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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



DRAFT International Standard

ISO/DIS 6029-2

Intelligent transport systems — Seamless positioning for multimodal transportation in ITS stations —

Part 2: Nomadic and mobile device dataset for positioning data fusion

*Systèmes de transport intelligents — Positionnement homogène
pour le transport multimodal dans les stations ITS —*

*Partie 2: Ensemble de données d'appareils nomades et mobiles
pour la fusion de données de positionnement*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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This document was prepared by Technical Committee ISO/TC 204, *Intelligent Transport Systems (ITS)*, Working Group WG 17, *Nomadic Devices in ITS Systems*.

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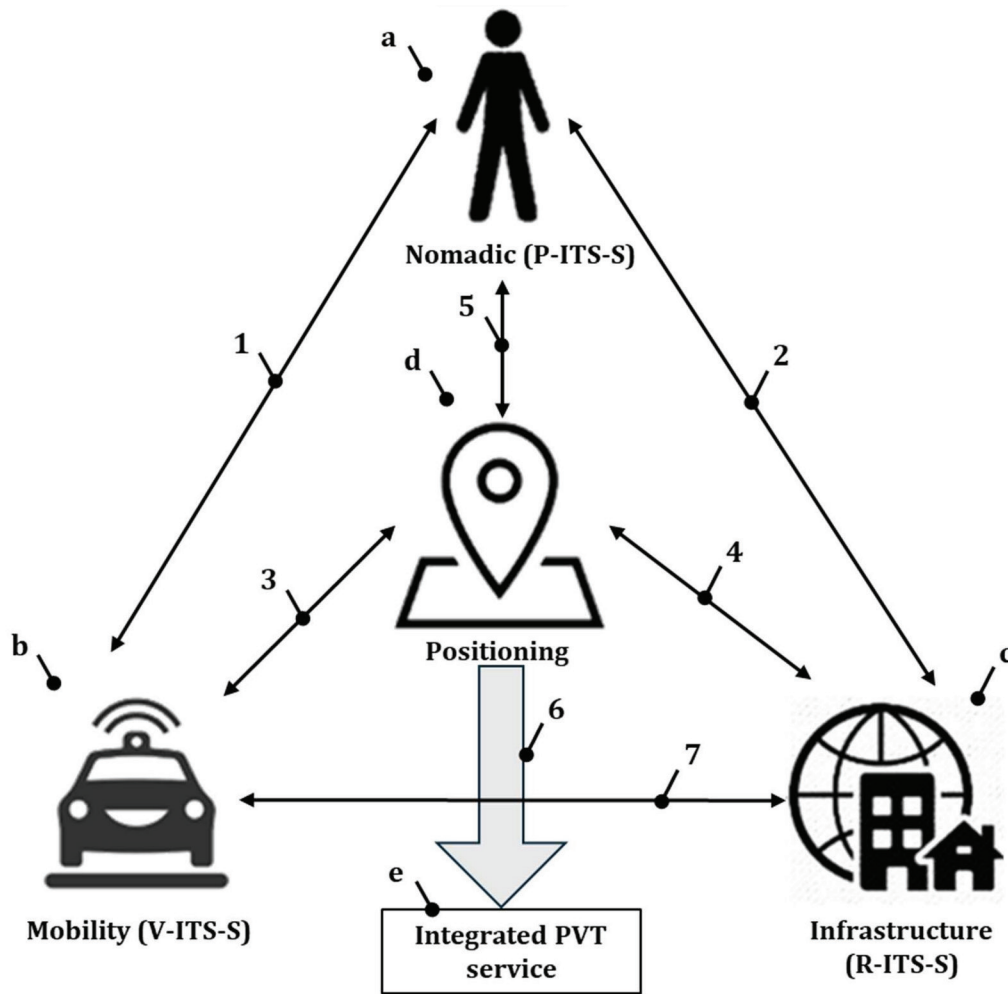
Introduction

As new forms of mobility services (e.g. e-mobility, delivery robot, autonomous driving) are emerging in the industry, the role of the nomadic device is becoming an indispensable part in the Intelligent Transport Systems (ITS) industry. The mobility service platform uses the position data gathered via the nomadic device of the passengers. Current positioning systems are relying on Global Navigation Satellite System (GNSS) technology and the functionality of the system is occasionally constrained by the network interference, GNSS-denied environment, and data loss. A seamless positioning system enables interoperability between ITS domains to provide a seamless location-based service.

The main objective of a seamless positioning system is to support the development of a robust and ubiquitous indoor and outdoor seamless positioning solution for a mobile user (e.g. multimodal transportation) so that anyone can experience mobility services regardless of location, environment and disabilities.

The seamless positioning system consists of three domains: nomadic device (e.g. Personal Intelligent Transport System Station (P-ITS-S)), mobility (e.g. Vehicle Intelligent Transport System Station (V-ITS-S)), and infrastructure (e.g. Roadside Intelligent Transport System Station (R-ITS-S)). The system integrates multiple data from different domains and provides positioning data (e.g. Position, Velocity, Time service implemented in the ITS-S)) in a seamless manner.

[Figure 1](#) shows the seamless positioning system.



