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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Internet of things and smart cities and communities – Frameworks, architectures and protocols

Functional architecture of network-based driving assistance for autonomous vehicles

Recommendation ITU-T Y.4471

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Recommendation ITU-T Y.4471

Functional architecture of network-based driving assistance for autonomous vehicles

Summary

Recommendation ITU-T Y.4471 defines a reference functional architecture of network-based driving assistance (NDA) for autonomous vehicles. It clarifies the concept of NDA, specifies key functional entities and defines reference points between entities. The use cases and operational procedures are also provided in Appendices I and II, respectively.

To improve the driving of autonomous vehicles, coordination between vehicles and infrastructures needs to be improved with network technologies to provide the increasing transportation services and application requirements. NDA can improve the safety and efficiency of automated driving with capabilities of cooperative perception and decisions.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T Y.4471	2021-05-17	20	11.1002/1000/14423

Keywords

Autonomous vehicle, edge computing, functional architecture, NDA, network-based driving assistance.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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Functional architecture of network-based driving assistance for autonomous vehicles

1 Scope

This Recommendation specifies the functional architecture of network-based driving assistance (NDA) for autonomous vehicles. The functionalities of different layers in the functional architecture are also specified. Additionally, the reference points are defined. The scope of this Recommendation includes:

– The functional architecture of NDA for autonomous vehicles;

– The functional entities to support NDA for autonomous vehicles;

– The reference points of the functional architecture for NDA.

2 Reference

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T Y.4401] Recommendation ITU-T Y.4401/Y.2068 (2015), *Functional framework and capabilities of the Internet of things*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 application [b-ITU-T Y.2091]: A structured set of capabilities, which provide value-added functionality supported by one or more services, which may be supported by an API interface.

3.1.2 cloud computing [b-ITU-T Y.3500]: Paradigm for enabling network access to a scalable and elastic pool of shareable physical or virtual resources with self-service provisioning and administration on-demand.

NOTE – Examples of resources include servers, operating systems, networks, software, applications, and storage equipment.

3.1.3 device [b-ITU-T Y.4000]: With regard to the Internet of things, this is a piece of equipment with the mandatory capabilities of communication and the optional capabilities of sensing, actuation, data capture, data storage and data processing.

3.1.4 functional architecture [b-ITU-T Y.2012]: A set of functional entities and the reference points between them used to describe the structure of an NGN. These functional entities are separated by reference points, and thus, they define the distribution of functions.

NOTE – The functional entities can be used to describe a set of reference configurations. These reference configurations identify which reference points are visible at the boundaries of equipment implementations and between administrative domains.

3.1.5 functional entity [b-ITU-T Y.2012]: An entity that comprises an indivisible set of specific functions. Functional entities are logical concepts, while groupings of functional entities are used to describe practical, physical implementations.

3.1.6 internet of things [b-ITU-T Y.4000]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

NOTE 1 – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled.

NOTE 2 – From a broader perspective, the IoT can be perceived as a vision with technological and societal implications.

3.1.7 thing [b-ITU-T Y.4000]: With regard to the Internet of things, this is an object of the physical world (physical things) or the information world (virtual things), which is capable of being identified and integrated into communication networks.

3.2 Term defined in this Recommendation

This document defines the following term:

3.2.1 network-based driving assistance (NDA): A set of capabilities which assists vehicles to make decisions for safe and efficient driving, by making use of the data collected by networks from vehicles and from roadside infrastructure.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

C-V2X	Cellular Vehicle-to-Everything
DLM	Data Lifetime Management
DOI	Domain of Interest
ERTRAC	European Road Transport Research Advisory Council
GNSS	Global Navigation Satellite System
IoT	Internet of Things
ISAD	Infrastructure Support levels for Automated Driving
NDA	Network-based Driving Assistance
ODD	Operational Design Domain
RSU	Roadside Unit
SAE	Society of Automotive Engineers

5 Conventions

The following conventions are used in this Recommendation:

– The keywords "required" indicate a requirement which must be strictly followed and from which no deviation is permitted, if conformance to this Recommendation is to be claimed.

– The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus, this requirement need not be present to claim conformance.

6 Introduction

Driving assistance helps vehicles to achieve higher traffic efficiency, lower fuel consumption and, more importantly, helps to improve driving safety. Traditional driving assistance only relies on on-board sensors and computers to make decisions. Due to the limiting view angle from the on-board camera and to complex road curvature and bumps, it can be challenging to gain a comprehensive perception. The insufficient information might lead to unreasonable decisions, which result in inefficient coordination between a vehicle and its surroundings. Network-based technologies provide possibilities to improve driving assistance [b-ETSI TR 102 638]. For example, by utilizing wireless communication and abundant resources in edge/cloud units for sensing and computing, the performance of driving assistance can be improved.

Network-based driving assistance (NDA) provides dynamic traffic and coordination information for vehicles in order to assist them to make the best driving decisions, making use of wireless communication technologies to collect information from vehicles and/or from the roadside infrastructure.

NDA provides two main advantages:

– For sensing, cameras and lidars, external to vehicles, can provide a perception of the surrounding traffic environment with a larger range and higher accuracy than on-board cameras [ETSI TR 103 562].

– Powerful computing devices can be deployed in edge/cloud units, which can more easily satisfy the high computing demand from advanced and complicated applications for driving assistance.

By accessing wireless networks, vehicles and edge/cloud units are connected, which makes NDA possible. Data from both on-board sensors and roadside sensors can be collected together and a reliable and accurate dynamical map can be easily constructed. Based on the perception, edge/cloud units can obtain optimal driving strategies according to current traffic conditions, therefore transmitting suggestions for each vehicle. Moreover, intervehicle coordination and coordination between vehicles and traffic infrastructures become feasible, which can improve safety and efficiency for the entire traffic system.

