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Intelligent transport systems — Mobility integration — Role and functional model for mobility services using low Earth orbit (LEO) satellite systems

Systèmes de transport intelligents — Intégration de la mobilité — Rôle et modèle fonctionnel des services de mobilité qui utilisent les systèmes de satellites en orbite terrestre basse (LEO)

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Foreword

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This document was prepared by Technical Committee ISO/TC 204, *Intelligent transport systems*.

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Introduction

Recent implementations of low Earth orbit (LEO) satellite communication systems (e.g. OneWeb,[13] Starlink[19]) offer advantages in terms of large coverage area, large capacity, multi-modal mobility access, low latency and resilience compared to other available communication service systems. These characteristics of LEO offer benefits when used for smart city or community mobility integration services. This document describes a role and functional model of LEO in the context of use cases for intelligent transport systems (ITS).

This document can contribute to the development of mobility service standards using LEO satellite system business cases.

Background information on LEO is provided in the Bibliography.

Intelligent transport systems — Mobility integration — Role and functional model for mobility services using low Earth orbit (LEO) satellite systems

1 Scope

This document describes a basic role and functional model for mobility services using low Earth orbit (LEO) satellite systems for ITS services. This document provides:

a) a role and functional model using a LEO satellite system for mobility services;

b) a description of the concept of operations (CONOPS), and the relevant role models;

c) a conceptual architecture between actors involved;

d) references for the key documents on which the architecture is based;

e) a mobility service use case summary.

In-vehicle control systems are not within the scope of this document.

This document scope is limited to mobility services using physical and digital infrastructure.

NOTE Physical infrastructure facilities include for example, battery charging facilities, dynamic charging facilities for battery electric vehicles, physical infrastructure markings, physical traffic regulation signs, mobility monitoring facilities, emergency response service support facilities, traffic operation control centre facilities, fee collection service facilities (e.g. road usage fee), battery electric vehicle charging facilities, online reservation and online mobility usage fee payment facilities, and other infrastructure platform facilities that support ITS mobility services.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Abbreviated terms

3D HD	three-dimensional high definition
AI	artificial intelligence
AM	automated mobility
CCTV	close circuit television
CONOPS	concept of operations
DSRC	dedicated short-range communications
EFC	electronic fee collection
EV	electric vehicle
FCV	fuel cell vehicle
LEO	low Earth orbit
QoS	quality of service
WIM	weigh in motion

5 Advantages of low latency in LEO satellite constellation

— LEO (<2 000 km, but often <500 km orbit) satellite constellations promise lower latency than traditional satellite systems because signals need to travel less distance than that required by ordinal geosynchronous orbiting satellites (geosynchronous orbits are 36 000 km altitude).

— It is planned that these constellations will use hundreds (OneWeb) or thousands (Starlink) of satellites with future upgrades to potentially include more than 30 000 satellites.

— Starlink plans to use a laser-based inter-satellite communication path when communicating parties access the network through different satellites. This will take advantage of the superior speed of laser signals in a vacuum, compared to fibre-optic links that are typically used between ground stations.

— LEO satellites connect with ground stations with radio wave paths such as Ka (12 GHz) or Ku (24 GHz) bands as a gateway to the ground network.

— There are plans for direct communication from LEO to handheld nomadic devices using the 5G frequency spectrum. This would eliminate the need for a cellular base station on the ground.

— There is a plan to use the current cellular frequency spectrum for direct connection to mobile phones on the ground.

— Devices on the ground connect to the LEO service through a terrestrial network to the ground station, or directly to the LEO satellite using a constellation-specific satellite antenna.

— Mobility service providers can provide services through LEO satellites in addition to conventional ground communication media, if necessary, as backup.

— A few satellites can provide service to an entire region without creating un-serviced zones; additional satellites can serve an increased user density and expand geographic coverage.

— Compared to terrestrial wired networks, LEO constellations can more readily provide low latency, high capacity to remote and rural locations.

— LEO constellations offer a resilience advantage over other communication techniques which rely on a single point through which all data flows.

