Towards an Architecture for Cooperative-Intelligent Transport System (C-ITS) Applications in the Netherlands

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Summary

The demand for mobility is growing faster than the available roadway infrastructure. Intelligent transport systems (ITS) have been deployed extensively over the last decades to solve or reduce issues like delays due to traffic jams, unreliable and unpredictable travel times, a lack of safety and air pollution, or at least to reduce the effects. A specific type of ITS is Cooperative ITS systems (C-ITS), where intelligent vehicles and intelligent roadside/back-office infrastructure communicate with each other to be able to implement even smarter and more effective applications to tackle these issues. For communication with vehicles, both short-range networks based on ITS-G5 and cellular networks are in scope.

This document describes the architecture for C-ITS applications that is based on an eco-system with business roles for both public and private stakeholders - in a Dutch context. The architecture should be considered as **descriptive** and can give guidance to these stakeholders involved in future ITS deployment projects in the Netherlands. Descriptions of the ‘building blocks’ of the ITS architecture - both physical and functional components - are provided, which should ease the composition and development of deployment architectures of future C-ITS systems in Dutch projects. Additionally the communication between the physical and functional components is described. The following seven projects have been used as input for the ITS architecture: (i) Shockwave Traffic Jams A58, (ii) ITS Corridor, (iii) Praktijkproef Amsterdam, (iv) DITCM 1.0 architecture project, (v) Converge, (vi) MOBiNET and (vii) VRUITS. ITS applications from these projects are used to describe the business model view and the technical system view of the architecture.

Business model aspects

The business model aspects of the eco-system related to the business roles of the identified stakeholders in deployment projects are analysed. Using a business-engineering framework for service-dominant business, business model blueprints have been designed for a set of ITS applications to act as templates for concrete models in specific projects. A business model blueprint of a particular ITS application shows the stakeholders that are involved in offering that solution including their contributions and the main cost and benefit involved in the deployment of the solution. The business framework acts as a guideline in understanding and presenting the operative and economic aspect of ITS applications. Concrete business models can further be designed for current and future C-ITS offerings in relevant projects and by market parties, facilitating an open collaboration of stakeholders in an operational way.

System architecture

The ITS applications of the selected projects are used to create the system architecture. From these applications the hardware and software ’building blocks’ have been derived together with the interfaces between these ‘building blocks’. An example of a physical building block is the On-Board Unit (OBU). This physical building block has one or more functional ‘building blocks’, e.g. ‘Vehicle V2V safety’ to support basic information exchange between cars of safety-related information.

The overall system architecture covers a **representative** set of ITS V2V, V2I and I2V applications for vehicles based on either short range (ITS-G5), cellular or hybrid communication. Also a representative set of ITS safety-related applications for vulnerable road users are included, taken from the VRUITS project. The architecture also describes relevant I2I components to support an open system (e-Market place) for multiple service providers and communication providers to deploy ITS applications to end-users, based on the projects Converge and MOBiNET.

The deployment phase (i.e. research, trial or deployment phase) of the ITS applications - and the corresponding status of specifications - differ per group of V2V, V2I and I2V applications. The main findings and conclusions listed per group of application on these specifications are:

- For V2V applications one should notice that the first V2V ITS systems based on ITS-G5 are not yet released by car manufacturers and are expected to become available between 2015 and 2020. Safety-related applications are the first ITS-G5 applications to be expected in deployments and are covered in the architecture. For V2V the deployment specifications of applications and interfaces (described in 'profiles') of the Car2Car Communication Consortium – based on the ETSI ITS standards framework – will be leading.
- For I2V with ITS-G5 the deployment guidelines of the Amsterdam Group - e.g. via application and interface specifications of the ITS Corridor projects - should be used. Many technical ETSI specifications are still under development in ETSI ITS, especially for I2V applications (e.g. IVI, MAP/SPAT and TSM message sets). White papers on specific applications will be needed to describe which safety-related information in real-world traffic situations needs to be send between vehicles and infrastructure. Also technical specifications on the deployment of cooperative roadside networks and their interfaces to back-office systems are missing today and need to be developed in the near future. In this document relevant architecture options are described, with security aspects addressed.
- I2V, V2I and I2I applications based on cellular communication to improve traffic flow, comfort or environment are already deployed today on a large scale, to inform **individual** road users, e.g. via connected navigation, pay-how-you-drive and fleet management applications. The application and interface specifications for these applications can be reused in future deployment projects.

The focus in projects like Praktijkproef Amsterdam and Shockwave Traffic Jams A58 is to see how information can be improved, either to prevent traffic jams by better detection or to reduce the negative effects or traffic jams by improved individual travel advices for end users, provided by private market parties. Information from several sources (connected and cooperative floating car data and existing traffic monitoring and control systems of road operator(s)) are fused and enriched. The implementation choices and interface specifications from these deployment projects are included in the architecture and are relevant for future projects – also to support the identified market roles in this future public-private eco-system for ITS applications.