The functions of NDA need to be separated according to different demands of urgency and complexity, as shown in Figure 1. The categories into which the functions can be grouped are as follows:

– Roadside data processing and vehicle data processing, which can collect and process the data from roadside sensors (e.g., camera and radar) and other units of roadside infrastructure (e.g., traffic lights), as well as from on-board sensors (from vehicles).

– Edge services, which can provide persistent support for driving assistance among multiple operators. Advanced and complicated applications such as vehicle-to-vehicle/infrastructure coordination can be implemented in edge hosts.

– Cloud services, which have a wide cover range and possess powerful computing ability. Considering the long transmission range, some functions with lower latency requirements can be implemented in the cloud, e.g., map construction and route planning. A more detailed introduction to the functional architecture of NDA is provided in clause 7.

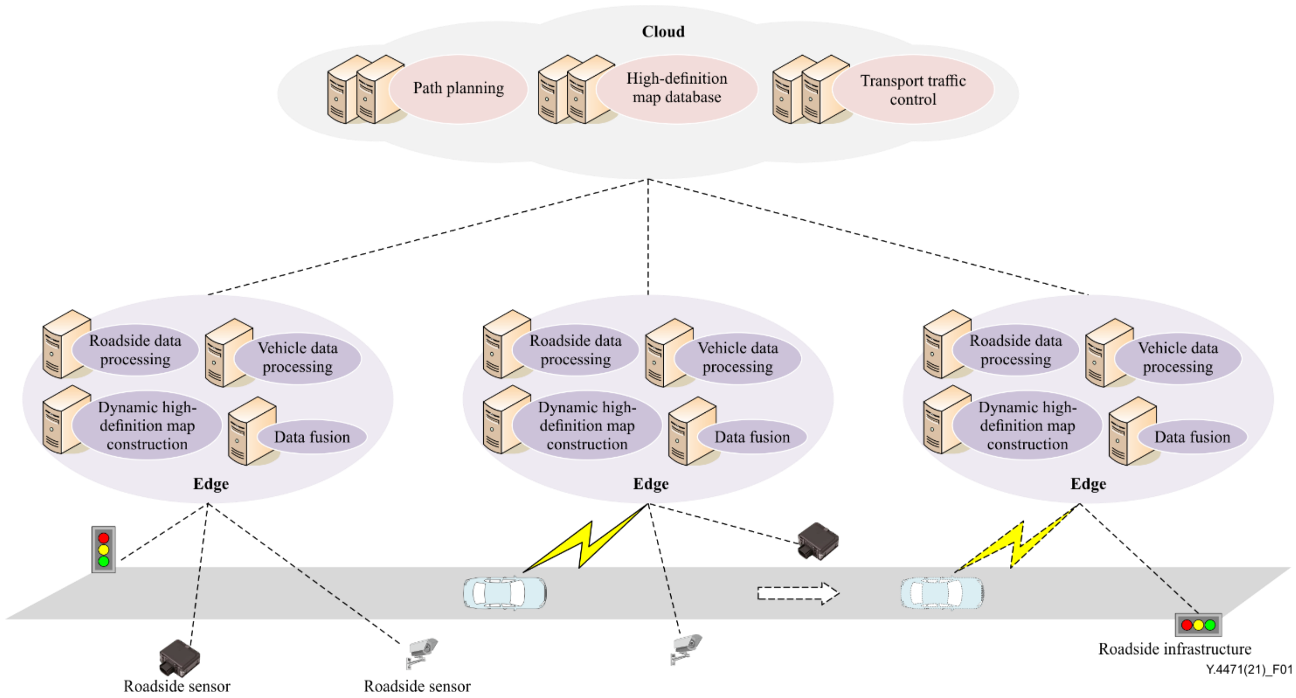

Figure 1 – Overview of NDA for autonomous vehicles

7 The functional architecture of NDA for autonomous vehicles

Figure 2 shows the functional architecture of NDA for autonomous vehicles. It includes the functionalities of edge and cloud. In the functional architecture, the functional entities in the service support and application support layer are the core functional entities. They can provide driving suggestions for vehicles to assist autonomous driving. To satisfy the requirements of ultra-low latency communication, highly reliable networks are needed. The network is transparent to the interaction information between different entities including vehicular devices, edge and cloud.