6 Disadvantages of using satellites and LEO

There are still unknown factors related to LEO operations that can impact ITS, such as:

— the effects of severe weather on Ku/Ka transmissions;

— life cycle cost impact;

— use of LEO constellations by moving vehicles, i.e. how hard is it for a moving vehicle to track the satellite;

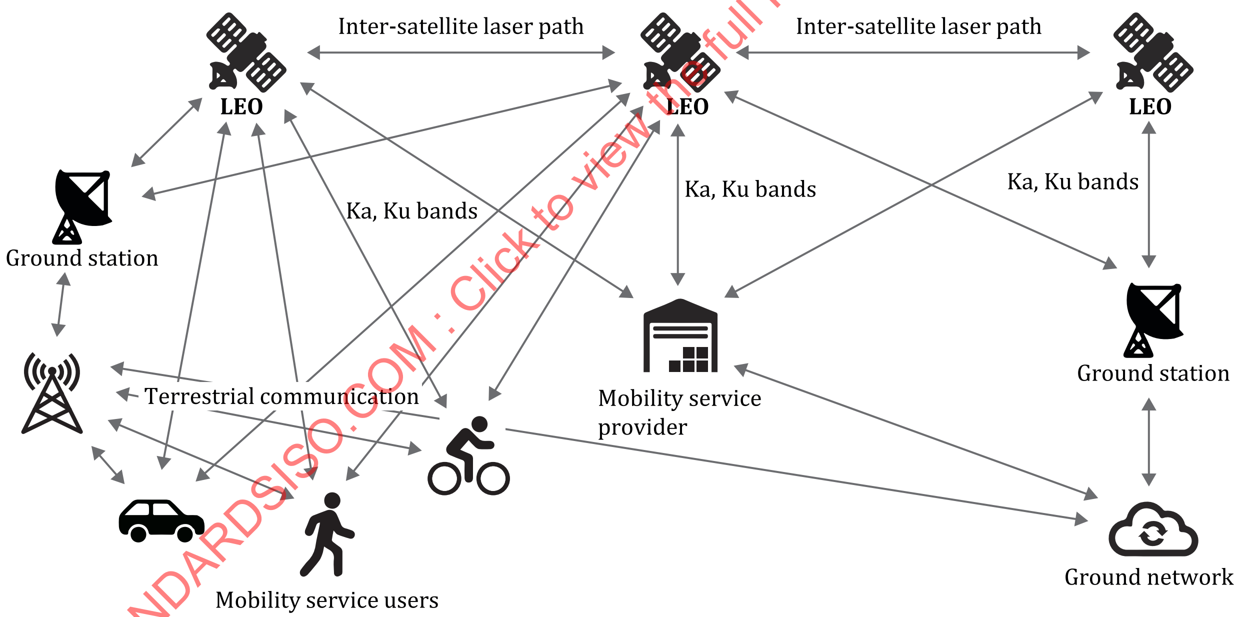
— how large is the antenna, and can it be mounted on a personal device.

7 Private 5G/6G

For ITS V2X use cases, one potential tool for achieving cost effective service in next generation mobility services is private 5G/6G, which could be used in conjunction with LEO. This statement is speculative, and further analysis is needed of how LEO use can potentially be leveraged by projections of cellular evolution. Such speculation includes considering whether LEO is part of 6G or an alternative. Satellite communication can also be complemented by wireless local access networks and DSRC 802.11p/bd in the transport sector.

8 Mobility role model example

Figure 1 shows an example of a mobility service role model for mobility integration. In this example, mobility service users are connected to service providers through satellite(s) or private 5G/6G through ground network/satellite(s).



NOTE Conventional DSRC and private 4G/5G/6G cellular network could potentially be utilized in addition to LEO.

Figure 1 — LEO satellite system use example

9 Definition of service domains suited to utilizing LEO satellite systems

9.1 General

It is possible that LEO satellite systems will support ITS service implementations. However, such scenarios ought to be assessed taking into account physical infrastructure needs. Further, they ought to be predicated on LEO offering improvements in safety or mobility over other communications technologies. While LEO offers broad and flexible coverage, the urban environment is not ideal for LEO systems. First, cities are dense and have many potential users that can saturate satellite communications links. Second, urban canyons and other occlusions can block access to the satellite network. Third, cities are not a suitable target for satellites because cities include users close to one another, who would be better served by terrestrial communications.