Glossary and abbreviations

Term	Description
Actor	An actor is a human or machine entity that interacts with the system to perform meaningful work.
Application	Software that can be deployed on end user devices that provides functions to the end user.
Communication Provider	A service provider that provides access to a communication network infrastructure
Customer	A person or an organization that uses services or applications.
Data provider	A service provider that provides data or information services to other organizations.
End user	An end user is a person who uses a product as an individual, i.e. not on behalf of an organization.
ITS station	Functional component responsible for implementing cooperative functionality in the system. An ITS Station reference architecture has been standardised by ETSI ITS, consisting of applications, facilities, communication, interfaces, security and management. Not all parts have to be present in every ITS Station. Examples of ITS stations are Vehicle ITS, Roadside ITS, Central ITS and Personal ITS.
Role	1. The usual or expected function of an actor, or the part somebody or something plays in a particular action or event. An Actor may have a number of roles. 2. The part an individual plays in an organization and the contribution they make through the application of their skills, knowledge, experience, and abilities.
Service	A Service provided to one or more Customers by an Service Provider. A Service is based on the use of Information Technology and supports the Customer's Business Processes. An IT Service is made up from a combination of people, Processes and technology.
Service provider	An organization supplying services to one or more customers. Customers can include both other organizations, and end users.
Use case	A Use Case represents a discrete unit of interaction between a user (human or machine) and the system. A Use Case is a single unit of meaningful work; for example creating a train, modifying a train and creating orders are all Use Cases. Each Use Case has a description which describes the functionality that will be built in the proposed system. A Use Case may 'include' another Use Case's functionality or 'extend' another Use Case with its own behaviour. Use Cases are typically related to 'actors'. An actor is a human or machine entity that interacts with the system to perform meaningful work.

Abbreviation	Definition
B2X/X2B	Business-to-X, X=Business (B), Consumer (C) or Government (G)
BO	Back Office
CACC	Cooperative Adaptive Cruise Control
CAM	Cooperative Awareness Message
CAN	Controller Area Network
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CIS	Central Intelligent Transport Sub-system
C-ITS	Cooperative Intelligent Transport System
CMD	Cooperative Mobility Device
CP	Communication Provider
DENM	Decentralized Environmental Notification Message
DITCM	Dutch ITS Test site for Cooperative Mobility
DP	Data Provider
EOBD	European On-Board Diagnostics
ETSI	European Telecommunication Standards Institute
EV	Electrical Vehicle
FCD	Floating Car Data
GLOSA	Green Light Optimized Speed Advise
GPS	Global Positioning System
HMI	Human Machine Interface
INS	Intersection Safety
IP(v4/6)	Internet Protocol, version 4 or 6
IPTS	Intelligent Pedestrians Traffic Signal
IRP	Intermodal Route Planner
ISO	International Organization for Standardization
ITS	Intelligent Transport System
ITSC	Intelligent Transport System Communications
ITS-S	Intelligent Transport System-Station
ITS-G5	ITS at 5 GHz frequency band
LDM	Local Dynamic Map
LTE	Long-Term Evolution (also called 4G mobile networks)
NDW	Nationale Databank Weggegevens
OBU	On-Board Unit
PID	Personal Information Devices (e.g. smart phone)
PTW	Powered Two Wheel vehicle
RHW	Road Hazard Warning
RIS	Roadside Intelligent transport Sub-system
RLVW	Red Light Violation Warning
RSU	Roadside Unit
RWS	Rijkswaterstaat
SD	Service Directory
SP	Service Provider
SPES	Service Provider Exchange System
SPAT	Signal Phase and Timing

Abbreviation	Definition
TIS	Traffic Information System
TLC	Traffic Light Controller
TMS	Traffic Management System
UMTS	Universal Mobile Telecommunications System (also called 3G mobile networks
VEE	Vehicle Electrical and Electronic system
V2X/X2V	Vehicle-to-X, where X can be Vehicle (V), Roadside I or Infrastructure (I)
VIS	Vehicle Intelligent transport Sub-system
VRU	Vulnerable Road Users
VRUITS	improving the safety and mobility of Vulnerable Road Users by ITS applications

1 Introduction

1.1 Background

The mobility of people and goods in Europe suffers from delays, unreliability, lack of safety and air pollution. The demand for mobility is growing faster than the available infrastructure. Intelligent transport systems (ITS) have been deployed extensively over the last decades to solve these issues or at least to reduce the effects. A specific type of ITS is Cooperative ITS systems (C-ITS), where intelligent vehicles and intelligent roadside infrastructure communicate with each other to be able to implement even smarter and more effective applications to tackle these issues.

Basic ideas for public-private cooperative intelligent traffic management services have emerged from Dutch or EU research projects like CVIS [1], SPITS [2], Contrast [3], Freilot [4], eCoMove [5] and many others. The ambition to bring these ideas to a large-scale deployment is the main goal of DITCM [6]. The resulting need for more integration between public and private data management systems has been described in a white paper of the Open Traffic Alliance on the next generation of traffic content management systems [7] and a proposal for an in-car platform - named Cooperative Mobility Device - to support such an approach is given in [8].

