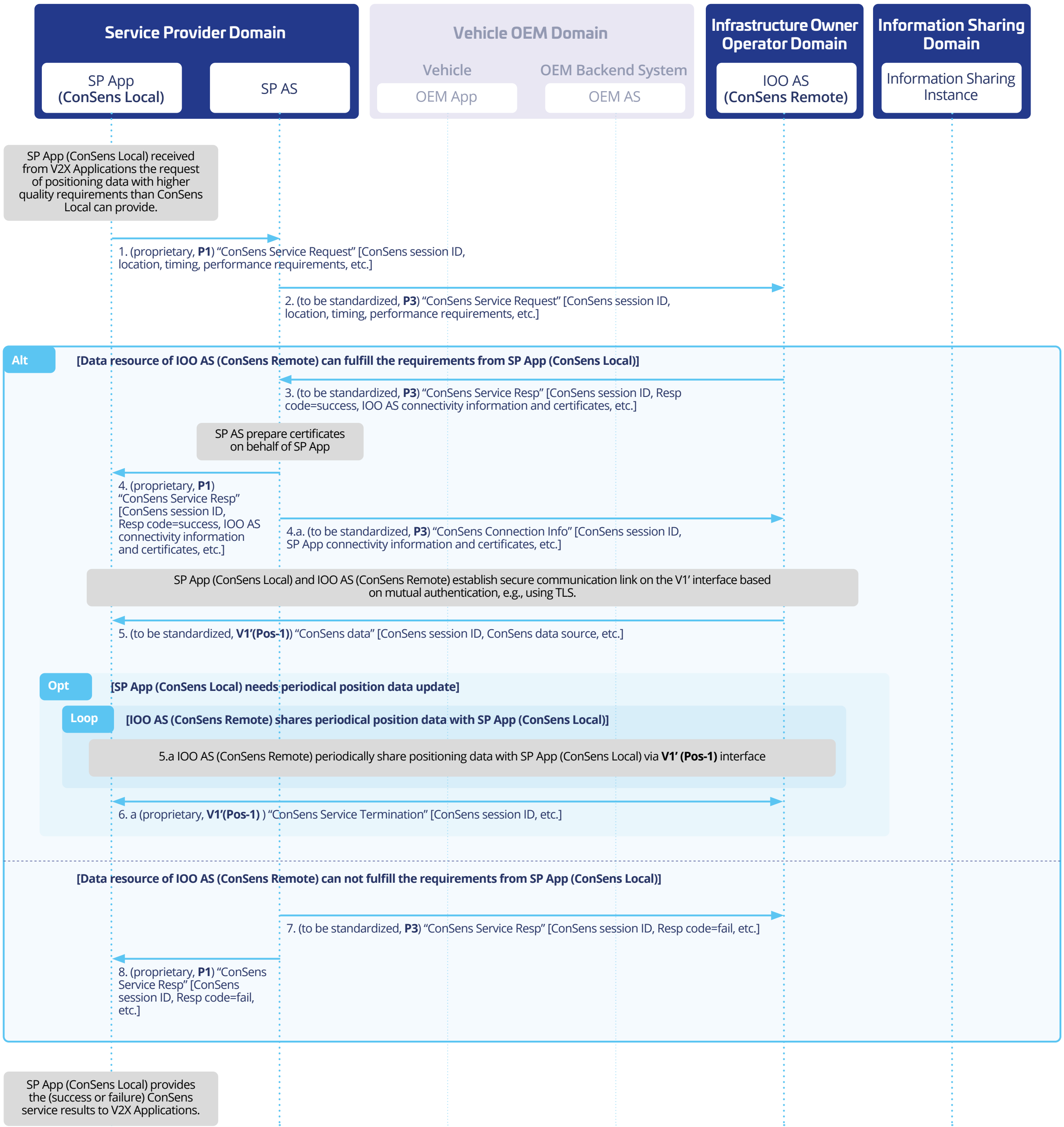
P3/O5 interface: P3/O1 interface is an inter-stakeholder domain interface, i.e., going cross the border of SP/OEM and IOO domains. For interoperability reason, messages and protocols used on this interface should be agreed between the connected stakeholders or being standardized.

V1'/V1 interface: V1'/V1 (Pos-1) interface is an inter-stakeholder domain interface, i.e., going cross the border of SP/OEM and IOO domains. For interoperability reason, messages and protocols used on this interface should be agreed between the connected stakeholders or being standardized.

Sequence diagram:

Note: The sequence diagram in the Figure 12 is for the V1' implementation option. Nevertheless, the general process and the sequence diagram still hold, substituting SP App with OEM App, SP AS with OEM AS, and V1' with V1.