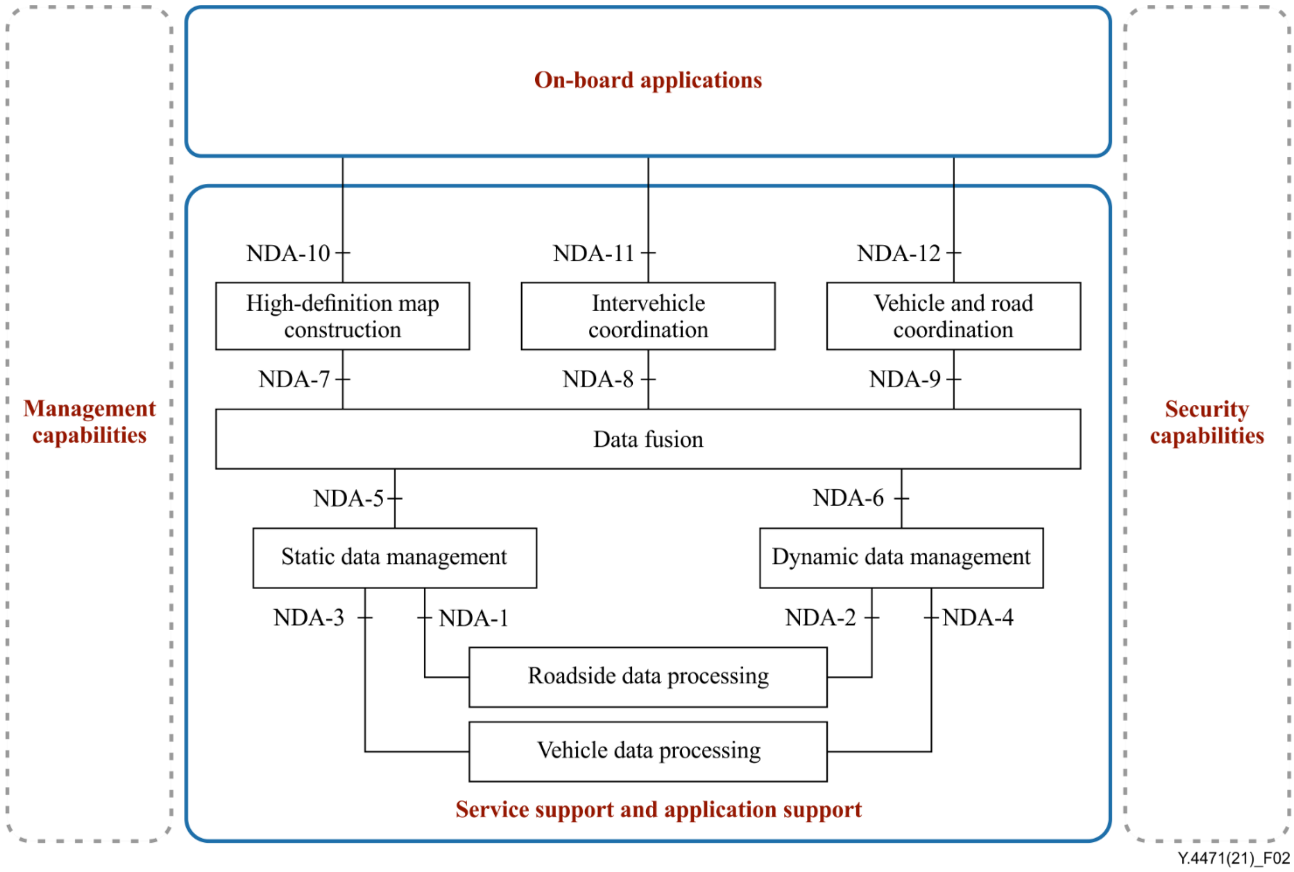

Figure 2 – The functional architecture of NDA for autonomous vehicles

In this architecture:

– Management capabilities can refer to clause 8.5, on management capabilities, of [ITU-T Y.4401]. Management capabilities are used to fulfil the interoperability, scalability, reliability, high availability and manageability requirements, which are required by the entities of this functional architecture. This Recommendation does not define any new management capability.

– Security capabilities can refer to clause 8.7, on security and privacy protection capabilities, of [ITU-T Y.4401]. Security capabilities are used to fulfil the communication security, data management, service provision security, security integration, mutual authentication and authorization, and security audit requirements of the entities of this functional architecture. This Recommendation does not define any new security capability.

– On-board applications represent the applications which are implemented on the vehicles, such as navigation, positioning and cooperative risk awareness.

– The functional entities in the service support and application support are the core functional entities. These core functional entities can provide driving suggestions as input information for on-board applications of autonomous vehicles to generate driving decisions.

8 The functional entities of NDA for autonomous vehicles

8.1 Roadside data processing

The roadside data processing functional entity is responsible for collecting and processing the data from roadside sensors (e.g., camera and radar) and other units of roadside infrastructure (e.g., traffic lights).

The following recommendations are given for the functionalities of the roadside data processing functional entity:

– It is recommended to provide data aggregation from roadside sensors and other units of roadside infrastructures with proper access control.

– It is recommended to provide data quality analysis in order to identify confidence of data collected for static and dynamic data management functional entities.

– It is recommended to provide the ability to process roadside data with different formats.

– It is recommended to provide comparative analysis in order to align information both in time domain and space domain, splice collected data under different perceptual fields of view and form a unified roadside perception.

– It is recommended to provide roadside perception identification and classification into roadside static data and roadside dynamic data according to update frequency.

– It is recommended to provide data encapsulation based on related interface protocols, in order to deliver roadside static data to static data management functional entity and deliver roadside dynamic data to dynamic data management functional entity.

8.2 Vehicular data processing

The vehicular data processing functional entity is responsible for collecting and processing the data from on-board sensors.

The following recommendations are given for the functionalities of the vehicular data processing functional entity:

– It is recommended to provide data aggregation from on-board sensors with proper access control.

– It is recommended to provide data quality analysis in order to identify confidence of data collected for static and dynamic data management functional entities.

– It is recommended to provide the ability to process vehicular data with different formats.

– It is recommended to provide comparative analysis in order to align information both in time domain and space domain, splice collected data under different perceptual fields of view and form a unified vehicular perception.

– It is recommended to provide vehicular perception identification and classification into vehicular static data and vehicular dynamic data according to update frequency.

– It is recommended to provide data encapsulation based on related interface protocols, in order to deliver vehicular static data to the static data management functional entity and deliver vehicular dynamic data to the dynamic data management functional entity.

8.3 Static data management

The static data management functional entity is responsible for preliminarily processing and managing the static data provided by the roadside data processing functional entity and vehicular data processing entity. The static data is time invariant, such as road topology and lane marks. The following recommendations are given for the functionalities of the static data management functional entity:

– It is recommended to provide data aggregation from roadside static data and vehicular static data.

– It is recommended to provide feature extraction and model-based filtering to obtain recognition of static elements, and subsequent semantic relationships among them, such as recognition of lane marks, traffic signs and modelling of lane network topology.