Various governmental, academic and industrial stakeholders are in the process of describing a shared vision on deployment of cooperative intelligent traffic systems. It is recognized that first practical steps toward this goal should be taken. At the same time investigations are going on about the various business models that can be applied to enable a financial feasible roll out of services partly or completely by commercial organisations.

In 2013 an ‘enabling’ project of DITCM Innovations was executed to develop an overall architecture for C-ITS systems based on a set of selected applications. European standards on C-ITS architecture, interfaces and protocols have been addressed where possible. The project also investigated how C-ITS systems could be integrated with existing roadside and traffic management systems of road operators (e.g. Rijkswaterstaat) and traffic info systems (e.g. NDW [9]) in the Netherlands. The deliverable of this project was a document on the DITCM architecture [10], called DITCM 1.0 in the rest of this document.

1.2 Objectives and Scope

The objective is to develop an ITS architecture consisting of a system architecture and a description of the business aspects of an eco-system with stakeholders from public and private parties in a Dutch context. The architecture should be used as a basis for future ITS deployment projects in The Netherlands and beyond. In this way, projects can be executed faster, results can easier be reused, and different projects can be integrated more easily. Furthermore, organisations can use the architecture to guide their internal development process, as it reflects a common understanding of how the (future) ITS landscape will evolve.

The objective of the current project is to define as a first step an integrated architecture based on a number of projects. The architecture should support the following high-level objectives:

- Include business model aspects of the ITS applications and the relation to identified business roles in the deployment projects of the Dutch programs *Beter Benutten* [11] and *Connecting Mobility* [12];
- Support for a representative set of cooperative connected applications, i.e. include applications via cellular and ITS-G5 communication;
- Support for safety applications for vulnerable road users, like pedestrians and cyclists;
- Support for an open e-Market place of ITS applications.
- System that is open, distributed, provider-independent, scalable, flexible and secure with use of hybrid communication

A selected set of seven projects is used in developing the business and system architecture. These are:

- *Shockwave Traffic Jams A58* - deployment project of Dutch program *Beter Benutten*. This project is selected to verify that the public-private market roles and the corresponding systems and interfaces developed by market companies are supported in the architecture;
- *Praktijkproef Amsterdam* [13] – deployment project of Dutch program Connecting Mobility. This project is also selected to verify that the public-private market roles and the corresponding systems and interfaces are supported in the architecture;
- *ITS Corridor* – deployment project from Amsterdam Group [14]. This project is selected to verify how a first European deployment of a cooperative roadside network between three European countries (Austria, Germany and the Netherlands) can be supported in the architecture;
- *Converge* [15] – a German funded project on an open platform for multiple service providers and communication providers. This project is selected to verify that the Converge concepts and elements to support flexible interaction between multiple service providers and mobile end-user nodes are supported in a centralized, scalable structure via multiple hybrid communication network providers, both ITS-G5 as other mobile (broadcast) networks;
- *MOBiNET* [16] - EU FP7 funded project on an e-Market place for tradable ITS services throughout Europe. This project is selected to verify that the MOBiNET concepts and elements to support an e-Market place for C-ITS applications are feasible in the architecture;
- *VRUITS* [17] – EU FP7 funded project (April 2013 – March 2016) on ITS applications for vulnerable road users like pedestrians and cyclists. This project is selected to extend the architecture with ITS applications for vulnerable road users, like pedestrians, cyclists and drivers of powered two-wheel vehicles;
- *DITCM 1.0 architecture* – this project is selected for the cooperative ITS applications and corresponding architecture.

A short description of the selected projects can be found in Section 9 (Appendix B).

The architecture developed in this project supports the ITS applications and concepts from the selected projects. The architecture is described in a Dutch context, i.e. with knowledge of the role of the Dutch road operators and the existing infrastructure along roadside and traffic management systems with e.g. loop detection, variable message signs, traffic light controllers (on intersections and on highway access) and their interface specifications. Also knowledge from non-infrastructure partners like service and data providers is taken into account. In a follow up activity, this integrated architecture should be simplified, e.g. by limiting the options to realise a specific function, limit business models supported, and removing unnecessary complexity that was introduced due to the context of a specific project. In that way, the resulting architecture can indeed meet the objective, but only if supported by all/sufficient stakeholders. This process is depictured in the figure below.