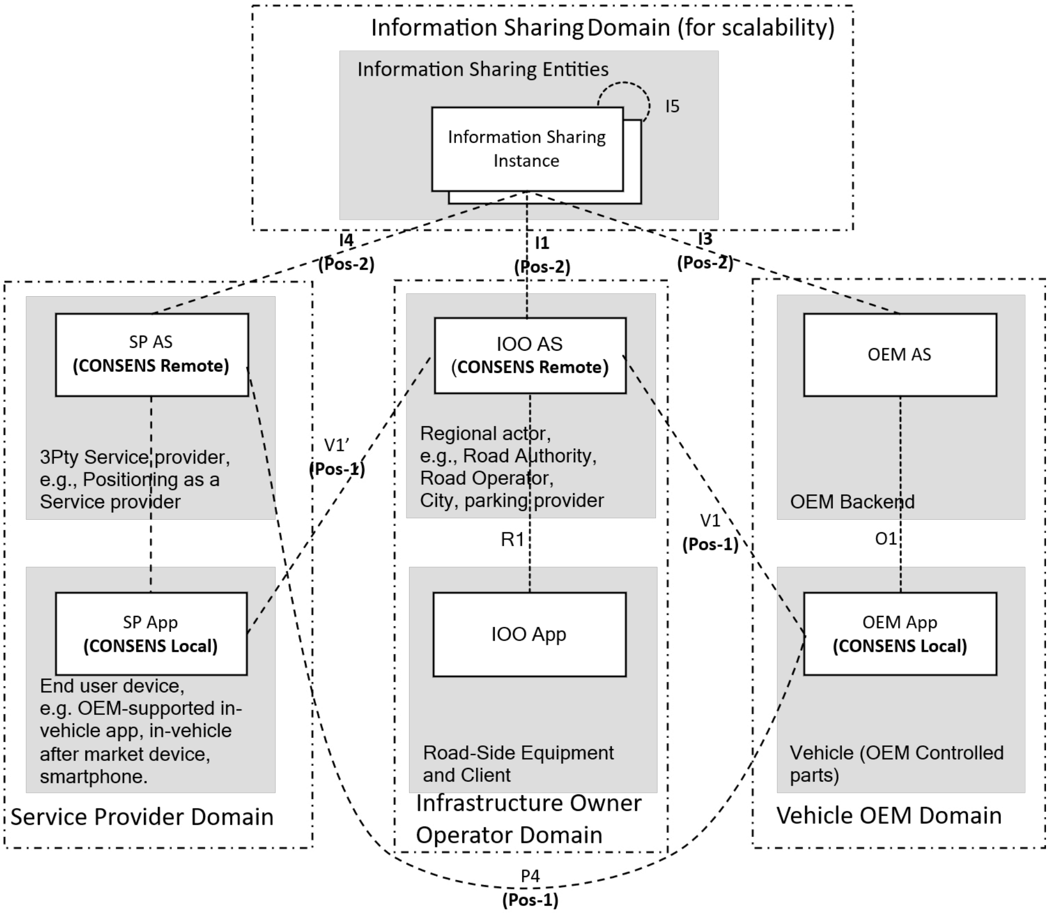
Message sequence of ConSens UC-I deployment architecture using V1' interface



12. Figure: Message sequence of ConSens UC-I deployment architecture using V1' interface

9.1.3 Scalable ConSens Deployment Using Information Sharing Instances

When the ConSens deployment scales up and involves more ecosystem stakeholders, the use case implementations described above will benefit from the use of Information Sharing Entities, e.g., to avoid a full mesh of connectivity among the backend of actors. The Information Sharing Concept and related preparation are further described in Section 6.4 of [8].



13. Figure: System architecture of ConSens use case deployment using Information Sharing Entities

Note: Figure 13 only shows cross-domain backend interfaces that are relevant to the Information Sharing Entities, i.e., I1, I3, and I4. Although not shown in the figure, cross-domain backend interfaces based on bilateral agreements can also be used between ecosystem stakeholders, e.g., O2, O5, P3 in the 20. Figure (Annex A).

Use Case Deployment Solution Description

In this scenario, Information Sharing Entities are used to share ConSens service information and data in a scalable way. The backend of an actor, e.g., vehicle OEM, IOO, or SP, is in general connected to one Information Sharing Instance, e.g., in one country or region. This Information Sharing Instance is then interconnected with those in other countries or regions.

Note: There can be more than one Information Sharing Instance per country or region depending on the system topology, organizations, data traffic load, etc.

The network of interconnected Information Sharing Instances thus provides a federated information sharing backbone, where information from the whole ecosystem is available wherever an actor is connected. (Note: An actor can be redirected to an Information Sharing Instance closer to the data source, e.g., to shorten the data path).

The following description shows an example based on the C-Roads specification (see [24]) for the IP-based interface profile, which has been implemented for other V2X use cases, e.g. Traffic Event Information Share [8]. The 'IP-based interface profile' enables a publish/subscribe model using Advanced Message Queuing Protocol (AMQP) with metadata (AMQP application properties) to allow message filtering based on what an actor is interested in, e.g., location, type of message, etc.

Use case execution steps:

Once preparations are in place, i.e., connectivity, published agreements and subscription filters have been established (as detailed in Section 6.4 of [8]), information exchange can be performed.

1. A trusted actor in the interconnected ecosystem, e.g., an IOO, a city, or a road operator has deployed infrastructure for ConSens service at certain locations, e.g., accident prone locations such as intersections, zebra crossings, or bus stops.
2. The trusted actor, e.g., the IOO AS, publishes information to the connected Information Sharing Instance with associated AMQP metadata indicating, for instance, the format of ConSens data, location of the service area, producer of the information, and address information of ConSens Remote (e.g., URL). This publishing action is done using I1.
3. The receiving Information Sharing Instance checks which backend clients (SP ASs and/or OEM ASs) have a matching subscription based on the established filters and pushes the information to those backend clients (SP ASs and/or OEM ASs) using the I3 and/or I4 interfaces. Operation on both interfaces basically follows the same mechanism but may have different filter configurations.