Key

- 1 exchange of data between P-ITS-S and mobility containing mobility/personal data and network environment
- 2 exchange of data between P-ITS-S and infrastructure containing personal data and infrastructure information
- 3 exchange of data between mobility end and sensor-fusion positioning application
- 4 exchange of data between infrastructure end and sensor-fusion positioning application
- 5 exchange of data between P-ITS-S and sensor-fusion positioning application
- 6 seamless positioning calculation
- 7 positioning exchange use cases
- a the P-ITS domain is represented by ITS-compliant nomadic devices carried by human beings
- b the V-ITS domain is represented by ITS-compliant vehicles
- c the R-ITS domain is represented by ITS-compliant roadside infrastructure devices
- d positioning domain of all devices in P-ITS, V-ITS, and R-ITS domain
- e outcome is the integrated position, velocity, and time service provision

Figure 1 — Seamless positioning system

ISO 6029 consists of the following parts, under the general title Intelligent transport systems – Seamless positioning for multimodal transportation in ITS stations:

- Part 1 : General information and use case definition
- Part 2 : Nomadic & mobile device dataset for positioning data fusion
- Part 3 : Data fusion dataset exchange interfaces on nomadic devices

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Intelligent transport systems — Seamless positioning for multimodal transportation in ITS stations —

Part 2: Nomadic and mobile device dataset for positioning data fusion

1 Scope

This document specifies the sensor data fusion applicable to the use cases of indoor and outdoor seamless positioning solution for a mobile user (multimodal transportation) in ITS stations.

This document includes all technical requirements for data fusion between three domains, nomadic device (e.g., P-ITS-S), mobility (e.g., V-ITS-S), and infrastructure (e.g., R-ITS-S). The data exchange between the domains is based on a standardized message and data format and this document identifies use cases for each different case of communication between domains.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13185, *Intelligent transport systems (ITS) — Vehicle interface for provisioning and support of ITS Services*

ISO 17438-1, *Intelligent transport systems (ITS) — Indoor navigation for personal and vehicle ITS station — Part 1: General information and use case definition*

ISO 17438-2, *Intelligent transport systems (ITS) — Indoor navigation for personal and vehicle ITS stations — Part 2: Requirements and specification for indoor maps*

ISO 17438-3, *Intelligent transport systems (ITS) — Indoor navigation for personal and vehicle ITS stations — Part 3: Requirements and specification for indoor positioning reference data*

ISO 17438-4, *Intelligent transport systems (ITS) — Indoor navigation for personal and vehicle ITS station — Part 4: Requirements and specifications for interface between personal/vehicle and central ITS stations*

ISO 17438-5, *Intelligent transport system (ITS) — Indoor navigation for personal and vehicle ITS station — Part 5: Requirements and message specification for central ITS station (C-ITS-S) based positioning*

ISO/TS 21176, *Cooperative intelligent transport systems (C-ITS) — Position, velocity and time functionality in the ITS station*

ISO/TS 21184, *Cooperative intelligent transport systems (C-ITS) — Global transport data management (GTDM) framework*

ISO 23150, *Road vehicles — Data communication between sensors and data fusion unit for automated driving functions — Logical interface*

IEC 61162, *Digital interfaces for navigational requirement within a ship*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TS 21177, ISO/TS 21184, ISO/TS 21176, ISO 17438, ISO 23150, IEC 61162, ISO 19116,^[1] SAE J2945/7,^[2] SAE J3224 and the following apply.

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1 positioning system

system of instrumental and computational components to determine position

EXAMPLE inertial, integrated, linear, optical, and satellite are examples of positioning systems.

[SOURCE: ISO 19116:2019, 3.24]

3.2 seamless positioning system

system which supports the continuity of positioning data (3.13) for nomadic device(P-ITS-S) location-based services utilizing multiple positioning technologies

3.3 multimodal transportation

multiple different modes of transport

3.4 infrastructure communication I-COMM

infrastructure (R/C-ITS-S) data exchange

3.5 handler

a routine or function

3.6 infrastructure location profile handler I-LPH

infrastructure location-based positioning data (3.13) profile function

3.7 infrastructure floor profile handler I-FPH

infrastructure triangulation measurement-based positioning data (3.13) profile function

3.8 motion

change in the position of an object over time, represented by change of coordinate values with respect to a particular reference frame

[SOURCE: ISO 19116:2019, 3.18]

3.9 motion positioning station gateway M-PSG

ITS-based positioning device

3.10 motion status profile handler M-SPH

motion detection and status profile function

3.11

personal floor profile handler

P-FPH

P-ITS-S-based altitude positioning data profile function

3.12

personal location profile handler

P-LPH

P-ITS-S-based positioning data profile function

3.13

personal status profile handler

P-SPH

P-ITS-S-based motion activity profile function

3.14

positioning data

POS

moving object position data

3.15

positioning accuracy profile handler

POS-APH

positioning data precision profile function

3.16

positioning fusion profile handler

POS-FPH

positioning data fusion profile function

3.17

positioning status profile handler

POS-SPH

positioning data status profile function

3.18

positioning velocity profile handler

POS-MPH

positioning data-based velocity profile function

3.19

requirement level

specifies the mandatory or optional status of domain data and sensor data based on the availability of sensor data

3.20

mandatory

data that is always required for the system operation

3.21

optional

data that is permitted but not required for system operation

3.22

domain requirement level

DRL

requirement level specified at the domain level

3.23

sensor requirement level

requirement level specified at the sensor level

3.24**sensor data format**

the data transmitting format gathered from sensors of each domain

3.25**common dataset**

a dataset for sensor data fusion within the positioning domain

3.26**sensor data fusion**

the process of computing positioning output by integrating sensor data, either from the same domain or different domains, after converting the sensor data to a common message format

Note 1 to entry: This integration process involves combining data from various sensors to enhance the accuracy and reliability of positioning information. The common message format facilitates seamless integration by providing a standardized format for representing sensor data, allowing for efficient processing and analysis.