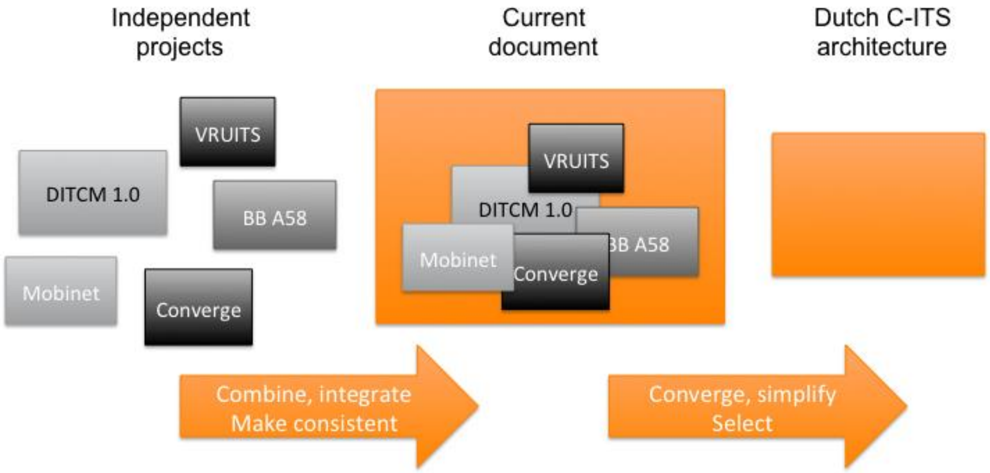

Figure 1-1 Steps to come to a reference architecture, based on input from independent projects. This report describes the first step and the resulting integrated architecture.

1.3 Definition architecture

An architecture of an information system defines that system in terms of computational components and interactions between those components, from the viewpoint of specific aspects of that system, and based on specific structuring principles for design and governance [18]. A reference architecture is a generic design (abstract blueprint) of (system) structure for a specific class of information systems.

A reference architecture is a collection of models that capture the different viewpoints of the system. It can be elaborated (detailed, extended, parameterized) for a specific situation to obtain a concrete or implementation / deployment architecture, as shown in Figure 1-2. This concrete architecture is used for sub-system specifications and interface specification that are further elaborated in detailed system design and interface specifications. The architecture described in this document should be regarded as a reference architecture that describes the relevant sub-systems and interfaces – as extracted from the projects. Public stakeholders like Rijkswaterstaat can use the architecture to derive a concrete architecture with a subset of the sub-systems and interfaces, based on strategic choices or context-specific choices.

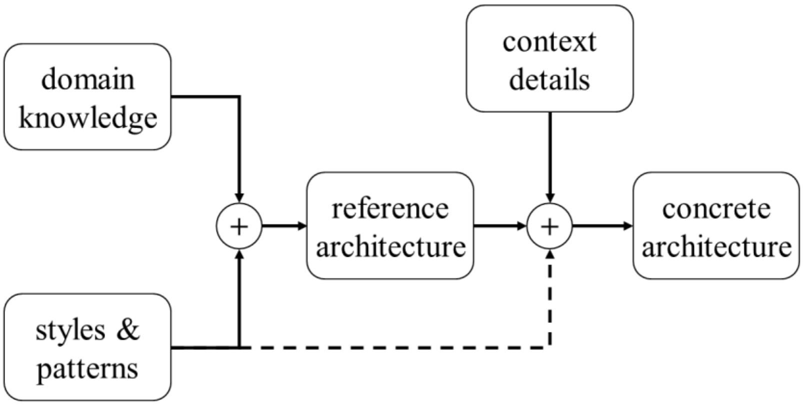

Figure 1-2 Reference architecture process: from reference architecture to concrete architecture

A reference architecture needs to be connected to a 'roadmap', as shown in Figure 1-3, to support near-term and long-term developments. A roadmap for C-ITS applications is e.g. defined by Car2Car CC and the Amsterdam Group.

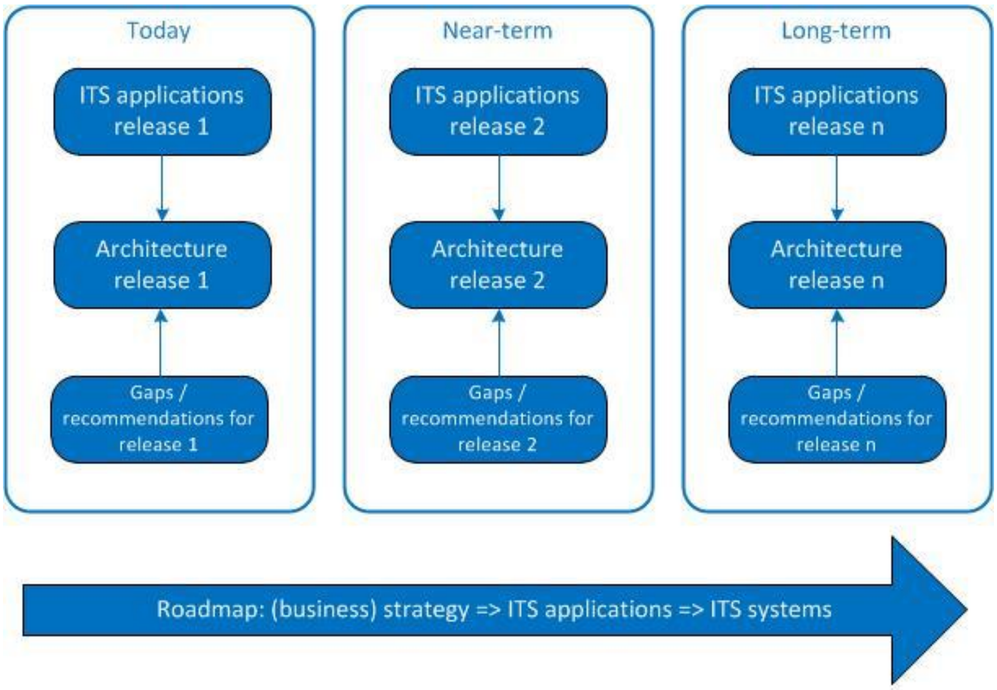

Figure 1-3 Development of a reference architecture, based on a road map.