– It is recommended to provide data lifecycle management (DLM) for static data, including generating, tracking, updating and erasing.

– It is recommended to provide data encapsulation based on related interface protocols, in order to deliver structured static data to the data fusion functional entity.

8.4 Dynamic data management

The dynamic data management functional entity is responsible for preliminarily processing and managing the dynamic data from the roadside data processing functional entity and vehicular data processing entity. The dynamic data is time variant, such as real time traffic flow, location and speed of traffic participants.

The following recommendations are given for the functionalities of the dynamic data management functional entity:

– It is recommended to provide data aggregation from roadside dynamic data and vehicular dynamic data.

– It is recommended to provide feature extraction and model-based filtering to obtain recognition and tracking of dynamic elements, and subsequent semantic relationships among them, such as recognition of vehicles and modelling of occupancy map.

– It is recommended to provide DLM for dynamic data, including generating, tracking, updating and erasing.

– It is recommended to provide data encapsulation based on related interface protocols, in order to deliver structured dynamic data to the data fusion functional entity.

8.5 Data fusion

The data fusion functional entity is responsible for merging and integrating pre-processed static data and dynamic data.

The following recommendations are given for the functionalities of the data fusion functional entity:

– It is recommended to provide data aggregation based on static data and dynamic data.

– It is recommended to provide matching and mapping of the static data and dynamic data to realize relative positioning, to provide coordinate transformation to realize absolute positioning, and to provide combination with other positioning mechanisms, such as global navigation satellite system (GNSS) based positioning and network-based positioning, to obtain accurate and reliable location awareness information.

– It is recommended to provide context and scene modelling and environment modelling based on constraints of static data and dynamic data to realize scene understanding, event detection and activity recognition, in order to obtain context awareness information.

– It is recommended to provide inpainting functions to infer the missing perception in order to generate a fusion result with full context and environment interpretation and description of traffic participants and infrastructures.

– It is recommended to provide data encapsulation based on related interface protocols, in order to deliver a fusion result to the high definition map construction, intervehicle coordination, vehicle and road coordination functional entities.

8.6 High definition map construction

The high definition map construction functional entity is responsible for constructing high definition maps based on the full view of the traffic network and update information of real time traffic conditions.

The following recommendations are given for the functionalities of the high definition map functional entity:

– It is recommended to provide vectorization of map elements to construct and update high definition maps based on the fusion result.
– It is recommended to provide maps on different hierarchical levels, such as road-level, lane-level and feature-level, to the field of automated driving.
– It is recommended to provide map clippings based on the location of vehicles, to deliver a real time map to autonomous vehicles simultaneously.
– It is recommended to provide data encapsulation based on application protocols, in order to deliver map information to on-board applications if required by vehicles.
– It is recommended to provide evaluation of feedback from on-board applications to improve driving assistance.

8.7 Intervehicle coordination

The intervehicle coordination functional entity is responsible for coordinating and generating driving suggestions for vehicles depending on different situations (e.g., distance of vehicles and priorities) in order to provide suggested driving behaviour and anti-collision warnings [b-SAE J3216] [b-ETSI-EN 302].

The following recommendations are given for the functionalities of the intervehicle coordination functional entity:

– It is recommended to provide driving information extraction of vehicles in the domain of interest (DOI), including position, speed, direction and destination, based on the information from the data fusion entity.
– It is recommended to provide modelling and updating of the relation of vehicles and predicting vehicles' movement tendency.
– It is recommended to generate driving suggestions based on the relation of vehicles and prediction results in order to improve cooperative driving and collision avoidance.
– It is recommended to provide data encapsulation based on application protocols, in order to deliver intervehicle coordination driving suggestions to on-board applications if required by vehicles.
– It is recommended to provide evaluation of feedback from on-board applications to improve driving assistance.

8.8 Vehicle and road coordination

The functional entity of vehicle and road coordination is responsible for coordinating and generating driving suggestions for vehicles, depending on the different situations (e.g., dynamic traffic rules and dynamic road conditions), in order to provide suggested coordination information for vehicles.

The following recommendations are given for the functionalities of the vehicle and road coordination functional entity:

– It is recommended to provide evaluation of road information, including the availability, capacity, efficiency of roads and phase of traffic lights, based on the information from the data fusion entity.

– It is recommended to provide modelling and updating relations between vehicle and road topology, predicting change in the macroscopic traffic situation, and to provide navigation suggestions.
– It is recommended to provide modelling and updating relations between vehicle and roadside infrastructures, optimizing the control signal of roadside infrastructures based on microscopic traffic situations, and provide driving behaviour suggestions.
– It is recommended to provide data encapsulation based on application protocols, in order to deliver vehicle and road coordination driving suggestions to on-board applications if required by vehicles.
– It is recommended to provide evaluation of feedback from on-board applications to improve driving assistance.

9 Reference points of the functional architecture

9.1 Reference points between entities

In the functional architecture, the functional entities for driving assistance for autonomous vehicles in different layers is connected through the reference points, including:

– NDA-1 reference point: reference point between the roadside data processing entity and static data management entity, in support of data collection and fusion of static data.
– NDA-2 reference point: reference point between the roadside data processing entity and dynamic data management entity, in support of data collection and fusion of dynamic data.
– NDA-3 reference point: reference point between the vehicle data processing entity and static data management entity, in support of data collection and fusion of static data.
– NDA-4 reference point: reference point between the vehicle data processing entity and dynamic data management entity, in support of data collection and fusion of dynamic data.
– NDA-5 reference point: reference point between the static data management entity and data fusion entity, in support of the data fusion function.
– NDA-6 reference point: reference point between the dynamic data management entity and data fusion entity, in support of the data fusion function.
– NDA-7 reference point: reference point between the data fusion entity and high definition map construction entity, in support of the high definition map construction function.
– NDA-8 reference point: reference point between the data fusion entity and intervehicle coordination entity, in support of cooperative control between vehicles.
– NDA-9 reference point: reference point between the data fusion entity and vehicle and road coordination entity, in support of cooperative control between vehicle and roadside infrastructure.
– NDA-10 reference point: reference point between the high definition map construction entity and on-board applications, in support of different on-board driving assistance or autonomous driving applications.
– NDA-11 reference point: reference point between the vehicles' coordination entity and on-board applications, in support of different on-board driving assistance or autonomous driving applications.
– NDA-12 reference point: reference point between the vehicle and road coordination entity and on-board applications, in support of different on-board driving assistance or autonomous driving applications.