3.27**vehicle-mounted device**

a device physically attached to or installed on a vehicle, designed primarily to enhance or assist the vehicle's internal operations, without necessarily being integrated into an Intelligent Transport System (ITS) or adhering to ITS-S standards.

4 Symbols and abbreviated terms**4.1 Symbols**

— empty table cell or feature undefined

4.2 Abbreviated terms

AES	advanced encryption standard
API	application programming interfaces
ASCII	american standard code for information interchange
ASN.1	abstract syntax notation one
AT	autonomous tech
BLE	bluetooth low energy
CAN	controller area network
CCPA	California Consumer Privacy Act
CEP	circular error probable
CSV	comma separated values format
DRL	domain requirement level
GNSS	global navigation satellite system
GDPR	General Data Protection Regulation
GPS	global positioning system

GSM	global system for mobile communications
GTDM	global transport data management
GW	gateway
HMAC	hash-based message authentication code
HIPAA	Health Insurance Portability and Accountability Act
HTTP	hypertext transfer protocol
I-COMM	infrastructure communication
I-FPH	infrastructure floor profile handler
IMU	inertial measurement unit
I-LPH	infrastructure location profile handler
IP	internet protocol
ITS	intelligent transport system
JSON	JavaScript object notation
KPI	key performance indicator
LaaS	logistics as a service
LRS	long-range sensor
LTE	long-term evolution
M-PSG	motion positioning station gateway
MQTT	message queuing telemetry transport
M-SPH	motion status profile handler
MaaS	mobility as a service
ND	nomadic device
NMEA	national marine electronics association
OAuth	open authorization
P-FPH	personal floor profile handler
PII	personally identifiable information
P-ITS-S	personal intelligent transport system station
P-LPH	personal location profile handler
P-RI	personal registration information
P-SPH	personal status profile handler
POS	positioning data

POS-APH	positioning accuracy profile handler
POS-FPH	positioning fusion profile handler
POS-SPH	positioning status profile handler
POS-MPH	positioning velocity profile handler
PVT	position, velocity, time
RBAC	role-based access control
RF	radio-frequency
RFID	radio-frequency identification
R-ITS-S	roadside intelligent transport system station
RL	requirement level
RMSE	root mean square error
RSA	Rivest–Shamir–Adleman asymmetric cryptography
RSSI	received signal strength indicator
S-SVC	sensor service
S-DEV	sensor device
SRL	sensor requirement level
SRS	short-range sensor
TaaS	transportation as a service
TCP	transport control protocol
UDP	user datagram protocol
UMTS	universal mobile telecommunications system
UUID	universal unique identifier
UVIP	unified vehicle interface protocol
UWB	ultra-wide band
V-ITS-S	vehicle intelligent transport system station
Wi-Fi	wireless fidelity
XML	extensible markup language

5 Seamless positioning system overview

5.1 General

5.1.1 Objective

The objective of the seamless positioning system is based on:

- extensibility, e.g. artificial intelligence, block-chain, and sensor fusion technology;
- simplification, e.g. standardized message format based on ISO/TS 21184 (GTDM) and IEC 61162 (NMEA);
- reliability, e.g. system reliability, data precision, fast first to fix, dilution correction factors;
- application, e.g. the ISO 17438 series, autonomous driving features, location-based service, safety-related industry.

5.1.2 Standard references and scope of application

This document serves as a comprehensive guide for continuous positioning systems between indoor and outdoor environments, defining datasets by sensor type and data exchange sequences by sensor fusion type. Sensor modules are categorized by data type, with corresponding data exchange processes defined by use cases.

This document particularly focuses on the moment when a nomadic device moves between areas with and without satellite signals, with all processes initiated based on GNSS availability information.