1.4 Approach

The ITS applications from the selected projects are described in Section 2. In the project a requirement analysis (both functional and non-functional) is not performed, since this is regarded as project specific. The ITS applications are meant to describe the functionality of the ITS architecture. The descriptions of these ITS applications and the corresponding sequence diagrams (see Section 8) are descriptive and representative for today's and future deployment and should be used for guidance in deployment projects to understand the functionality of the C-

ITS system towards end users (B2C) or organisations (B2B, B2G, G2B). All applications are used to build the overall system architecture and a representative set is used as input for the business model view. The (interface) specifications developed and used in the selected Dutch projects are described in this document, but cannot be regarded as definitive i.e. obligatory for a public stakeholder like a road operator to provide to market parties.

In the business model view, applications are described in terms of services provided by one business role to other business roles. In the technical views of the architecture, these services are translated into functional components and interfaces, where a single functional component is always the responsibility of a single role. To determine system and organisational boundaries for a specific implementation, first one needs to determine which organisation will fill in which role, and then these boundaries will follow from the mapping. This is depicted in the figure below.

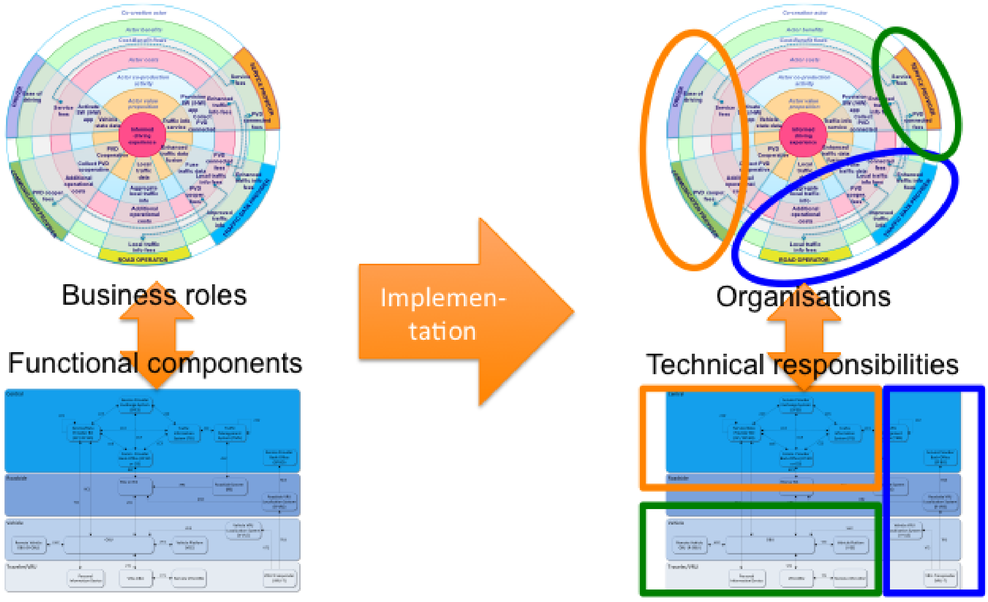

Figure 1-4 Example of the relation between business and technical views for the reference architecture and actual implementations.

Public documentation and expert sessions with the above project teams were used to verify and validate the architecture. Workshops with public and private stakeholders were organised to discuss the scope and approach and to get feedback on the results.

The architecture is described in two parts: in Section 3 the business model aspects of a representative set of applications are presented. In Section 4 the system architecture is described and applied to the ITS applications. This architecture is verified with the selected projects, by giving deployment architecture examples for the projects A58 and ITS Corridor in Section 5.

1.5 Project governance

The project governance is shown in Figure 1-5. The project team (4) is responsible for the deliverables of the project. This document on the ITS architecture is the main

deliverable. The project board (1) of DITCM and Connecting Mobility is responsible for the release of the deliverable.
The architecture board (2) is a public-private board to give direction to the approach and discuss the intermediate results. The project team interacts with expert groups (3) from the projects to gather input for the architecture.