9.2 Reference point identifications

9.2.1 NDA-1

This is for communication between the roadside data processing entity and static data management entity across the NDA-1 reference point. It transmits time invariant information, which is collected from roadside infrastructures, such as road network information, static traffic sign information and lane markings.

9.2.2 NDA-2

This is for communication between the roadside data processing entity and dynamic data management entity across the NDA-2 reference point. It transmits time variant information which is collected from roadside infrastructures, such as detected traffic participants' information and phase of traffic lights.

9.2.3 NDA-3

This is for communication between the vehicle data processing entity and static data management entity across the NDA-3 reference point. It transmits time invariant information which is collected from vehicles, such as vehicle essential parameters and identifications.

9.2.4 NDA-4

This is for communication between the vehicle data processing entity and dynamic data management entity across the NDA-4 reference point. It transmits time variant information which is collected from vehicles, such as a vehicle's driving status (e.g., speed, engine torque, fuel consumption rate) and autonomous vehicle-related perception data from on-board sensors (e.g., on-board camera and lidar).

9.2.5 NDA-5

This is for communication between the static data management entity and data fusion entity across the NDA-5 reference point. It transmits pre-processed static data which is collected from vehicle data processing and roadside data processing to data fusion for further processing.

9.2.6 NDA-6

This is for communication between the dynamic data management entity and data fusion entity across the NDA-6 reference point. It transmits pre-processed dynamic data which is collected from vehicle data processing and roadside data processing to data fusion for further processing.

9.2.7 NDA-7

This is for communication between the data fusion entity and high definition map construction entity across the NDA-7 reference point. It transmits fusion results for the construction of high definition maps, including location awareness information and context awareness information of traffic participants (e.g., pedestrians, cyclists, vehicles).

9.2.8 NDA-8

This is for communication between the data fusion entity and intervehicle coordination entity across the NDA-8 reference point. It mainly transmits fusion results of vehicle information for the generation of intervehicles coordination driving suggestions to on-board applications.

9.2.9 NDA-9

This is for communication between the data fusion entity and vehicle and road coordination entity across the NDA-9 reference point. It mainly transmits fusion results of vehicle information and roadside infrastructure information, which are used for the generation of vehicle and road coordination driving suggestions to on-board applications.

9.2.10 NDA-10

This is for communication between the high definition map construction entity and on-board applications across the NDA-10 reference point. It mainly transmits clipped high definition maps, including the road-level, lane-level and feature-level map.

9.2.11 NDA-11

This is for communication between the vehicle's coordination entity and on-board applications across the NDA-11 reference point. It mainly transmits optimal driving assistance suggestions to vehicles based on the relations of on-road vehicles, such as recommending driving behaviour or an anti-collision warning.

9.2.12 NDA-12

This is for communication between the vehicle and road coordination entity and on-board applications across the NDA-12 reference point. It mainly transmits optimal driving assistance suggestions to vehicles based on roadside infrastructure information, such as optimized driving speed or driving route.

10 Security considerations

From the functional architecture perspective, the NDA security described in clause 7 refers to the security and privacy protection functional entity of [ITU-T Y.4401]. From the basic capabilities perspective, the capabilities for security and privacy protection, such as communication security, data management, service provision security, security integration, mutual authentication and authorization, and security audit, which are described in clause 8.7 of [ITU-T Y.4401], will fulfil the common requirements for NDA security.

Appendix I

Use cases of NDA

(This appendix does not form an integral part of this Recommendation.)

This appendix provides use cases to illustrate the deployment of the functional architecture of NDA.

I.1 Use case 1: High definition map

A high definition map, which is considered one of the key technologies to achieve automated driving, is the carrier of real time perceptions of traffic environments, and furthermore provides basic information to support driving assistance for autonomous vehicles.