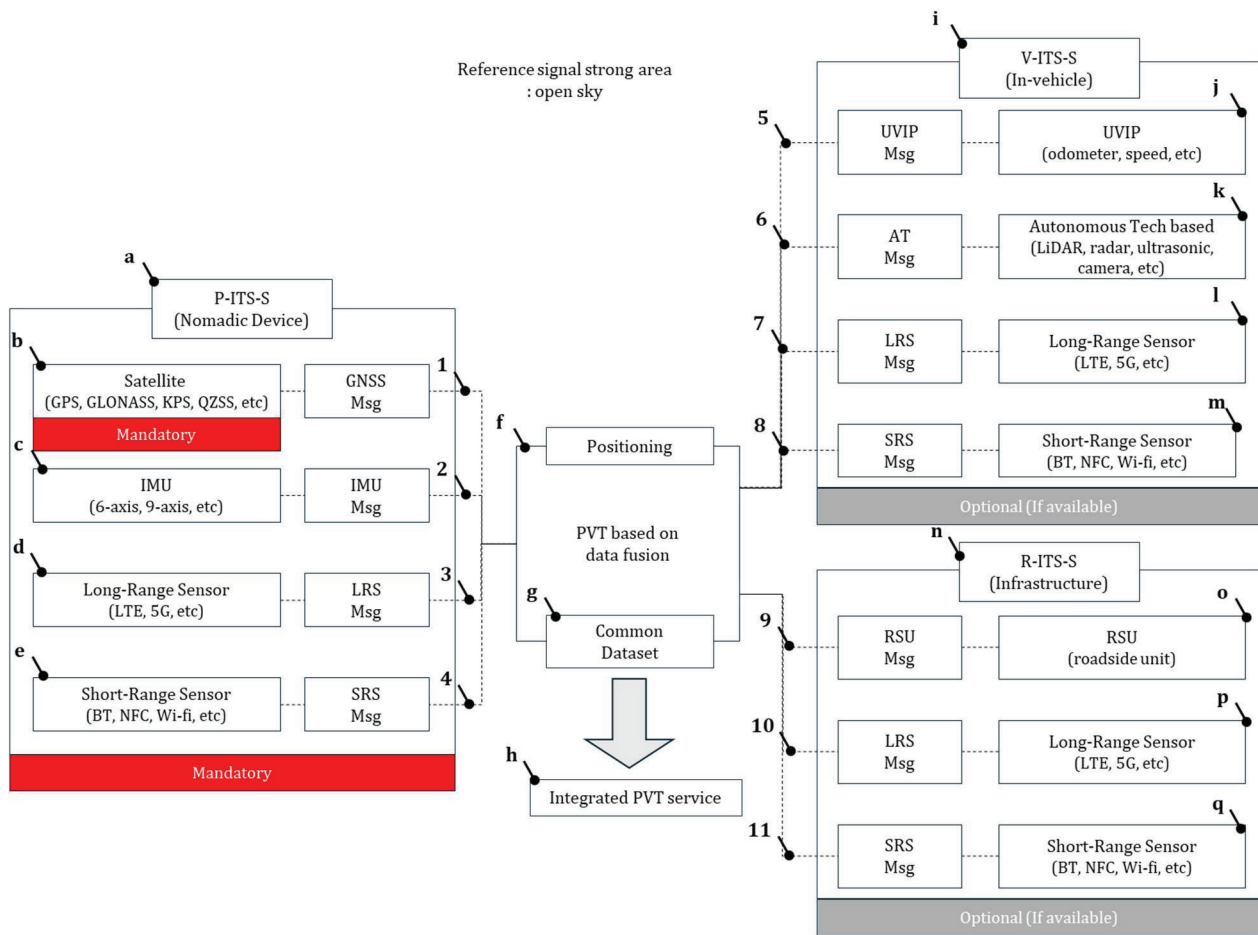
5.1.3 Compliance requirements

This document encompasses most technical requirements for sensor fusion among nomadic devices, mobility-related data, and infrastructure-related data. It is developed to optimize continuous positioning systems between indoor and outdoor environments while minimizing additional processing.

This document provides guidelines for seamless integration of sensor data from various domains, ensuring precise and reliable positioning under diverse environmental conditions.

5.1.4 Positioning scenario

[Figure 2](#) illustrates a positioning scenario in an open space with GNSS satellite signals. It shows the data fusion of satellite data as the primary source for positioning, with other sensor data utilized for sensor fusion to enhance the accuracy and reliability of location data. The determination of positioning reference points for sensor data fusion is based on attenuation information of sensor signals as specified in ISO/TS 21176 (PVT).



Key

- 1 satellite sensor data flows from P-ITS-S to support positioning through data fusion
- 2 IMU sensor data flows from P-ITS-S to support positioning through data fusion
- 3 long-range sensor data flows from P-ITS-S to support positioning through data fusion
- 4 short-range sensor data flows from P-ITS-S to support positioning through data fusion
- 5 unified vehicle interface protocol based data flows from V-ITS-S to support positioning through data fusion
- 6 autonomous technology-enabled sensor data flows from V-ITS-S to support positioning through data fusion
- 7 long-range sensor data flows from V-ITS-S to support positioning through data fusion
- 8 short-range sensor data flows from V-ITS-S to support positioning through data fusion
- 9 roadside unit data flows from R-ITS-S to support positioning through data fusion
- 10 long-range sensor data flows from R-ITS-S to support positioning through data fusion
- 11 short-range sensor data flows from R-ITS-S to support positioning through data fusion
- a P-ITS-S domain
- b satellite-based sensor components
- c IMU sensor components
- d long-range sensor components
- e short-range sensor components
- f positioning through data fusion
- g data fusion common dataset
- h integrated PVT output for the service
- i V-ITS-S domain
- j unified vehicle interfaces protocol related components
- k autonomous technology-enabled sensor related components

- l long-range sensor components
- m short-range sensor components
- n R-ITS-S domain
- o roadside unit components
- p long-range sensor components
- q short-range sensor components

Figure 2 — Positioning scenario common dataset conversion and PVT output based on sensor data fusion

5.2 Positioning system components

5.2.1 Global navigation satellite systems (GNSS)

Global navigation satellite systems support [Source : ITU-R M.1787-4(01/2022)]

- GPS (Global Positioning System);
- GLONASS (Global Navigation Satellite System);
- Galileo;
- BeiDou;
- other regional navigation systems (i.e., KPS, QZSS, IRNSS)

5.2.2 Inertial measurement units (IMU)

Inertial measurement units contain:

- gyroscopes;
- accelerometers;
- magnetometers;
- wireless communication technologies.

5.2.3 Short-range sensor (SRS)

Short range sensors are:

- radio frequency identification (RFID);
- bluetooth (BT);
- ultrasonic; and
- infrared radar.

5.2.4 Long-range sensor (LRS)

Long range sensors are based on mobile cellular system for networks based on the Global System for Mobile Communications (GSM) standard:

- 3G: third generation mobile network: Universal Mobile Telecommunications System (UMTS);
- 4G: fourth generation mobile network: Long-Term Evolution (LTE);

- 5G fifth generation mobile network: New Radio (NR).
- radar
- long-range LiDAR.

5.2.5 Infrastructure components

Infrastructure components are:

- roadside units (RSUs);
- base stations;
- data centers;

5.2.6 Nomadic devices

- smartphones;
- wearable devices;
- vehicle-mounted devices;

5.2.7 Integration and fusion units

- sensor fusion algorithms;
- data processing units;
- positioning calculation engines.