   Note: Here, the federated Information Sharing Domain is applicable, i.e., a client (SP AS or OEM AS) connected to another Information Sharing Instance, but subscribing to the same information/event can also get this information.
4. A backend client (SP AS or OEM AS) receiving the information about the availability of ConSens service can thus select to forward this information to its relevant clients (e.g., SP Apps or OEM Apps) depending on their location and request status.
5. SP Apps or OEM Apps, if allowed by the respective SP AS or OEM AS, can thus establish a connection to the ConSens Remote (IOO AS) and obtain object data using the V1' or V1 interface.

Protocols used:

On I1, I3, I4, and I5 interfaces, standard IT technology and processes should be used (see Annex G of [8], e.g., AMQP can be used for information sharing (publish/subscribe) and for providing metadata required in filtering operations to identify the payload, relevant area, etc. TLS 1.3 with mutual authentication can be used for security.

Note: The I5 interface is used in scenarios where actors are connected to different Information Sharing Instances. In such cases, subscriptions are federated between the Information Sharing Instances.

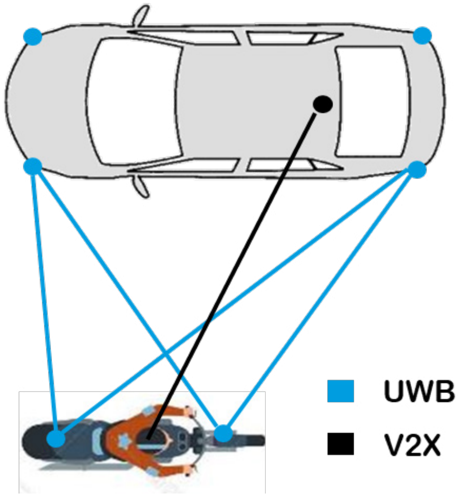
The payload encapsulated by AMQP can be according to agreed formats among actors (i.e., the transport and information sharing solutions are payload-agnostic).

9.2 Use Case II: Local PaaS Using UWB and V2X

UWB is a point-to-point distance measurement technology which requires a UWB RF transceiver on each end of the link. UWB operates in a 500 MHz bandwidth, which can provide accuracies on the order of +/-10 cm. In addition, cybersecurity methods in the protocol can be used to ensure the distance measurement cannot be spoofed. With double-sided and two-way ranging, both ends of the link know the distance after a series of ranging exchanges.

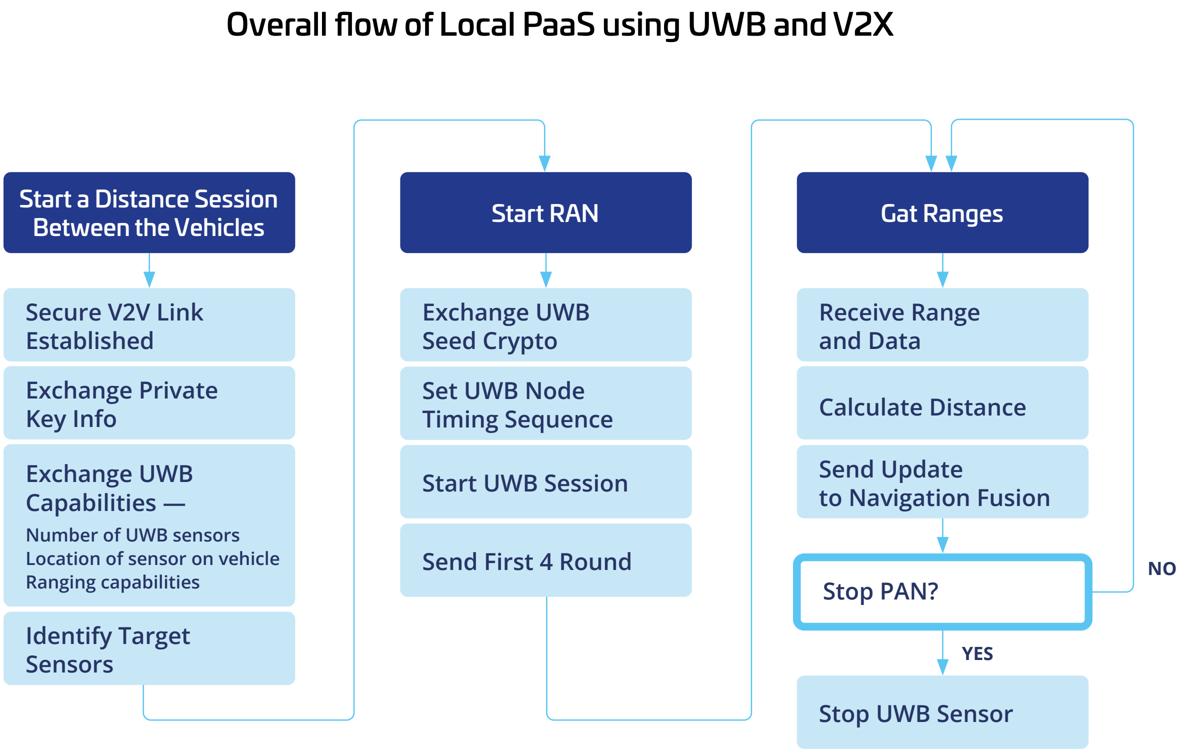
Figure 14 shows one possible implementation where the UWB sensors are present on the vehicle and on the VRU.