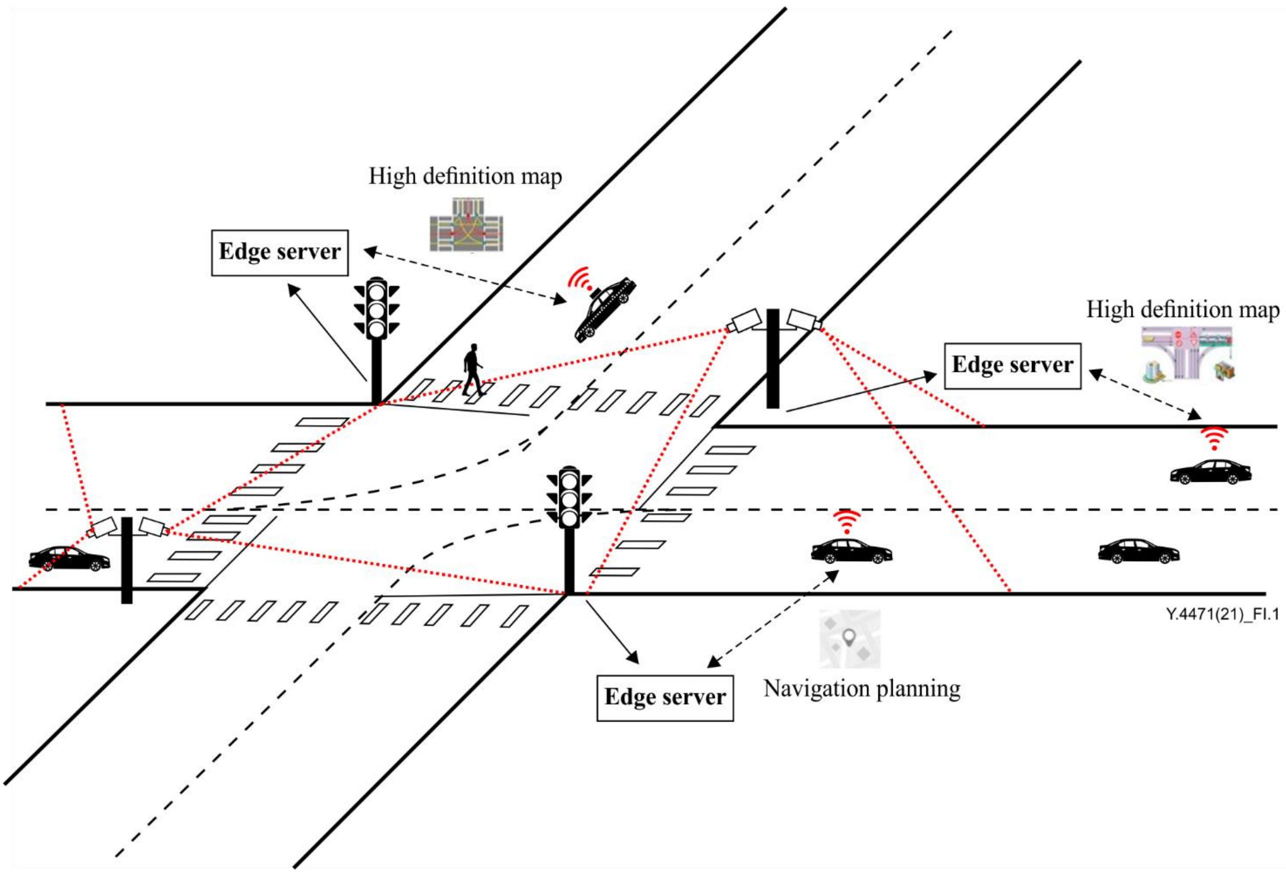

Figure I.1 – High definition map use case

Compared with a traditional navigation electronic map, a high definition map is considered a necessary technology for automated driving at level 3 and up to level 5 (L3~L5) (where levels of driving automation are defined by the Society of Automotive Engineers (SAE) [b-SAE J3016]). High definition maps contain abundant and accurate traffic environment information, such as road conditions and traffic and event information, and provide adaptive updating based on the analysis of large amounts of data that have been collected from all kinds of sensors and infrastructures. NDA can meet these requirements for constructing high definition maps as follows:

– Data source: environmental perception of autonomous vehicles is limited by the range and capability of on-board sensors. NDA is able to collect data from roadside sensors and infrastructures, therefore providing more information for constructing reliable high definition maps.

– Computing mode: NDA has redundant computing resources at the cloud and edge to process large amounts of information, therefore realizing effective scheduling of computing to achieve adaptive updating of high definition maps.

A high definition map is considered an important technology for assisting autonomous vehicles to make decisions. For example, when the on-board perception system of autonomous vehicles fails to work, as if the autonomous vehicle were 'blind', a high definition map will become the final basis for driving control. It will tell the vehicle the accurate location of the stop line at a junction, for example, which will improve driving safety and reliability.

I.2 Use case 2: Intervehicle coordination

Based on the relation of vehicles analysed by NDA, some scenarios of intervehicle coordination can be realized in order to improve driving safety and traffic efficiency.

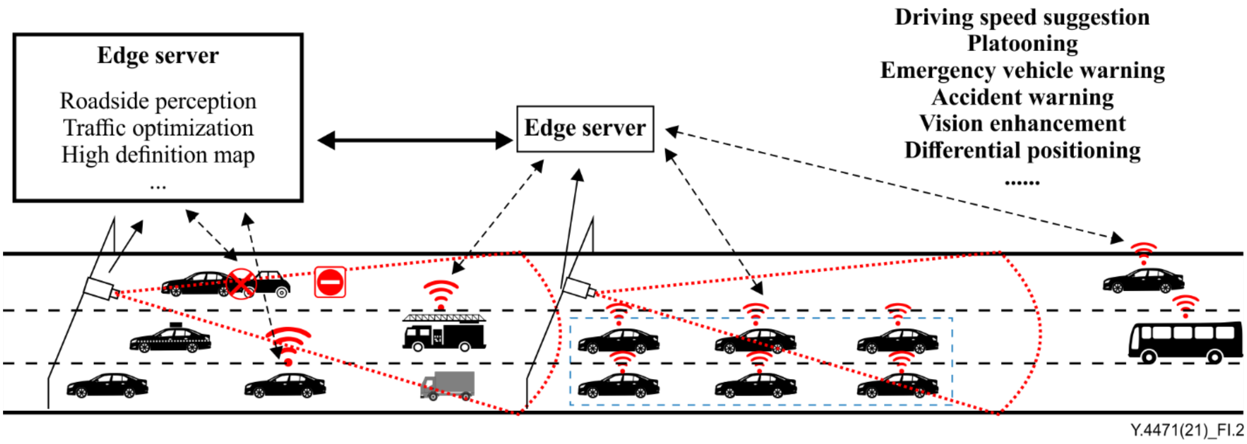

Figure I.2 – Intervehicle coordination use case

I.2.1 Driving speed suggestion

NDA at the edge server will analyse the traffic conditions and each vehicles' relation to one another in the covered road segment and generate safe and energy efficient driving speed suggestions for certain vehicles. The suggestion will be sent to the vehicles via roadside base stations, and the vehicles could cruise in this road segment with the suggested speed.