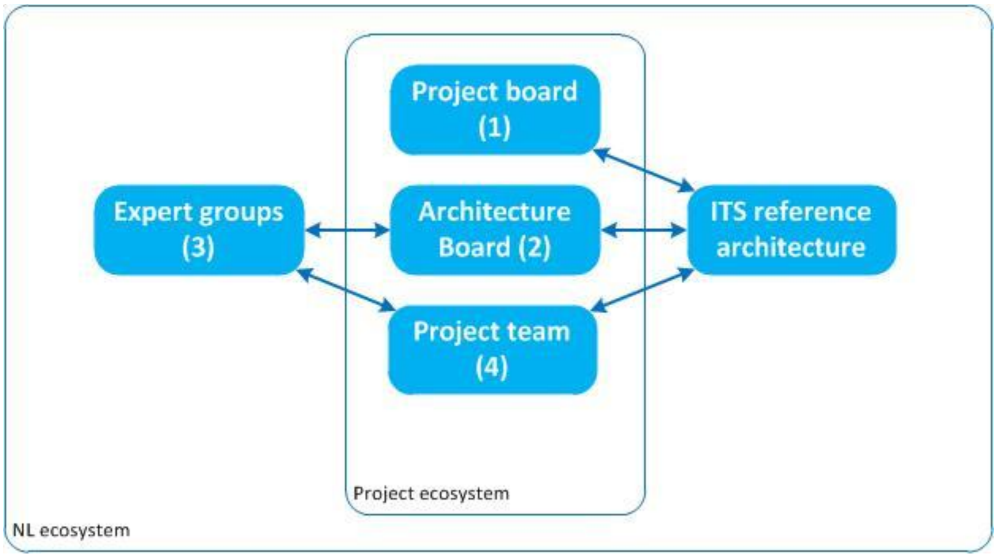

Figure 1-5 Project governance

2 C-ITS Applications

2.1 Introduction

This chapter presents the C-ITS application types and a set of representative C-ITS applications that are referred in the business and system architecture description in Sections 3 and 4. The applications are used to explain the high-level functionality of the C-ITS system and to build up the underlying architecture that supports these applications from a functional and business viewpoint. The description of the ITS applications in this chapter is generic. Sequence diagrams are used to explain the information flow between the physical building blocks (see Section 8, Appendix A). These diagrams are used to **illustrate** how applications can be deployed, and what functional elements are involved together with the data flow.

One should note that the C-ITS applications / services are typically implemented by market parties in different ways, to have a differentiated service offering compared to competitors and will therefore depend on a suitable individual business model and/or technical approach. For an **actual** implementation of a C-ITS system a more detailed description of the **selected** C-ITS applications and the corresponding implementation architecture (both business and system architecture) are needed.

The architecture is open and flexible and should support new future applications and new future roles from service providers or service enablers. With the ‘building blocks’ and the roles the model is flexible, so institutional and economical organisations are flexible to decide who will provide a specific role with a related functional component. Also the information exchange is flexible, to add new functionality in the future.

2.2 C-ITS applications in selected projects

In this section the C-ITS applications from the selected projects are described.

2.2.1 C-ITS application in ITS Corridor

In the NL-DE-AT Cooperative ITS corridor project the next I2V and V2I applications are in scope for the whole corridor:

1. Road Works Warning
2. Basic Probe Vehicle Data

The next additional services are planned for the Dutch part of the corridor:

1. Extended Probe Vehicle Data
2. In-Vehicle Signage

2.2.2 C-ITS applications in Shockwave Traffic Jams A58

In the project *Shockwave Traffic Jams A58* a split in three market-related areas is used: (i) data collection, (ii) end-user services and (iii) roadside communication services. These areas are related to expertise of the involved market parties with their service offerings and business perspective and are **data provider**, **communication provider** and **service provider**. Besides these market roles also the **road operator** has a role to provide information on traffic state (traffic flow, incidents, and traffic jam) and on traffic control measures (dynamic speeds).

Although the applications in this project are not explicitly specified in e.g. *service descriptions* – as these are left free for the involved market consortia to develop differentiated service offering compared to competitors - the following applications are identified for the above market roles:

1. Data provider: a data provider collects traffic state information from several sources and uses the information in specific algorithms to detect traffic jams or to predict the chance on traffic jams and their location. The data provider sends the enriched information to service providers and road operators. The data provider uses information from applications of the other roles:
    a. Local Traffic State Data: a road operator gives access to local (near) real-time information from loops along highways on traffic state (detection), e.g. loop data or aggregated data at time intervals up to tens of seconds (typical <30s);
    b. Floating Car Data collection from connected car: Floating Car Data is collected by a service provider from connected cars, e.g. via a connected navigation application that uploads speed and position of individual vehicles;
    c. Floating Car Data collection from cooperative roadside network: a communication provider with a cooperative roadside network with ITS-G5 radio units receives the messages from cars (e.g. situational awareness messages with vehicle state like position and speed or warning messages) and forwards this aggregated FCD data to a data provider. The communication provider acts In this case as a B2B service provider for the data provider;
2. Service provider: the service providers develop specific services for individual end-users to prevent traffic jams. Typical services are:
    a. Pre-trip or on-trip (re)routing advise: at strategic and tactical level a rerouting advise can be given to drivers, both pre-trip and on-trip;
    b. Speed Advice: at operational level service providers provide individual speed advices to drivers;
    c. Traffic Jam Ahead warning: at operational level a warning can be given to individuals on a traffic jam with location;
    d. Others: it's left to market parties to create own differentiating services;
3. Communication provider: the communication provider operates a cooperative roadside ITS network with ITS-G5 radio units. The communication provider supports several services for data providers and services providers:
    a. Floating Car Data collection from cooperative cars: see above;
    b. Cooperative Message Distribution from service providers and road operators to cooperative vehicles e.g.
        i. Shockwave Damping via local speed advise
        ii. Traffic Jam Ahead Warning
        iii. Transparent Service Messages from service providers
4. Road operator: the road operator provides in this project several information services to data providers:
    a. Local (Micro) Traffic State Data: see above;
    b. Local (Micro) Traffic Control Data: dynamic speed limits, and blocked road lanes are send to the data provider.