Service applications using LEO can include, but are not limited to:

— critical safety information provision (low latency in receiving service is key to implementation);

— safety driving support (low latency in receiving service is key to implementation);

— infrastructure planning (latency is not important);

— dynamic traffic management (latency is not important);

— traffic rule enforcement (latency is not important);

— dynamic map updates (latency is not important);

— emergency evacuation support (latency is not important);

— curb-side management; service robots (latency is not important).

Where applicable, mobility services already defined by the local authority can be applicable.

Further research or development of digital infrastructure is needed for efficient use of LEO in ITS.

9.2 Referenced target use cases

Mobility service applications rely upon data collected through applications. In many cases, these are large volumes of data. Service quality depends upon the quality and quantity of data held and maintained by the relevant operating entity, e.g. a smart city data manager. Mobility services can be grouped into two categories: services provided by the authority/jurisdiction or road operator; and services provided by public and private service providers. The applications offered and managed by the authority/jurisdiction or road operator can be further classified into four groups:

1) infrastructure operation management;

2) traffic management;

3) road traffic operation management;

4) enforcement.

The applications provided by the service providers can be offered through public or private sectors.

Many of the use cases in this document presume an urban environment. This is not necessarily the best use for LEO. Expected use cases of LEO will potentially focus on transportation safety concerns unique to environments that do not typically have access to terrestrial communications, e.g. locations that are in a remote and rural environment.

The number of emerging mobility service applications for smart city deployment have grown rapidly in recent years. The following list provides examples of such applications:

— avalanche and falling rock warnings;

— disaster information provisioning systems for safer and more timely evacuation activities, emphasizing the widespread dissemination;

— tachograph monitoring over remote areas (such as the long drives road trains take in Australia);

— other services unique to remote and rural environments;

— traffic management applications to ease traffic congestion and maintain safety in urban areas;

— road traffic operation applications to realize efficient and safer use of infrastructure;

— electronic fee collection (EFC) support for urban-ITS traffic management to realize dynamic road pricing.

— weigh in motion (WIM) to ease heavy good transport vehicles;

— dangerous goods/hazardous materials transport management to enforce geo-fencing;

— infrastructure service applications for efficient and automated maintenance works;

— access control in urban areas to enhance vehicle entry to certain areas;

— traffic signal (SPaT-MAP): information provisioning of signal phase and timing and road topology messages for safer and efficient traffic flow in the urban area;

— law enforcement applications for regulated freight vehicles such as overloaded vehicle shut out from certain urban areas;

— remote digital tachograph monitoring to maintain safe freight transport vehicle movement;

— heavy vehicle air quality controls and geo-fencing in certain urban areas;

— emission control of vehicles entering certain urban areas to enforce geo-fencing in certain areas of the smart city;

— autonomous vehicle applications such as monitoring, emergency controls, override command, regulated information provisioning;

— urban/suburban/expressways mobility mode-specific safety information provisioning and traffic monitoring;

— dynamic map management including probe data collection, data aggregation, managing digital twin in the cloud and provisioning of safety information;

— EFC from services such as parking, event admission and car sharing;

— vehicle remote maintenance applications such as over the air software updates;

— freight vehicle management applications supporting efficient and safer transport fleet operations;

— electric vehicle charging applications such as booking, monitoring, fee collections with security management;

— fuel cell vehicle charging applications;

— intelligent parking such as automated valet parking supporting systems;

— car sharing management including booking, matchmaking between user and driver, safety information provisioning;

— public transit information provisioning to users in timely and dynamic real-time basis;

— taxi fleet management applications such as booking, matchmaking between users and drivers, safety information provisioning;

— dynamic map-utilizing service applications for automated driving buses, shuttles and freight vehicles for more efficient and safer operations;

— tourist information/advice provisioning service applications for inbound users;

— bicycle/motor cyclists' ITS service applications such as vulnerable road user safety information provision services;

— curb-side management (service robots).

Major use cases and business cases for smart city mobility service applications (those currently available and future ones) are provided here for information only. Further applications can be expected to be developed in the future depending on how the smart city mobility regulators can implement their initiative with the local government.

9.3 Infrastructure operation management

The use cases that fall into the “infrastructure operation management” category are infrastructure service applications focusing on service vehicle operational efficiency and automated maintenance.