I.2.2 Vehicle platooning suggestion

NDA at the edge server will analyse the destination of vehicles in the covered road segment and their relation to each other and generate driving instructions to form a vehicle platoon of adjacent vehicles with same destination, including expected cruise positions and speeds. The driving instructions will be sent to the vehicles via roadside base stations and the platoon with high traffic efficiency is then formed.

I.2.3 Emergency vehicle notification

Emergency vehicles driving in the covered road segment are able to send a notification of the need for the right-of-way during emergency conditions. The NDA at the edge server could analyse the relations of nearby vehicles and give avoidance instructions to the related vehicles to give right-of-way to the emergency vehicles.

I.2.4 Risk warning

NDA at the edge server will analyse the vehicles' relation to each other, evaluate collision risk in the covered road segment and generate warning information to be sent to vehicles with potential driving risks (such as blind spot, in-ramp). The warning will be sent to certain vehicles to avoid collision.

I.3 Use case 3: Vehicle and road coordination

There are numerous roadside infrastructures (e.g., camera, radar, roadside unit (RSU)) for cellular vehicle-to-everything (C-V2X) electronic information board employed to support automated driving. In order to classify and harmonize the capabilities of a road infrastructure, the European Road Transport Research Advisory Council (ERTRAC) has defined the infrastructure support levels for automated driving (ISAD) which provide import elements for operational design domain (ODD) definitions in which the automated driving system is designed to properly operate.

NDA will collect the data from numerous roadside infrastructures and analyse the relation of vehicle and road; therefore, some scenarios of vehicle and road coordination can be realized in order to improve driving safety and traffic efficiency.

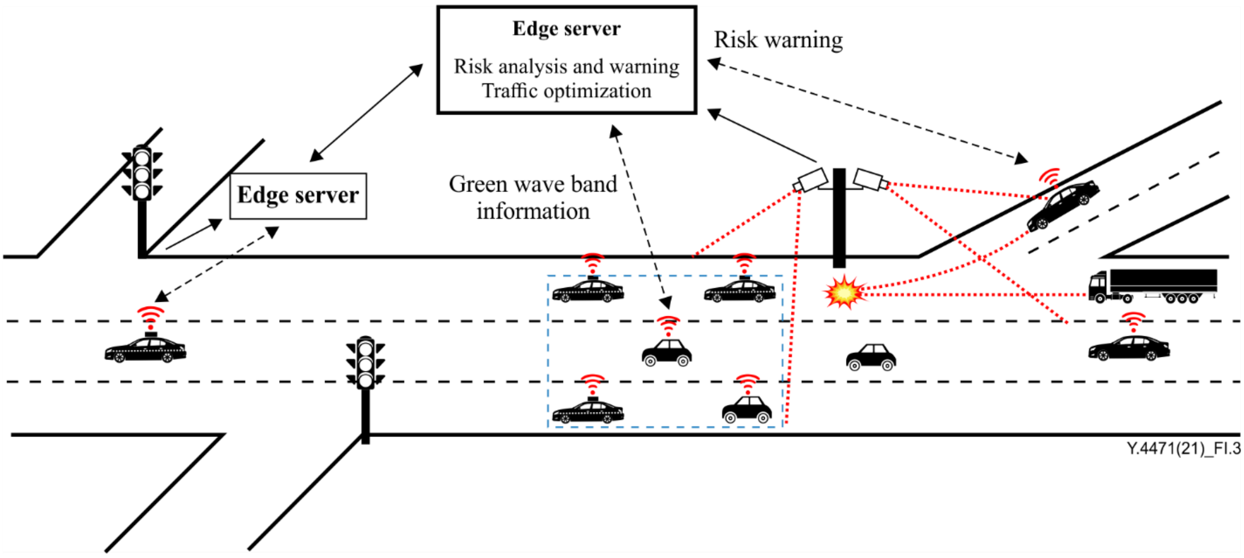

Figure I.3 – Vehicle and road coordination use case

I.3.1 Hazardous location warning

NDA at the edge server will collect road conditions (including road maintenance, road surface conditions) from the roadside perception information or traffic management department. Alongside this, the roadside server will analyse the relation between the road and vehicles and generate warnings to the vehicles that may be affected by certain road conditions.

I.3.2 Green light optimal speed advisory

NDA at the edge server will collect the vehicles' location and phase of traffic lights and generate suggestions to vehicles (expected driving speed) to improve driving comfort and fuel economy when passing a junction. Meanwhile, it also generates suggestions to roadside infrastructures (expected traffic light phase) to improve the traffic efficiency of covered junctions.

I.3.3 Reversible lanes

NDA at the edge server will collect and analyse traffic information from the roadside perception information or traffic management department and allocate driving directions to certain reversible lanes in order to optimize traffic efficiency in a covered road segment. The notification of driving directions of certain lanes will be sent to vehicles in advance.

I.3.4 In-vehicle signage

NDA at the edge server will collect and analyse traffic information from the roadside perception information or traffic management department, and generate dynamic traffic signs (dynamic speed constraint, dynamic stop sign) according to management demand and related traffic regulations. The dynamic traffic sign information will be sent to vehicles in advance.

Appendix II

Operational procedure of NDA

(This appendix does not form an integral part of this Recommendation.)