Note: UWB distance measurement technology is being used today to implement The Car Connectivity Consortium® Digital Key 3.0 specification. This provides a base of UWB sensors existing on many vehicles.



14. Figure: complementarity of UWB and V2X

As discussed earlier in the ‘Awareness of the presence of VRUs near potentially dangerous situations’ use case, the ConSens system can be used to identify a key VRU which needs highly accurate positioning between the vehicle and the VRU. Once the two parties are identified, then a communication link can be established using either V2N2X or V2X. Once this link is established, then the initialization and operation of the UWB sensors can be started. The following is a summary of the overall flow.



15. Figure: Overall flow of Local PaaS using UWB and V2X

9.2.1 Capabilities Exchange

Then next step in the process is to exchange capabilities. Ranging capabilities include protocol, ID and pulse shape. This allows the UWB transceivers to ensure they can talk with each other and will use compatible protocols and algorithms.

In addition to ranging capabilities, each user must know the location of the UWB sensor on the vehicle/VRU and know the shape of the vehicle/VRU. The following shows the capabilities message exchanges.

Capabilities exchange

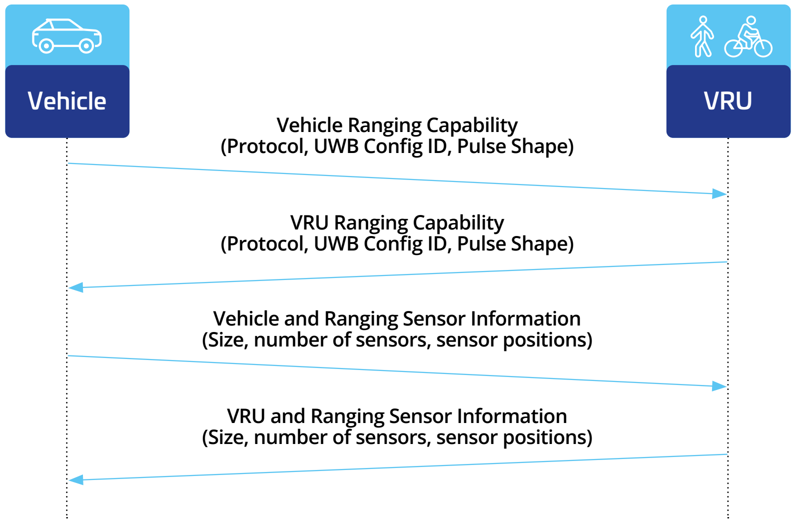


Figure 16: Capabilities exchange

9.2.2 UWB Ranging Secret Key (URSK) Exchange

A key part of the secure UWB protocol requires that each end of the link has a common UWB ranging secret key or URSK. This must be generated and stored in a secure element. One of the key functions of ConSens is to provide the capability for secure data exchange. V2X standards provide for the creation and use of public keys for each vehicle so they can exchange information securely. The UWB exchange of USRK information must occur using this V2X public key encoding and decoding process. Figure 17 outlines the process for exchanging URSK information.

Exchanging URSK information

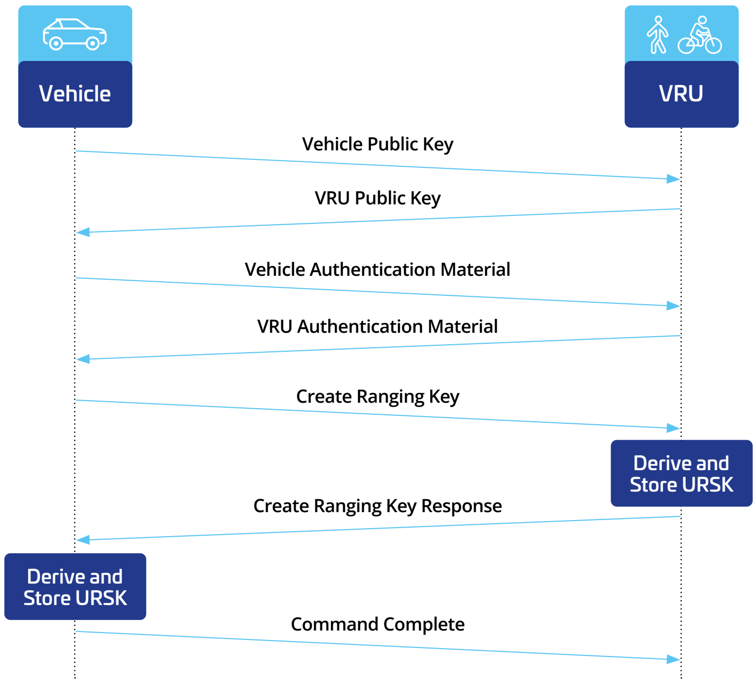
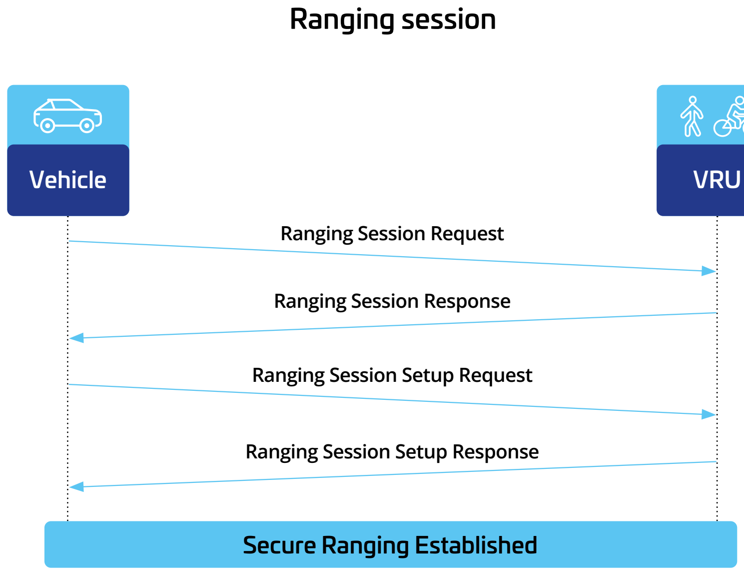