Infrastructure operation management service applications are effective for efficient and automated maintenance works.

In this case, road maintenance services such as a snowplough dispatching and monitoring can become safer and more efficient with proper monitoring and controlling; LEO enables more comprehensive monitoring of such vehicles in remote locations, if it can support moving vehicles.

9.4 Traffic management

The “traffic management” use case can be applied to all vehicles, but especially to freight vehicles and automated vehicles.

For all vehicles, traffic management applications to ease traffic congestion and maintain safety in urban areas can be effective.

For automated vehicles, automated driving vehicle support applications such as monitoring, emergency control, override command and regulated information provisioning can be effective.

EFC support for urban-ITS traffic management can be effective for realizing dynamic road pricing.

The use cases include:

a) traffic management applications to ease traffic congestion and maintain safety in urban areas, in which the smart city ITS traffic centre monitors traffic conditions and controls both signals and road signs to ease traffic congestion;

b) EFC support for smart city ITS traffic management to realize dynamic road pricing, in which the smart city traffic centre controls traffic by changing toll fees dynamically to divert traffic flows to other road networks. In such cases, the traffic centre also provides feedback to the toll operator to adjust toll fees to maintain the quality of service (QoS) of the toll road operations;

c) automated vehicle support applications, to monitor road conditions, assist with emergency control, respond to override command and update regulated information provisioning. Generally, the automated vehicle relies on its own sensor data, but the safety level can be increased with the support from the infrastructure.

9.5 Road traffic management

In the "road traffic management" use case, road traffic operation applications can improve efficiency and make it safer to use the infrastructure by allowing the road authority to control the traffic volume of the road more easily, especially on the expressways.

Road traffic operation management applications can be effective for realizing more efficient and safer use of infrastructure.

Road traffic operation management applications are usually implemented by controlling the volume of vehicles entering the road with ramp metering.

9.6 Enforcement

"Enforcement" is a broad subject which can be divided into two categories: enforcement for all vehicles and enforcement for freight vehicles.

For all vehicles, access control in urban areas to enforce vehicle entry to certain areas can be effective.

For freight vehicles, WIM to enforce heavy goods transport vehicles, dangerous goods/hazardous materials transport management to enforce geo-fencing and law enforcement applications for regulated freight vehicles such as overloaded vehicle shutout from urban area can be effective.

Applications such as remote digital tachograph monitoring to maintain safe freight transport vehicles movement, heavy vehicle air quality controls and geo-fencing in urban areas, and emission control of vehicles entering urban areas to enforce geo-fencing in certain areas of the city can also be effective.

The use cases include:

a) access control in urban areas to manage vehicle entry to certain areas, in which the smart city ITS enforcement controls the traffic volume by controlling the access to the city centre of each vehicle;

b) emission control of vehicles entering urban areas by enforcing geo-fencing in restricted areas of the city, in which the smart city ITS enforcement centre monitors and controls the traffic volume to keep the air clean near the city centre;

c) WIM to manage heavy goods transport vehicles, in which the smart city ITS enforcement agency monitors or detects overloaded vehicles to keep road traffic safe;

d) dangerous goods or hazardous materials transport management to enforce geo-fencing, in which the smart city ITS enforcement agency monitors and controls the vehicles carrying dangerous goods or hazardous cargos and keeps those vehicles from entering the city centre for safety reasons. Furthermore, by monitoring those vehicles, first responders can be despatched in a timely manner to the accident site in case of emergency;

e) law enforcement applications to regulated freight vehicles such as overloaded vehicle shutout from smart city ITS area, in which the smart city ITS enforcement agency monitors or controls the speed, size and load of the vehicle to keep the road traffic safe;

f) remote digital tachograph monitoring to maintain safe freight transport vehicle movement, in which the smart city ITS enforcement agency monitors or controls the commercial vehicle and ensures that the operator of the vehicle complies with the regulations and laws, such as maintaining minimum resting time, to keep the road traffic safe;

g) heavy vehicle air quality controls and geo-fencing in smart city areas, in which the smart city ITS enforcement agency monitors or controls the emission of the monitored heavy vehicle to keep high polluting vehicles out of the city.