The operational procedure of NDA between an autonomous vehicle, roadside sensor and infrastructure edge and cloud is shown in Figure II.1 and described in Steps 1 to 15 below. NDA is recommended to be deployed both in edge and cloud to achieve best practice and invoked at edge because of latency sensitive services in the local area that are requested by an autonomous vehicle.

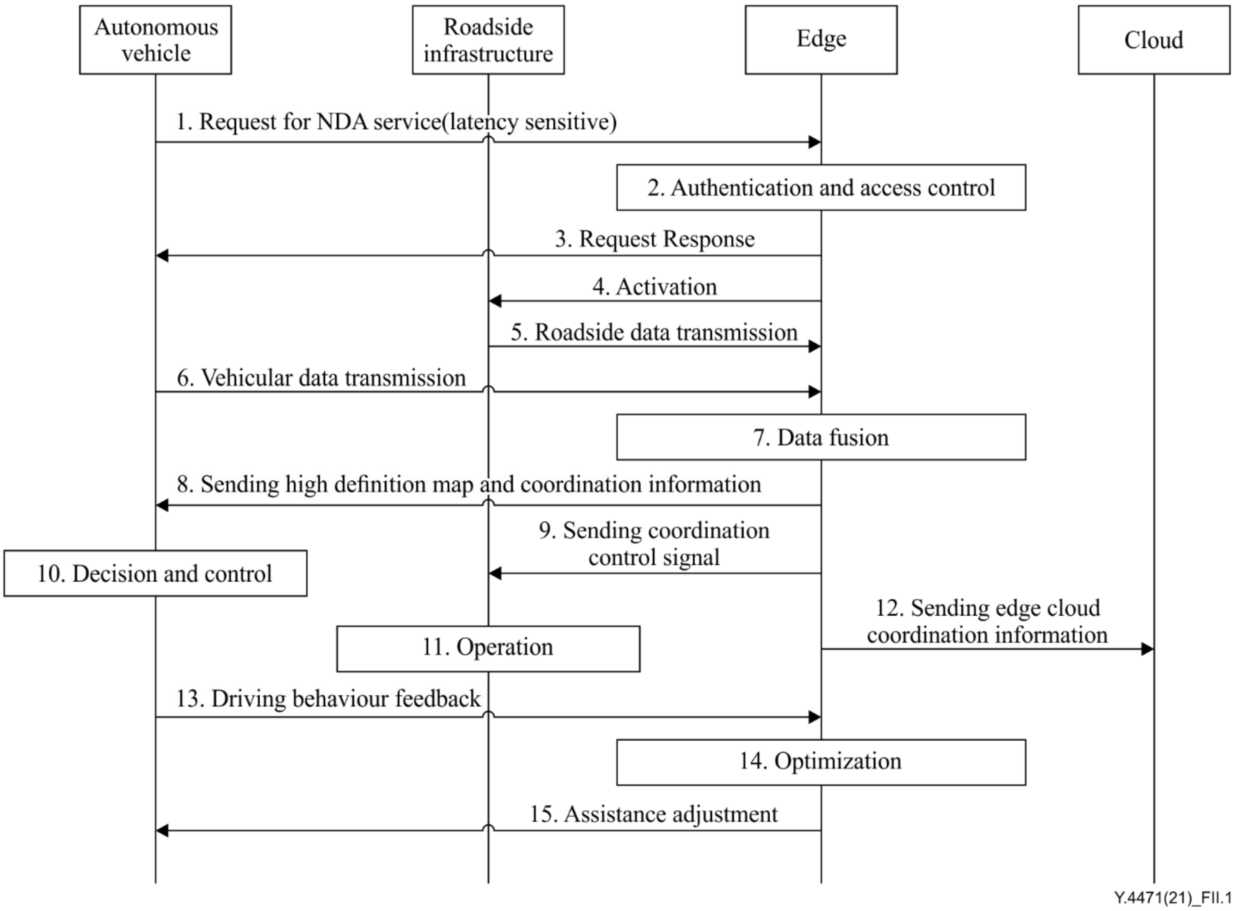

Figure II.1 – Procedure of NDA with latency sensitive service

Step 1: An autonomous vehicle sends a request to the NDA through a wireless network. The request includes information such as priorities of service, vehicle ID number and initial location. The wireless network transmits the request to the optimal nearby edge server after analysing the vehicle's request information.

Steps 2–4: Upon receiving the request, the edge server is responsible for authentication and access control to set up a secure connection with the vehicle and NDA. Once the request from the vehicle has been verified, the edge server will send a response to the vehicle, and simultaneously activate roadside sensors and infrastructures to collect roadside data.

Steps 5–9: Roadside data will be transmitted from roadside infrastructure, and meanwhile, vehicular data will be transmitted from the autonomous vehicle. The NDA at the edge server collects and analyses this data to obtain the data fusion result, then provides a driving assistance service and forwards the high definition map and coordination information to the vehicle through reference points

NDA-10, NDA-11 and NDA-12, and sends the control signal to roadside infrastructures if coordination between the vehicle and road is necessary.

Steps 10–11: Upon receiving the driving suggestions, the vehicle is responsible for generating driving decisions, and the controller of the vehicle responds to such decisions. At the same time, roadside infrastructures respond with control signals such as changing the phase of traffic lights.

Step 12: The edge server synchronizes fusion results to the cloud server, and the NDA at the cloud server is responsible for handling latency non-sensitive services, such as macroscopic path planning and traffic monitoring. In such cases, the microscopic fusion results provided by the edge server are very important.

Steps 13–15: The NDA is responsible for making adjustments based on driving behaviour feedback from vehicles for the purpose of self-optimizing, in order to provide the best driving suggestions.

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