Figure 17: Exchanging URSK information

9.2.3 Secure Ranging Area Network

Lastly, the ConSens system can request the ranging session to begin a Ranging Area Network (RAN). This starts with a ranging session request. This will include a *UWB_Session_ID* allowing the system to select the correct URSK. The next step is to start the actual ranging session. This is the point at which the system will synchronize their internal clocks to establish a coarse time reference.



18. Figure: Ranging session

10 Advanced Positioning for C-V2X Safety: RTK, Sensor Fusion, and Hybrid Systems

The integration of advanced positioning technologies into Vehicle-to-Everything systems is a critical step toward enhancing road safety, particularly for Vulnerable Road Users. This chapter explores the core technologies – Real-Time Kinematic (RTK) positioning, Sensor Fusion, and Hybrid Approaches – that provide the high-accuracy location data necessary for modern transportation networks. We will examine their competencies, applications in different C-V2X modes, and the foundational requirements, such as high-definition mapping and a supportive regulatory landscape, that enable their global deployment.

10.1 Core Positioning Technologies

At the heart of advanced V2X safety systems are three primary approaches to vehicle and user localization.

10.1.1 Real-Time Kinematic

RTK is a satellite navigation technique used to enhance the precision of position data derived from satellite-based positioning systems (like GNSS). By using a network of fixed base stations to broadcast corrections, RTK can achieve **centimeter-level accuracy** in open environments, making it ideal for safety-critical applications requiring precise location information.

10.1.2 Sensor Fusion

Sensor fusion is a process that combines data from multiple onboard sensors – such as lidar, radar, and cameras – to generate a more accurate and reliable understanding of the surrounding environment than any single sensor could provide. This approach offers **robust performance** in challenging conditions where GNSS signals may be weak or unavailable, such as urban canyons or tunnels.

The Hybrid Platform-as-a-Service Approach

Combining RTK and Sensor Fusion into a Hybrid Platform-as-a-Service leverages the strengths of both technologies. This integrated approach provides robust, redundant, and highly accurate positioning even under complex real-world conditions. Hybrid systems are crucial for enabling edge intelligence and Multi-access Edge Computing (MEC)-integrated V2X use cases.

- **Seamless operation** in GNSS-limited areas.
- **High reliability** via redundant sensing.
- Enables **AI-driven predictive safety systems** at the network edge.

However, this approach introduces its own challenges, including complex system integration, certification, and a dependency on HD-mapping support.

10.2 Comparative Analysis and Applications

Understanding the distinct strengths and weaknesses of each technology is key to applying them effectively in different C-V2X architectures and environmental conditions.

10.2.1 Core Competencies, Pros, and Cons

The following table outlines the core competencies, advantages, and disadvantages of RTK, Sensor Fusion, and the Hybrid Approach, providing a clear comparison of their respective capabilities.

Technology	Core Competencies	Pros	Cons
RTK	▸ Centimeter-level accuracy in GNSS environments ▸ Low latency for safety-critical applications	▸ High precision in open areas ▸ Essential for direct V2X applications	▸ Performance degraded in urban environments ▸ Sensitive to signal obstructions
Sensor Fusion	▸ Integrates multiple sensor types (lidar, radar, cameras) ▸ Robust performance in challenging environments	▸ Reliable in all weather and urban conditions ▸ Enhances situational awareness	▸ Lower precision compared to RTK ▸ Relies on the accuracy of individual sensors
Hybrid Approach	▸ Combines RTK with Sensor Fusion for redundancy ▸ Ensures accuracy in both GNSS-rich and GNSS-poor environments	▸ Best of both worlds ▸ Resilient to different environmental challenges	▸ Increased system complexity ▸ Higher deployment costs

Table 1: Pros and cons of the different approaches

10.2.2 Use of Technology Across C-V2X Modes

The choice of positioning technology is heavily influenced by the C-V2X communication mode being used – Network (Uu interface), Direct (PC5 interface), or a Hybrid of both. The table below details the suitability and challenges of implementing these technologies across the different modes.

Technology	Network C-V2X	Direct C-V2X	Hybrid C-V2X
RTK	Used via cloud correction services.	Challenging without connectivity.	Reliable with multi-link correction.
Sensor Fusion	Moderate effectiveness; depends on the onboard computer.	Highly effective in short-range detection.	Augmented by edge inferencing.
Hybrid Approach	Best suited for MEC-supported networks.	Redundant and adaptive safety layer.	Offers both global and local accuracy.