5.2.8 Data transmission and networking

- communication protocols (CAN, ethernet, UDP);
- network architectures (client-server, peer-to-peer);
- cloud computing platforms.

5.2.9 User interfaces and applications

- **mapping and navigation apps;**
- **location-based services;**
- **fleet management systems:** fleet management systems are comprehensive software and hardware systems primarily designed to manage and monitor extensive vehicle fleets. These systems offer functionalities such as vehicle location tracking, driver behavior analysis, maintenance scheduling, and trip logging to enhance the efficiency of vehicle operation and management. Fleet management systems are generally designed to optimize vehicle efficiency and reduce operational costs.
- **nomadic device:** a portable location-tracking and communication device, can enhance interaction with fleet management systems. By receiving real-time vehicle location and driving data through Nomadic Device and transmitting this information to fleet management systems, better insights into vehicle operation and management can be obtained. This can lead to improved efficiency in vehicle operations and optimization of maintenance schedules, among other benefits.

5.3 Multimodal transportation concepts

This subclause delves into the multifaceted realm of multimodal transportation, which encompasses the integration of various modes of transportation for efficient and sustainable mobility. It aims to provide a comprehensive understanding of the following key aspects:

- **concept and benefits of multimodal transportation:** Multimodal transportation is defined and its benefits elucidated. It entails seamlessly combining multiple modes of transportation to achieve efficient mobility, alleviate traffic congestion, and reduce environmental impact.
- **key characteristics of multimodal transportation:** The distinctive features of multimodal transportation are outlined, including multimodal routes and connectivity, compatibility of infrastructure and facilities, and integration of payment and fare systems.
- **implementation examples of multimodal transportation:** Real-world cases of multimodal transportation systems are presented, showcasing how diverse modes of transportation are integrated to facilitate efficient mobility. Examples may include public transit, bike-sharing systems, and ride-sharing services.
- **technological aspects of multimodal transportation:** The technological and information systems employed in multimodal transportation systems are discussed. This may encompass location tracking technologies, big data analytics, and IoT technologies.
- **policies and regulations for multimodal transportation:** Government policies and regulations aimed at supporting and advancing multimodal transportation are examined. This may include transportation policies, traffic regulations, and support policies.

By encompassing these aspects, the subclause aims to provide a comprehensive overview of multimodal transportation systems and their role in facilitating efficient and sustainable mobility.

5.4 Seamless positioning system architecture

The seamless positioning system architecture describes the structure and interaction of navigation and positioning systems. This architecture is composed of the following key components:

- **nomadic device (P-ITS-S):** P-ITS-S is a portable intelligent transportation system device used by human beings or inside vehicles. This device collects location and motion data through various sensors, along with GNSS and other positioning technologies. It tracks the human being's (user's) location in real-time and communicates with other domains to acquire and process location data.
- **mobility (V-ITS-S):** V-ITS-S is an intelligent transportation system device installed within vehicles. It primarily collects location data of the vehicle and tracks the vehicle's motion and driving status. Additionally, this device communicates with other vehicles and infrastructure to acquire different location data, which is then shared with P-ITS-S.
- **infrastructure (R-ITS-S):** R-ITS-S is an intelligent transportation system device installed in road infrastructure. It mainly collects location data in the road environment and monitors the conditions of the road and its surroundings. This device communicates with P-ITS-S and V-ITS-S to share road conditions and location data, managing traffic flow.
- **seamless positioning data fusion:** seamless positioning data fusion is the process of integrating location and motion data collected from each domain. This process combines various positioning technologies and sensor data to continuously track the user's location and provide accurate positioning information in real-time.
- **communication infrastructure:** the communication infrastructure is a vital element that supports data exchange between P-ITS-S, V-ITS-S, and R-ITS-S. This infrastructure securely transmits data using various communication protocols and efficiently exchanges location and motion data. These components interact with each other to continuously track the user's location indoors and outdoors, forming a flexible and efficient system that provides positioning information. [Figure 2](#) and [Figure 3](#) visually illustrate the interaction of these components.

[Figure 3](#) illustrates the movement of P-ITS-S from an outdoor environment, where GNSS data is available to an indoor facility and underground area, where GNSS signal is weak or unavailable. In the outdoor environment (A), satellite data such as GNSS, gathered through P-ITS-S, becomes mandatory for positioning.