9.7 The role of service providers

Service providers are public or private entities.

The following services can be practical and relevant for implementation using LEO constellations for communication. Examples are used to examine the roles of the service providers.

a) Disaster information provisioning systems for safer and more timely evacuation activities: the service provider offers information needed to the vehicle in the case of emergency, as well as instructions for the vehicle to evacuate from the disaster area.

b) Traffic signal (SPaT-MAP), information provision of the signal phase and timing and road topology messages for safer and more efficient traffic flow: the service provider offers traffic signal timing information to the vehicles to help minimize vehicle emissions and encourage safe driving behaviour.

c) Urban/suburban/expressways mobility mode-specific safety information provisioning and traffic monitoring: the service provider offers mobility-specific safety information to each vehicle and monitors vehicle behaviour.

d) Dynamic map management, including probe data collection, data aggregation, remote management of cloud-based digital twins and dissemination of safety information provisioning to vehicles: the service provider collects vehicle probe data, updates the dynamic map at the centre and monitors traffic on the digitally-structured infrastructure platform (also called the “digital twin” or the “twin of real traffic”) so that the service provider can provide targeted safety information to individual vehicles in a timely manner if they are needed.

e) EFC from services such as parking, event admission and car sharing: the service provider monitors the vehicle entering the parking facility, event facility, or a car sharing facility (can be road or kerb side) and collects fees from users of those services.

f) Vehicle remote maintenance applications such as over-the-air software updating: the service provider provides remote maintenance service to the vehicle users by performing software updates when the vehicle is idle.

g) Intelligent parking such as automatic valet parking systems: the service provider provides automated valet parking services by monitoring and informing each vehicle parked inside or nearby an area of the parking facility. Verification of user rights and payment processes are included in the service.

h) Car sharing management, including booking, payment, battery monitoring and maintenance: the service provider provides information required by the car sharing application to the car or ride sharing service entity and to the car share users for booking confirmation, fee collection and issuing receipts.

i) Public transport and freight applications using dynamic maps for efficiency gains: the service provider monitors and informs the automated vehicles (AV) and records the status for passengers and goods for an efficient and safe operation.

j) Freight vehicle management applications supporting efficient and safe fleet operation: the service provider monitors freight vehicles by collecting vehicle probe data and provides safety information to the vehicles. A vehicle owner can monitor and control the routes and monitor the surroundings of the vehicle to maintain efficient pick-up or drop-off schedules and safety for both the driver and the goods.

k) EV charging applications such as charging stall booking, monitoring, fee collection and security: the service provider offers an EV user the availability and status information of the charging facility for timely booking and use.

l) FCV charging applications: the service provider offers an FCV user the availability and status information of the charging facility for timely booking and use.

m) Public transport information provisioning to users in a timely and dynamic real-time basis: the service provider provides timely, real-time public transit information to users for a stress-free use of public transit services.

n) Taxi fleet management applications such as booking, matching between user and driver, and taxi safety information provisioning: the service provider offers the taxi user a service which provides users the information to support a timely booking. This also enables the owner of the taxi fleet to manage the fleet more efficiently. A driver can pick up or drop off users by using the information provided by the matching service, with the service provider ensuring the correct rider is picked up at a mutually identified, accurate location.

P) Automated taxi (robot taxi) fleet management applications such as booking, matching between user and robot.

r) Tourist information or advice provisioning service applications to visitors: the service provider provides inbound tourists with information or advice based on their interests.

s) Bicycle or motorcyclists' ITS service applications such as vulnerable road user safety information dissemination: the service provider provides safety information to the bicycle or motorcycle users in a timely manner, in conjunction with V2X provision of vehicle or infrastructure sensor data.

10 General communication functions

10.1 Overview

Communication services used to provide mobility services include all types of telecommunications, not just LEO-based communications. These communications services connect the various actors considered in the mobility service framework. These actors perform functions within mobility service applications. These functions in turn place various demands on communications services.

10.2 Cyber security in ITS service applications

The communications service provider maintains the cyber security of its network, but this is distinct from the need for application-layer authentication, encryption of personal data and the message integrity checking that is typically performed by the security management entity and reported as appropriate to the relevant application.