Table 2: Overview of the different approaches

10.2.3 Performance in Outlying Conditions

The performance of RTK and Sensor Fusion varies significantly based on environmental conditions. RTK provides absolute accuracy in ideal GNSS conditions, while Sensor Fusion ensures operational continuity when signals are compromised. The subsequent table compares their effectiveness in several challenging scenarios.

Condition	RTK	Sensor Fusion
Urban Canyons (Tall Buildings)	Less accurate; signals obstructed.	More accurate; uses lidar/radar for mapping.
Adverse Weather (Rain, Fog)	Less effective; GNSS signals degraded.	More reliable; uses radar and cameras for object detection.
Open Rural Areas (Good GNSS Coverage)	Highly accurate; performs best.	Reliable but not as precise as RTK.
Areas with High GNSS Jamming	Severely affected; accuracy drops.	Still effective, as it can compensate for GNSS failure.

Table 3: Comparison of the approaches under different conditions

10.3 Foundational Requirements and Global Landscape

The successful deployment of these technologies depends on a supportive ecosystem of data, infrastructure, and regulations.

10.3.1 High-Definition Mapping and Certification

For both RTK and Sensor Fusion systems, HD-mapping data is crucial to anchor positioning data to the real-world road network, ensuring accuracy and reliability.

- **ISO/OGC Geospatial Standards:** These standards provide a framework for certifying the reliability of HD- mapping data, which is essential for aligning RTK positioning with road infrastructure.
- **Navigation Data Standard (NDS):** This industry norm is used to certify HD maps for autonomous vehicles and V2X systems, ensuring that both RTK and Sensor Fusion applications utilize trusted, standardized data.

10.3.2 Global Technology Penetration

The adoption of these advanced positioning technologies is not uniform globally. Market readiness, infrastructure investment, and regulatory support influence their availability. The following table provides a snapshot of technology penetration in key regions.

Country/Region	RTK Availability	Sensor Fusion Availability	Hybrid Availability
United States	Available in most urban and rural areas.	Widely adopted in urban areas and vehicles.	Increasing availability, especially in autonomous vehicle trials.
Germany	Extensive RTK networks for V2X.	Strong adoption, especially in autonomous vehicles.	Highly advanced, particularly in automated transport systems.
China	Limited RTK availability in certain cities.	Rapid adoption in smart vehicles.	Widespread, especially in autonomous transport trials.
India	Limited availability, mostly urban regions.	Growing adoption in urban areas.	Emerging, especially in pilot projects for smart city applications.
Europe (EU)	Widely available in major markets.	Common in high-tech vehicles, especially in cities.	Adopted in selected pilot projects and advanced transport systems.

Table 4: Technology penetration in different regions

10.3.3 Global Regulatory Considerations

The deployment of RTK and Sensor Fusion for V2X is subject to global regulatory frameworks governing spectrum, data privacy, and safety. Regulatory bodies like the **FCC** (U.S.), **ETSI** (E.U.), and standardization organizations like the **3GPP** play a crucial role in shaping the V2X landscape.

Key regulatory aspects include:

- **Spectrum Allocation:** Direct V2X (PC5) communications rely on dedicated spectrum, such as the 5.9 GHz band, while Network V2X (Uu) may require service providers to manage public spectrum traffic. Harmonized spectrum policies are critical for cross-border interoperability.
- **Data Privacy and Security:** Regulations like GDPR in Europe and CCPA in California mandate robust encryption and anonymization of user data to protect privacy.
- **Vehicle and Infrastructure Compliance:** Agencies require stringent safety testing, certification, and standardization to ensure V2X technologies integrate seamlessly and safely with existing transportation infrastructure.
- **Liability and Legal Considerations:** The rise of V2X safety systems introduces complex legal questions regarding accident liability, data ownership, and compliance with evolving autonomous vehicle laws.

10.4 Summary and Impact

The integration of RTK, Sensor Fusion, and Hybrid Approaches into V2X systems marks a significant leap forward in transportation safety and efficiency. RTK's centimeter-level accuracy complements the environmental resilience of Sensor Fusion, and when combined, these technologies offer unparalleled reliability for protecting VRUs. The growth of MEC and AI-driven analytics further enhances real-time hazard detection, paving the way for safer, more intelligent road networks.

As this technology matures, its success will depend on addressing challenges related to global regulatory compliance, data privacy, and the standardization of HD maps. Business models such as Public-Private Partnerships (P3), subscription services, and data monetization will be key to sustaining scalable deployment. The future of connected transportation lies in harmonizing these advanced technologies with regulatory and business strategies that prioritize safety and facilitate broad adoption, ultimately reducing VRU-related accidents and fatalities worldwide.

11 Business Models

To ensure the financial viability and widespread adoption of the ConSens framework and PaaS for VRU protection, several business models could be considered or explored. By integrating any of the ConSens services, like the RTK-enhanced positioning with Sensor Fusion and advanced communication technologies, V2X solutions can deliver superior safety outcomes for VRUs.