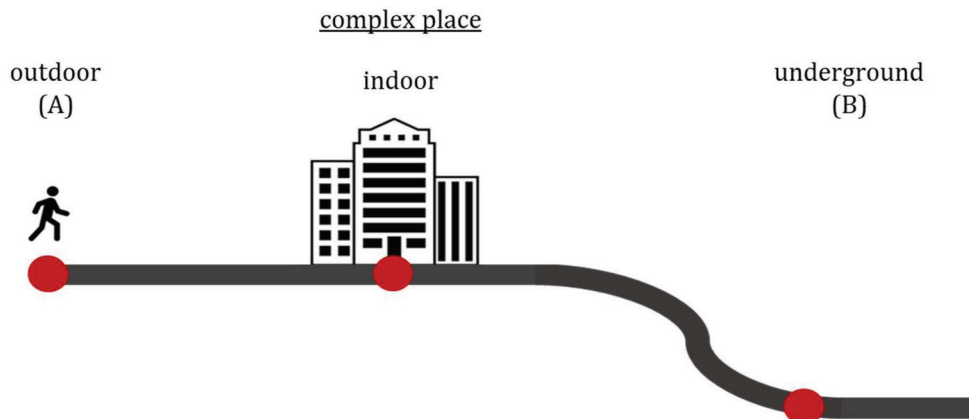
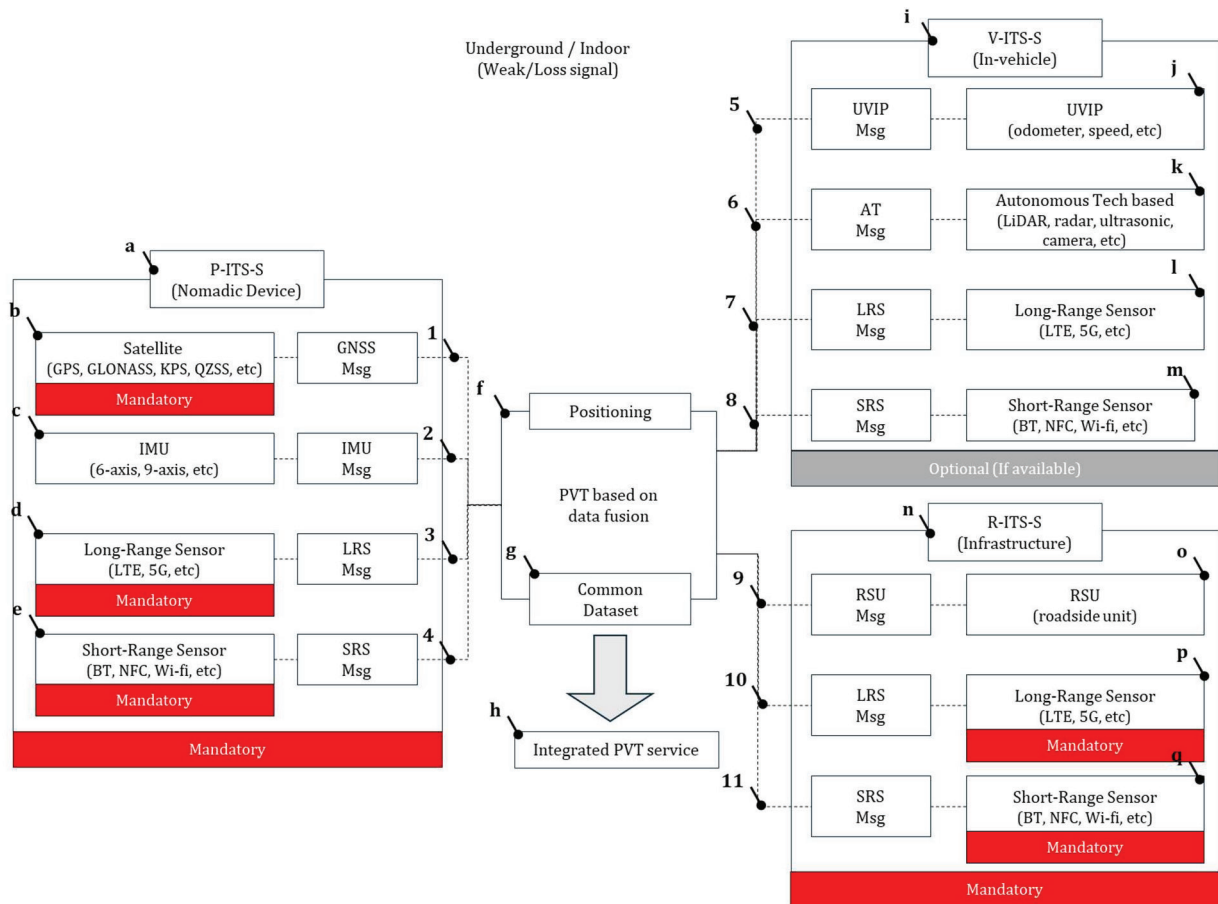


Figure 3 — Transition of P-ITS-S from outdoor (A) to underground (B) through indoor environment

The indoor and underground environments (B), where GNSS data is not accessible, Short-Range Sensor (SRS) and Long-Range Sensor (LRS) from the R-ITS-S domain are utilized for sensor data fusion to determine positioning. In this scenario, any available data from R-ITS-S is considered mandatory as P-ITS-S moves into indoor and underground environments. Communication between the SRS of P-ITS-S and R-ITS-S facilitates the exchange of sensor data, while LRS in this case a cellular network serve as a means of data transmission between domains.

[Figure 4](#) demonstrates the Position, Velocity, Time (PVT) output, as specified in ISO/TS 21176, while in the underground environment by converting sensor data into a common dataset and computing PVT through sensor data fusion.



Key

- satellite sensor data flows from P-ITS-S to support positioning through data fusion
 - IMU sensor data flows from P-ITS-S to support positioning through data fusion
 - long-range sensor data flows from P-ITS-S to support positioning through data fusion
 - short-range sensor data flows from P-ITS-S to support positioning through data fusion
 - unified vehicle interface protocol based data flows from V-ITS-S to support positioning through data fusion
 - autonomous technology-enabled sensor data flows from V-ITS-S to support positioning through data fusion
 - long-range sensor data flows from V-ITS-S to support positioning through data fusion
 - short-range sensor data flows from V-ITS-S to support positioning through data fusion
 - roadside unit data flows from R-ITS-S to support positioning through data fusion
 - long-range sensor data flows from R-ITS-S to support positioning through data fusion
 - short-range sensor data flows from R-ITS-S to support positioning through data fusion
- a** P-ITS-S domain
- b** satellite-based sensor components
- c** IMU sensor components
- d** long-range sensor components
- e** short-range sensor components
- f** positioning through data fusion
- g** data fusion common dataset
- h** integrated PVT output for the service
- i** V-ITS-S domain
- j** unified vehicle interfaces protocol related components
- k** autonomous technology-enabled sensor related components
- l** long-range sensor components