2.2.3 C-ITS applications in Praktijkproef Amsterdam

In the sub-project *PPA in-car* traffic information services for end-users will be used to reduce the chance and impact of traffic jams at incidents, rush hour and events. In the sub-project *PPA roadside* there is a special focus on traffic management coordination between road operators in the area of Amsterdam (RWS, Province of North Holland and City of Amsterdam). For this project the application Coordinated Traffic Management was developed. With this application improved traffic flow can be reached by aligning the use of scarce road capacity of different road authorities via more efficiently distributing traffic over the roads. Information on traffic state (sensing/detection) from geographically related road operators of e.g. high-ways and local roads is collected and used in centralized traffic management algorithms. The information of the algorithms is used to dynamically activate traffic flow control scenarios (actuation). This application is not included in this document since it does not involve communication with drivers or service providers.

2.2.4 C-ITS applications in MOBiNET

MOBiNET is building “the Internet of (Transport and) Mobility”. It is an Internet-based network linking travellers, transport users, transport system operators, service providers, content providers and transport infrastructure. It connects users (people, businesses, objects) with suppliers (operators, providers, systems), and brokers (or helps to broker their interactions). At its core is a “platform” providing tools and utilities to enable those interactions, with components both for users and for suppliers.

MOBiNET comprises a User Community and a Provider Community. Users may be private or business (end-users), as well as service and data providers who consume B2B services. Providers are data (information and content) providers as well as applications (“apps”) and services providers for end users, suppliers and developers. The MOBiNET platform [19] is a place to meet and exchange or buy location- and time-dependent transport and mobility services.
In MOBiNET four applications (initial use cases) are used to demonstrate the platform:

1. Green Light Optimal Speed Advice
2. Usage Based Insurance (=Pay How You Drive)
3. Multimodal Travel Assistant
4. Parking Assistant

2.2.5 C-ITS applications in Converge

In the German project Converge a similar vision as in MOBiNET is used and a generic system architecture [20] is developed to support a flexible interaction between service providers and communication network providers. In Converge there is a specific focus on how service providers can discover and use different communication networks (short-range ITS-G5 and long-range mobile networks) from these network operators. Special attention is paid to support for governance and security/privacy within the architecture.

Both Converge and MOBiNET develop a platform to support an e-Market place with elements for discovery, authorization and billing of for applications from service providers and C-ITS networks from communication providers.

2.2.5.1 C-ITS applications in VRUITS

In the EU FP7 VRUITS project a number of typical VRU safety applications is defined and worked out in an architecture:

1. Intelligent Pedestrians Traffic Signal (IPTS)
2. Intersection Safety for VRU's (INS)
3. VRU presence warning via
    - VRU presence warning via VRU Beacon System (VBS)
    - VRU presence warning via Roadside Pedestrian Presence (RPP)
    - VRU presence warning via Bicycle-to-Car Communication (BCC)
    - VRU presence warning via Pedestrian-to-Car communication (P2C)
    - Road safety via Powered Two Wheel Vehicle Info System PTW-VIS)
    - VRU warning via Cooperative VRU Detection (CVD)
4. Green Wave for Cyclist (GWC)

The detailed descriptions of these applications can be found in [21].

2.2.6 C-ITS applications in DITCM 1.0

In the DITCM 1.0 architecture project, the state-of-the-art analysis of the C-ITS applications in EU research projects identified a large number of C-ITS applications (100+) available as offerings. However, there is limited consistency in the naming and description of these applications. One should be aware of this when 'comparing' applications or services between projects. The C-ITS applications are typically implemented by market parties in different ways, to have a differentiated service offering compared to competitors and will therefore depend on a suitable individual business model and/or technical approach.

In the DITCM 1.0 architecture project a set of 23 applications was selected by the DITCM stakeholders as starting point for the architecture description, see Table 1. This set covered the Day One applications of the Amsterdam Group and additional applications from the DITCM stakeholders. The table shows if the application in DITCM 1.0 is described with cooperative and connected communication systems:

- 15 applications with use of cooperative (ITS-G5) communication only
- 6 applications with cellular communication only and
- 2 applications (IVS and Rerouting) with hybrid communication.