11.1 Business Models at a Glance

Business Model	Description	Pros	Cons
Subscription-Based	Vehicle manufacturers and especially urban fleet operators could subscribe to PaaS as a premium feature through monthly or annual subscriptions. VRUs can opt in via smartphone apps that integrate improved positioning and V2P safety alerts.	Recurring revenue, scalable adoption	May limit access to those who can afford it
Public-Private Partnership (P3)	Government agencies collaborate with telecom operators, automakers, DOTs, municipalities and local governments to fund and deploy V2X infrastructure. PaaS like RTK base-station networks and MEC resources are maintained as a public asset.	Widespread adoption, shared costs	Requires regulatory support and complex agreements
Advertising and Data Monetization	Anonymous VRU movement data collected through V2X systems can be leveraged for urban planning, traffic, optimization, and commercial insights. Roadside digital billboards and in-vehicle infotainment systems utilize V2X data for location-based advertisements.	Creates new revenue streams, supports free services	Privacy concerns, potential data misuse
Infrastructure-as-a-Service	DOTs, cities and municipalities pay service providers for access to cooperative positioning services, ensuring seamless integration with smart city frameworks. For example, private road operators and logistics companies subscribe to RTK-powered services for enhanced safety and fleet management.	Sustainable funding, long-term investment	High initial deployment costs, requires municipal engagement
Edge-Enabled Safety Services	Leveraging MEC, AI-driven predictive analytics, and RTK-enhanced V2X to provide proactive safety alerts VRUs and vehicles.	Real-time hazard detection, improved safety outcomes	High initial infrastructure investment
V2X Marketplace	Open platform for third-party developers and service providers to create and offer V2X-based cooperative positioning services according to ConSens guidelines.	Encourages innovation, diverse application ecosystem	Standardization and interoperability challenges

Table 5: Different business models envisioned for ConSens

12 Conclusions and Next Steps

This Work Item has laid down the foundations, main considerations and framework of a cooperative Positioning-as-a Service (PaaS) system. There are countless combinations of possibilities for positioning and sensing technologies to extend and improve 5G-V2X, V2N2V and C-V2X in general. Many examples provided in this Technical Report may already be available in certain regions and application areas, while others still need time to be deployed.

This report also uncovered several aspects that have yet to be fully investigated or remain largely unanswered. However, some concrete recommendations of this Work Item are collected below.

Real-world Evaluation and Comparison of Alternative PaaS Solutions

To validate the effectiveness of these PaaS enhancements, ConSens would benefit from a comprehensive evaluation framework that assesses the performance improvements brought by the framework. This evaluation not only measures the technical improvements in positioning accuracy and data latency but also examines the practical impacts on road safety and traffic flow.

Fully Interoperable PaaS

As concluded in chapter 7, to ensure the interoperability of the ConSens service, the interfaces Pos-1 and Pos-2, including the messages and protocols as well as implementation profiles, need to be agreed among the stakeholders or standardized by SDO(s). ConSens messages and protocols over the Pos-1 and Pos-2 interfaces should be better described once more users of the framework appear and pilots can be set up to test the APIs.

New Business Models

Business models need to be investigated to overcome go-to market obstacles in providing precise positioning and timing information for road users independent of their own sensor capabilities. New business models could be developed for solutions that are collecting, combining and providing positioning information, and offering them as a service.

Identification of Standardization Gaps

Although the implementation examples and use cases are detailed in this report, not all parts of the cooperative exchange and data exchange are fully specified. Future work could investigate preferred methods to identify which extensions of the messages are needed and which additional technologies are not yet supported in the message types.

13 References

[1] **World Health Organization (WHO)**, 'Global Status Report on Road Safety,' 2023.

[2] **5GAA** (5G Automotive Association), 'C-V2X Use Cases and Deployment Strategies,' 2022.

[3] **Misra, P., & Enge, P.**, "Global Positioning System: Signals, Measurements, and Performance," Ganga-Jamuna Press, 2018.

[4] **Zang, S., et al.**, 'Ultra-Low Latency RTK Positioning for Autonomous Vehicles,' IEEE Transactions on Intelligent Transportation Systems, 2023.

[5] **Furgale, P., et al.**, 'Mitigating GNSS Errors in Urban Environments Using RTK,' Autonomous Systems Journal, 2022.

[6] **International Telecommunication Union (ITU)**, 'ITU-R M.2083-0: Framework and Overall Objectives of the Future Development of IMT for 2020 and Beyond,' 2021.

[7] **General Data Protection Regulation** (GDPR), 2018.

[8] **5GAA**, 'Vehicle-to-Network-to-Everything (V2N2X) Communications: Architecture, Solution Blueprint, and Use Case Implementation Examples', June 2024, https://5gaa.org/vehicle-to-network-to-everything-v2n2x-communications-architecture-solution-blueprint-use-cases/

[9] **5GAA**, 'Evaluation of Radio-Based Positioning Enhancements for Automotive Use Cases,' October 2023, https://5gaa.org/5g-automotive-associationxwi-evaluation-of-radio-basedpositioning-enhancements-for-automotive-use-cases/