- m short-range sensor components
- n R-ITS-S domain
- o roadside unit components
- p long-range sensor components
- q short-range sensor components

Figure 4 — Common dataset conversion & PVT output through sensor data fusion

5.5 System reliability and security

5.5.1 Data exchange protocols

This subclause delves into the technical aspects of data exchange protocols, which serve as the backbone for secure and efficient communication between system components. The following elements are emphasized:

- **Protocol standards:** the data exchange protocols adhere to internationally recognized standards such as ISO 23150, ISO/TS 21184, ISO 13185, SAE J2945/7, and ISO 17438 to ensure interoperability and compatibility across different systems.
- **Message format:** standardized message formats, such as XML or JSON, are employed to structure data exchanged between system components. These formats facilitate seamless parsing and interpretation of data, ensuring uniformity and consistency in communication.
- **Encryption and authentication:** data transmitted between system components is encrypted using robust cryptographic algorithms (e.g., encryption standard (AES), Rivest–Shamir–Adleman asymmetric cryptography (RSA)) to prevent unauthorized access and ensure data confidentiality. Additionally, authentication mechanisms (e.g., hash-based message authentication code (HMAC), digital signatures) are employed to verify the integrity and authenticity of exchanged data.
- **Error handling:** error handling is categorized into rational and robust error handling, depending on the error type and context. Rational Error Handling focuses on the logical and efficient classification of errors based on predefined, context-specific criteria (e.g., GPS signals indoors). It aims to identify errors through clear and reasonable standards, enabling straightforward resolution with minimal resource use. This approach emphasizes simplicity by utilizing appropriate codes and basic recovery procedures. Robust Error Handling ensures system resilience and reliability by addressing complex errors through advanced mechanisms (e.g., weak or distorted GPS signals). Integrated into data exchange protocols, it employs sophisticated detection codes, retry mechanisms, and comprehensive recovery procedures to maintain system functionality even in the presence of errors. This approach prioritizes maintaining operational integrity and minimizing the impact of failures.
- **Scalability and performance:** the data exchange protocols are designed to accommodate varying data loads and system scalability requirements. Efficient data compression techniques, optimized message routing algorithms, and scalable infrastructure configurations are employed to enhance system performance and responsiveness.
- **Interoperability and compatibility:** special emphasis is placed on ensuring interoperability and compatibility between different system components, regardless of their underlying technologies or implementations. Compatibility testing and conformance validation procedures are conducted to guarantee seamless integration and communication across heterogeneous systems.
- **Continuous improvement:** the data exchange protocols undergo continuous evaluation and improvement to adapt to evolving technological landscapes and emerging requirements. Feedback from system users and stakeholders is solicited to identify areas for enhancement and optimization, ensuring the long-term viability and effectiveness of the communication infrastructure.

5.5.2 Communication infrastructure configuration

The communication infrastructure configuration encompasses the setup and arrangement of communication channels and technologies to facilitate seamless data exchange among the system components. This subclause outlines the key aspects and requirements related to configuring the communication infrastructure for optimal performance and reliability.

- **Technological components:** the communication infrastructure comprises various technological components, including networking hardware, protocols, and software systems. These components work together to establish reliable data transmission pathways between the Nomadic Device (P-ITS-S), Mobility (V-ITS-S), and Infrastructure (R-ITS-S) components.
- **Network architecture:** the network architecture defines the layout and structure of the communication network, including the arrangement of network nodes, topology, and protocols used for data transmission. It ensures efficient data routing and connectivity among the system components while accommodating scalability and fault tolerance.
- **Data transmission protocols:** data transmission protocols govern the format, structure, and rules for exchanging data packets between the system components. Commonly used protocols such as transport control protocol/internet protocol (TCP/IP), message queuing telemetry transport (MQTT), and hypertext transfer protocol (HTTP) are employed to ensure reliable and secure data transmission over the network.
- **Security measures:** security measures are implemented to safeguard the communication infrastructure against unauthorized access, data breaches, and cyber threats. Encryption techniques, authentication mechanisms, and access control policies are enforced to protect sensitive data and ensure the integrity and confidentiality of communications.
- **Scalability and performance:** the communication infrastructure is designed to accommodate varying data loads and system scalability requirements. Efficient data compression techniques, optimized message routing algorithms, and scalable infrastructure configurations are employed to enhance system performance and responsiveness.
- **Interoperability and compatibility:** special emphasis is placed on ensuring interoperability and compatibility between different system components, regardless of their underlying technologies or implementations. Compatibility testing and conformance validation procedures are conducted to guarantee seamless integration and communication across heterogeneous systems.
- **Continuous improvement:** the communication infrastructure undergoes continuous evaluation and improvement to adapt to evolving technological landscapes and emerging requirements. Feedback from system users and stakeholders is solicited to identify areas for enhancement and optimization, ensuring the long-term viability and effectiveness of the communication infrastructure.

5.5.3 Rational error handling and security measures

This subclause addresses the logical classification and efficient resolution of errors through predefined criteria, minimal resource use, appropriate codes, and simple recovery procedures. The key characteristics include:

- **Error detection and analysis:** errors occurring during communication are identified, and their causes are analyzed for immediate resolution. Appropriate error codes are assigned and logged based on the type of error encountered.
- **Retry mechanisms:** in case of communication errors, the system automatically attempts retries to resolve the errors efficiently. This ensures effective error handling and continuity of service.
- **Error recovery procedures:** when errors occur, the system executes appropriate recovery procedures to restore it to a normal state. This minimizes data loss, ensuring the reliability of the system and the overall service.