In past decades, it was envisioned that mobility services would be provided through dedicated communication media such as DSRC, in which case cyber security would be maintained by a service provider and relevant publicly created/maintained security management entities.

In recent years, commercial enterprise-provided cellular mobile telecommunication networks emerged for use in ITS services. While the applicable use cases, performance and constraints vary from the DSRC case, similar concerns exist regarding cybersecurity, and again the security of the network is maintained by the service provider, using relevant publicly created/maintained security management entities to provide application-layer security.

Evolution in satellite-based communications suggests that low earth orbit satellite systems can potentially be a viable alternative for some ITS communications needs, both those originally envisaged for DSRC and those that can use cellular communications. Application-layer cyber security concerns are the same regardless of media, though securing the communications network remains the service provider’s responsibility. If nothing else, having an alternative with LEO enables more resilience in case of a cyber-attack on one mode of communication.

Regarding cyber security in ITS services, there are set of document created for ITS station security services, connection interfaces, and communication protocols, (ISO 21177, ISO/TS 21184, ISO/TS 21185) which include a method for using ITS security credentials (e.g. IEEE 1609.2 certificates) using Transport Layer security which is relevant across ITS, regardless of the underlying communications mechanism.

Additionally, when designing ITS service cyber security systems, necessary measures need to be satisfied. The vehicle cyber security design engineering standards, ISO/SAE 21434 and UN R155 are good reference sources.

10.3 Moving data between actors

The major capability that LEO offers is low latency without direct access to terrestrial infrastructure.

Satellites at the lower end of LEO also self-terminate well, as their orbit degrades within a few years. Space junk is an environmental pollution problem, and agencies that focus on environmental concerns will potentially be incentivized to use deployment architectures that offer more responsible management of space junk. Different companies are operating and planning at significantly different altitudes, but some decay much faster than others. In terms of space junk, faster decay is best.

Using edge computing will help decrease overload onto central systems. For most safety applications, moving data with low latency is required, though the exact requirements vary depending on the use case (i.e. vehicle kinematic data is generally considered to be needed within 100 ms of its generation). Generally, latencies under 500 ms offer some promise for safety-related data provision.

10.4 Connected vehicle/device environment

10.4.1 General

Since LEO communications systems use less terrestrial hardware than other networks, and since in some cases communications can be accomplished without any terrestrial hardware except that which is used by the sender and receiver, the LEO system can potentially exhibit more resilience than other networks in some scenarios (e.g. natural disaster).

The communication used in ITS services can need low latency, high capacity, multi-device (high density) access depending upon type of services.

10.4.2 Low latency

ITS safety function performance is expected to be measured by considering communications latency created by the entire application system including the steps in various stages (A/D conversion, compression, decompression). Latency in communication links all as crucial factors. Current long term evolution as used in major cellular networks is not favourable for safety applications. For 5G technology, emerging 6G technology, and technologies beyond cellular communication, LEO satellite communication systems can be favourable. Inter-LEO satellite communication using laser communications can significantly benefit some uses cases, as this promises a substantial reduction in in-network communications. The selection of communication media is important when deploying an entire ITS system service, but selection of the media and radio frequency spectrum is out of scope of this document.

10.4.3 Multi-device access capability

In a connected vehicle or device environment, multi-device access capability to communication services is important. Effective use of communication infrastructure resources will enable more applications, and presumably more benefits. Network slicing services provided by communication service providers can play a role in ensuring such resource use.

10.4.4 Network slicing

Different ITS applications have different communications profiles. For instance, when the ITS user device downloads/uploads large amounts of data from network infrastructure, the large data volume will saturate a low bandwidth data pipe. On the other hand, some safety applications would potentially function over commercial networks if the quality of service were sufficiently high and the latency were sufficiently low. Network slicing is a concept by which the communication service provider can subdivide its network into different performance virtual networks, which will potentially be able to support these different requirements. Network slicing technology can be deployed with 5G, but further technical discussion or selection of networking slicing concepts is out of scope of this document.

10.4.5 Carrier aggregation

Carrier aggregation is a concept by which the communication service provider provides a large capacity data pipe by aggregating multiple communications resources. Carrier aggregation is thus related to networking slicing.