[10] **5GAA**, C-V2X Use Cases and Service Level Requirements Volume I

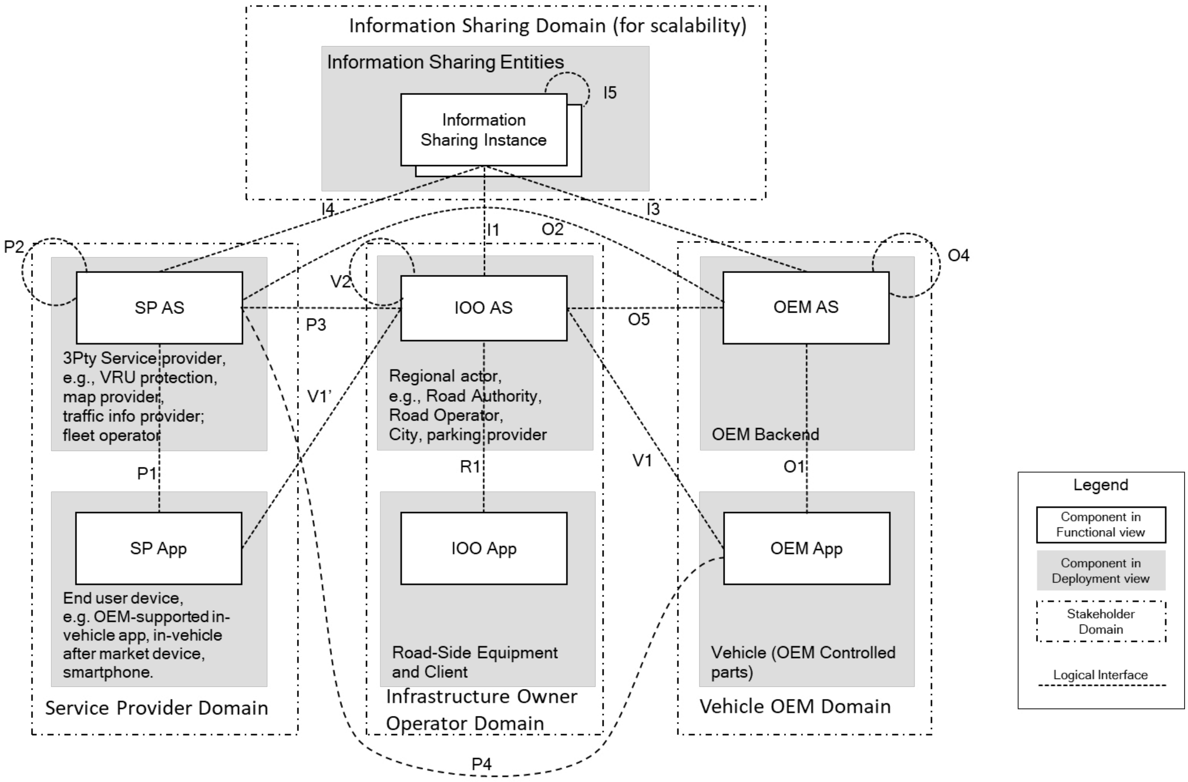
[11] **C-Roads**, Release 2.0 of harmonized C-ITS specifications

Annex A: V2N2X Application Layer Architecture

The application layer reference architecture of V2N2X is shown in Figure 19,[7] and as described by [8]. It includes identified ecosystem stakeholders, their domains and system components, as well as logical interfaces at the application layer that are needed for the End-to-End (E2E) implementation of V2X services using cellular network communications and information sharing. All interfaces are logical interfaces at the application layer. The implementation details of each interface depend on the deployment options, e.g., using Uu or other communication technologies.

The V2N2X application layer reference architecture in Figure 19 can be applied in the implementation of selected V2X services using specific V2N2X deployment option(s) documented in this Technical Report. In some V2N2X implementations, only a subset of the stakeholders, system components, and logical interfaces are needed. The architecture helps in identifying ecosystem stakeholders, functional allocation, as well as interfaces that need harmonized or agreed profiles[8] for interoperability reason.

Details about the V2N2X application layer architecture can be found in the 5GAA V2N2X Technical Report [8]



19. Figure: Application layer reference architecture of V2N2X[9]

[7] The application layer reference architecture is an applied system architecture of the generic V2X architecture to V2N2X.

[8] Depending on the interests of relevant ecosystem stakeholders, harmonized or agreed profiles for the identified interfaces may or may not be standardized in or by Standards Development Organizations (SDOs).

[9] This architecture figure has been developed as part of the 5GAA V2N2X Work Item. When this architecture (Figure 19) is used outside the present Technical Report, a note needs to be added stating that the system architecture shall be used always with reference to the '5GAA V2N2X Technical Report', where system components and interfaces in this architecture are defined for the V2N2X communication solution blueprint.

Annex B: Service Level Requirements

Service Level Requirements (SLR) for different use cases are listed in [1] and positioning indicators for use cases are summarized in [2]. Within the use cases in [1], reliability, latency, and accuracy are applicable to GNSS positioning service performance. Safety-related use cases, in particular, introduce the most stringent requirements for positioning. For instance, the Automated Intersection Crossing use case requires an SLR of 99.999%, latency of 10 ms, and positioning accuracy of 0.15 m (3σ). These SLRs are associated with a set of integrity Key Performance Indicators (KPIs) defined in [3], which collectively inform the computation of an overarching KPI known as 'positioning integrity'.

Positioning integrity is defined in [3] as "a measure of the trust in the accuracy of the position-related data provided by the positioning system and the ability to provide timely and valid warnings to the Location Services client when the positioning system does not fulfil the condition for intended operation".

To fulfill the aforementioned SLRs, it is imperative that a positioning system furnishes a Positioning, Velocity and Timing (PVT) solution characterized by high precision, high reliability, and ubiquitous availability.

5GAA

Automotive Association