- **Error reporting and monitoring:** information about errors is recorded and reported to administrators for immediate action. The system monitors error frequency and types to identify and address potential issues proactively.
- **User notifications:** the system provides users with notifications about encountered errors, allowing them to take appropriate actions. This improves user experience and service reliability.

5.5.4 Robust error handling and security measures

This subclause addresses the management of complex errors to ensure system resilience and reliability through advanced detection codes, retry mechanisms, and comprehensive recovery procedures, often integrated into data exchange protocols. The following are the key characteristics:

- **Error detection and analysis:** identifying and analyzing errors that occur during communication to promptly address them. Appropriate error codes are assigned and logged based on the type of error encountered
- **Retry mechanisms:** automatically attempting retries when communication errors occur to resolve them efficiently. This helps in handling errors and maintaining service continuity effectively.
- **Error recovery procedures:** executing appropriate error recovery procedures to restore the system to a normal state when errors occur. This minimizes data loss and ensures the reliability of the system.
- **Error reporting and monitoring:** recording and reporting information about errors to administrators for immediate action. The system monitors error frequency and types to identify and address potential issues.
- **User notifications:** providing users with notifications about encountered errors to raise awareness and enable them to take appropriate actions. This enhances user experience and improves the reliability of the service.

6 Data fusion for seamless positioning

6.1 Sensor data specification

6.1.1 Data specification by sensor type

Sensor data specifications encompass the technical details and format of data collected by various sensors integrated within the positioning system. These specifications are fundamental for ensuring seamless integration, compatibility, and accuracy in data processing and fusion. The following key aspects are addressed in sensor data specifications:

- **Sensor types:** classify and identify the types of sensors utilized in the positioning system, including GNSS receivers, accelerometers, gyroscopes, magnetometers, and environmental sensors.
- **Data format:** define the format of sensor data, including its structure, encoding, and representation. Common formats may include binary, american standard code for information interchange (ASCII), JavaScript object notation (JSON), extensible markup language (XML), or proprietary formats developed by sensor manufacturers.
- **Data size and length:** specify the size and length of sensor data packets or frames, determining the volume of information transmitted with each sensor reading. This includes the number of bytes or bits allocated for representing individual data elements.
- **Data resolution:** describe the level of precision or detail in sensor measurements, typically quantified in terms of bits or decimal places. Higher resolution allows for more accurate representation of sensor readings but may necessitate increased bandwidth or processing resources.
- **Data rate:** define the sampling frequency at which sensor data is acquired and transmitted, typically measured in samples per second (Hz) or milliseconds (ms). The data rate impacts the temporal resolution of sensor data and influences system performance and power consumption.

- **Coordinate system:** specify the coordinate system utilized to express spatial data captured by sensors, such as latitude and longitude for GNSS data or XYZ coordinates for accelerometer and gyroscope readings.
- **Calibration parameters:** include calibration coefficients or parameters utilized to mitigate sensor errors and biases, ensuring the precision and reliability of sensor data. Calibration factors may encompass sensor drift, temperature effects, and environmental influences.
- **Timestamping:** detail the methodology for timestamping sensor data to denote the time of measurement. Timestamps are crucial for synchronizing data from multiple sensors and correlating sensor readings with other system events or data sources.

By furnishing comprehensive sensor data specifications, the positioning system can collect, integrate, and process sensor data to facilitate seamless positioning and navigation functionalities.

[Table 1](#) shows the example of data specification by sensor type.

Table 1 — Example data specification by sensor type

Sensor type	Data type	Data resolution	Data rate (Hz)	Coordinate system	Calibration parameters	Time stamp
Accelerometer	Float/Integer	e.g., 0,01 g	e.g., 100	e.g., WGS84	Yes	Yes
Gyroscope	Float/Integer	e.g., 0,01°/s	e.g., 100	WGS84	Yes	Yes
Magnetometer	Float/Integer	e.g., 1 μ T	e.g., 100	WGS84	Yes	Yes
GNSS	Float	e.g., 1 m	e.g., 1	WGS84	Yes	Yes
Wi-Fi	String/Integer	e.g., 00-B0-D0-63-C2-26	Variable	Local	No	Yes
LRS	String/Integer	e.g., 10 m	e.g.,	WGS84/Local	Yes	Yes
SRS	String/Integer	e.g., 1 m	e.g.,	WGS84/Local	Yes	Yes
Odometer	Integer	e.g., 0,1 m	e.g., 10	vehicle reference	Yes	Yes

6.1.2 Sensor data types and characteristics

Sensor types and their respective data characteristics play a vital role in understanding the nature of the data collected by each sensor within the positioning system. This subclause includes a description of the data types and ranges measured by each sensor:

a) Global navigation satellite system (GNSS)

- data type: GNSS receivers collect positioning and timing data, including latitude, longitude, altitude, and time.
- range: GNSS data covers a wide range of geographic locations globally, providing precise positioning information.

b) Inertial measurement unit (IMU)

- data type: IMUs measure acceleration, angular velocity, and sometimes magnetic field strength.
- range: acceleration data typically ranges from ± 2 to ± 16 g, angular velocity from ± 250 to $\pm 2\,000^\circ/\text{s}$, and magnetic field strength from several microteslas to several teslas.