10.4.6 Propagation speed difference between wired and wireless environment

As noted, some of the LEO communications providers are planning to deploy inter-satellite communications links using lasers. This has a significant potential impact for communications that need to use more than one satellite, as the communications path in space would replace a path between ground stations. In addition to avoiding two terrestrial-space links, the inter-satellite past will be faster than the inter-ground station links as light propagates at twice the speed in a vacuum compared to in a fibre. Radio wave speed is almost the same in both environments.

10.4.7 Radio frequency spectrum sharing

As the resources of the radio wave frequency spectrum are limited, spectrum sharing is highly recommended and interference mitigation technologies need to be adopted.

11 Role and function model of mobility service framework

11.1 Objective

Some LEO providers sell direct to the consumer (e.g. StarLink) and some sell to telecoms (e.g. OneWeb). Different business models can fit into the role model differently. This clause is not specific to LEO but rather it is a generic description for all modes of telecommunications.

This clause describes a generic role and functional model for the provision of mobility services. It provides the general concept of role and functional model operations. The following subclauses provide a role and functional model definition and an elaboration of the model at a conceptual level.

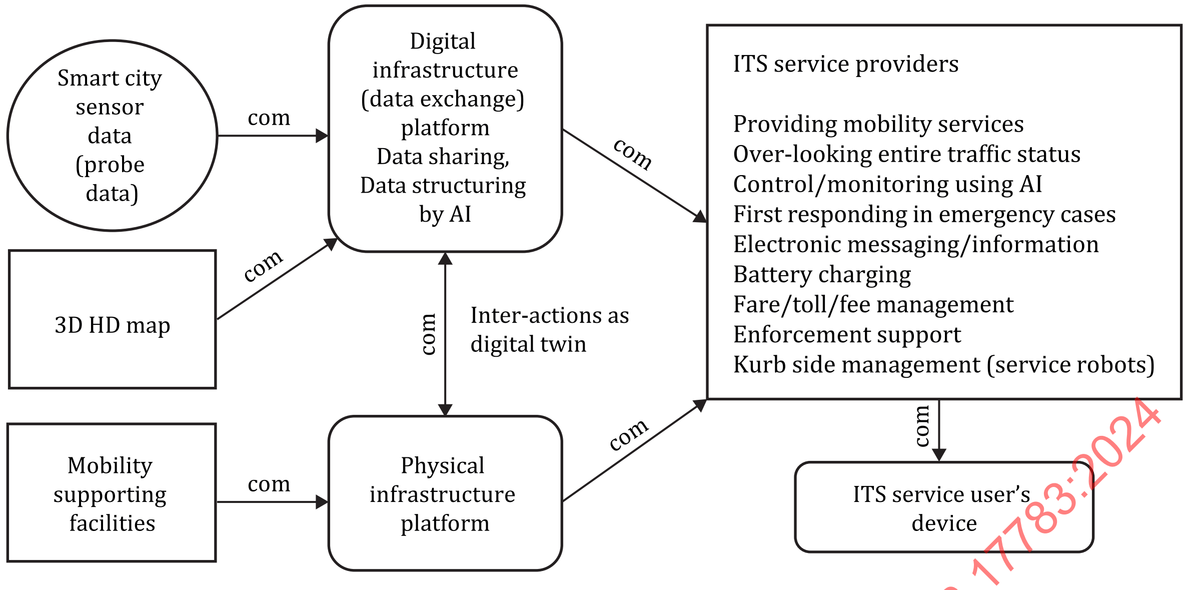
11.2 National variations

The definition of what comprises a mobility service application is as an issue for national decision and can vary from region to region. The instantiation of interoperable onboard platforms (or nomadic devices such as smart phones) for service applications with common features is ideal, but can also vary from region to region. It is possible that certain regions will mandate the use of such a platform, whereas others will offer it as an option to meet the requirements of a mobility service application with minimum administration and paperwork (providing a good business case for operators to fit and use the equipment). Certain regions will potentially implement a single, government-operated, controlled, or contracted service provider, which is the single communication manager between the user and the service. Other regions will potentially provide a market-based solution with multiple service providers competing for the business of vehicle operators.

11.3 Basic role model architecture

11.3.1 General

The role model concept architecture defined in ISO/TR 4445 is considered as a baseline document. Figure 2 shows the basic role model for ITS service for smart cities and communities.



Key

com communication infrastructure provided by communication service provider

Figure 2 — ITS architecture for framework

11.3.2 Smart city sensor data (probe data)

Smart city sensor data are collected by the smart city data aggregator. These data are fed to the digital infrastructure (data exchange platform). The following are candidates for smart city sensor data:

- vehicle probe data from infrastructure sensors, vehicle onboard sensors/ITS devices;
- traffic counter data;
- WIM (and onboard WIM) data and other enforcement data;
- toll data;
- CCTV (close circuit television) camera captured video data;
- loop coil data;
- other smart city sensor data relevant to transportation (e.g. EV charge point information, emissions data).

11.3.3 3D HD map

A three-dimensional high definition (3D HD) point cloud map is created by the digital map provider in the smart city, and it feeds those maps to the digital infrastructure.

11.3.4 Digital infrastructure

Digital infrastructure is suggested to be created by public funds and operated by public or private partnerships. Digital infrastructure is responsible for structuring the smart city sensor data (including static, semi-dynamic and dynamic), onto the 3D HD map, likely with the support of AI and other automated data aggregation tools. As sensor data have different timing, units and formats, automated tools are necessary. Standardization of the terminology and definition of each data will facilitate data aggregation; if different terminology or definitions are used, automated tools such as ontology-automated software will be needed prior to data aggregation.

Digital infrastructure interacts with physical infrastructure. For data accuracy, the location referencing data and clock timing mythologies such as global navigation systems broadcasting data and clock timing are essential. Other location referencing technologies are available, such as radio frequency identification markings. Creating digital infrastructure by using open application interface standard digital platforms will enable the use of standardized tools, facilitating easy access for users.

11.3.5 Mobility supporting facility

Mobility supporting facilities include battery charging facilities, dynamic charging facilities for battery electric vehicles, physical infrastructure markings, physical traffic regulation signs, mobility monitoring facilities, emergency responding service support facilities, traffic operation control centre facilities, fee collection service facilities such as for road usage fees, battery EV charging facilities, online reservation and online mobility usage fee payment facilities, and other infrastructure platform facilities to support automated mobility services. For the air/water-born system, an AI-based traffic control centre is a key facility as it will monitor air/water-born vehicles (which are likely to be broadcasting identification signals). For heavy air/water traffic, vehicle-to-vehicle location data exchange will become effective.

11.3.6 Physical infrastructure platform

Physical infrastructure refers to land space for mobility such as roads, guided ways, water space for mobility, and air space for mobility. Physical infrastructure includes the mobility supporting facility, battery charging facility, dynamic charging (vehicle is charged while driving) facility for battery electric vehicle, physical infrastructure markings, physical traffic regulation signs, mobility monitoring facility, emergency responding service support facility, traffic operation control centre facility, fee collection service facility such as road usage fee, battery EV charging facility, online reservation and online mobility usage fee payment facility, and other infrastructure platform facilities to support automated mobility services. Physical infrastructure interacts with digital infrastructure.

11.3.7 ITS service providers

ITS service providers provide ITS services to users in smart cities and communities. A service can be provided by the digital infrastructure. AI is an effective tool to be used for automated mobility data structuring. The production of an enforcement report can assist in enforcing use by agencies. The sustainability of service provider operations and service user fees are a key factor. A subscription-type business model is suggested.

11.3.8 Communication (communication service provider)

Communication is a significant role that connects relevant actors and roles in the entire framework. Communications technology advantages are relevant to each application, including media selection, importance of redundancy, resilience, and ease of integration. Recent emerging 5G technologies are achieving a candidate position for smart city communication role, which has low latency, high data capacity and multiple device access. However, powerful LEO satellite systems and 6G and beyond are potentially be more desirable candidates for smart city communication media because of their ability to better meet performance requirements.

Communication needs secure cyber security functions. The security credential management system needs to be prepared in each region and it publishes digital certificates and block/allow lists to ITS devices.

11.4 Application layer role and functional model for ITS service application

11.4.1 Overview

The role model concept defined in ISO/TR 4445, ISO/TR 7878 and ISO/TR 12770 is shown in Figure 3 for reference only. This figure describes major roles in smart city ITS service.