Table 1 ITS applications covered in DITCM 1.0 architecture project

Application	**Type of Communication**	
	Cooperative	**Connected**
1. Incident Warning	V2I+I2V	No
2. Road Works Warning	I2V	No
3. Hazardous Location Warning	V2V	No
4. Red Light Violation Warning	V2I+I2V	No
5. Emergency Brake Light	V2V	No
6. Slow Vehicle Warning	V2V	No
7. In Vehicle Signage	I2V	Yes
8. Cooperative Adaptive Cruise Control	V2V	No
9. Merging Assistant	I2V	No

10. Shockwave Damping	V2I/+I2V	No
11. Green Light Optimal Speed Advice	V2I+I2V	No
12. Green Wave	V2I+I2V	No
13. Stopping Behaviour Optimization	I2V	No
14. Priority Request	V2I	No
15. Rerouting	I2V	Yes
16. Cooperative Traffic Information Service	V2I	No
17. Intermodal Route Planner	No	Yes
18. Navigation	No	Yes
19. Eco Route Planner	No	Yes
20. Electrical Vehicle Charging Point Planner	No	Yes
21. Smart Parking Assistant	No	Yes
22. Pay How You Drive	No	Yes
23. Probe Vehicle Data	V2I	No

The Amsterdam Group [22] is a strategic alliance to facilitate the deployment of cooperative ITS in Europe. It includes both car manufacturers and road operators from CEDR, ASECAP, POLIS and Car2Car-CC. The group has developed a joined roadmap for the deployment of cooperative ITS. They have defined a set of "day one" applications to start the initial deployment of C-ITS. The set includes both V2V and applications and I2V applications for urban, interurban and rural environments:

- V2V "day one" applications:
  1. Hazardous location warning => DITCM 1.0 Hazardous Location Warning
  2. Slow vehicle warning => DITCM 1.0 Slow vehicle warning
  3. Traffic jam ahead warning => DITCM 1.0 Hazardous Location Warning
  4. Stationary vehicle warning => DITCM 1.0 Slow vehicle warning
  5. Emergency brake light => DITCM 1.0 emergency brake light
  6. Emergency vehicle warning => DITCM 1.0 Slow vehicle warning
  7. Motorcycle approaching indication => DITCM 1.0 Slow vehicle warning
- I2V "day one" applications:
  1. Road works warning => DITCM 1.0 Road works warning
  2. In-vehicle signage => DITCM 1.0 In-vehicle signage
  3. Signal phase and time => DITCM 1.0 GLOSA and Green wave
  4. Probe Vehicle Data => DITCM 1.0 Probe Vehicle Data

2.3 Selected applications for the architecture

The following applications are selected to build the aggregated system architecture in Section 4, with the physical and functional building blocks and the information flows. All applications of the A58, ITS Corridor, PPA and DITCM 1.0 project are in scope. From the projects MOBiNET, Converge and VRUITS a representative set of applications is selected. The detailed descriptions of the applications with data flows in sequence diagrams can be found in Section 7 (Appendix A).

2.3.1 V2V applications

Application	Project
1. Hazardous Location Warning	DITCM 1.0
2. Emergency Brake Light Warning	DITCM 1.0
3. Slow Vehicle Warning	DITCM 1.0
4. Cooperative Adaptive Cruise Control	DITCM 1.0

2.3.1.1 Hazardous Location Warning (HLW)

Application area: safety - project: DITCM 1.0
A vehicle detects a hazardous location by analysing all available in-vehicle sensor information. The vehicle Electronic Stability Program (ESP) can for example detect slippery spots on the road. The vehicle can broadcast this information on a hazardous location to its environment. Other cars or motorcycles receive the information and the system can either warn the driver if the hazardous location is on the route in front or forward the information to other vehicles. Also incidents detected by in-vehicle sensors (e.g. inflated airbag) can be broadcast by vehicles via an Incident Warning message [source: DITCM 1.0, based on C2C].

2.3.1.2 Emergency Brake Light Warning (EBLW)

Application area: safety - project: DITCM 1.0
This function enhances the safety of vehicles in a dense driving environment. It aims to avoid (fatal) rear end collisions which can occur if a vehicle driving ahead suddenly brakes on highways, especially in dense driving situations or in situations with decreased visibility. The driver will be warned before he is able to realize that the vehicle ahead is braking hard, especially if he/she does not see the vehicle directly (vehicles in between) [source: DITCM 1.0, based on DriveC2X].

2.3.1.3 Slow Vehicle Warning (SVW)

Application area: safety - project: DITCM 1.0
The slow vehicle warning system is designed to aid the driver in avoiding or mitigating rear-end collisions with vehicles in front of the own car. The driver will be alarmed through driver notification or warning of the impending collision on slow vehicles. The system does not attempt to control the vehicle in order to avoid an impending collision; instead it warns the following vehicles on the potential danger of the slow vehicle [source: DITCM 1.0, based on DriveC2X]

2.3.1.4 Cooperative Adaptive Cruise Control (CACC)

Application area: traffic flow - project: DITCM 1.0
CACC (also called Platooning) is Cooperative Adaptive Cruise Control based on communication of car position, speed and other vehicle properties of nearby cars. CACC is an advance of current generation Adaptive Cruise Control (ACC) systems, where speed is adjusted based on the distance to the nearby car in front. An on-board algorithm in the vehicle is used to calculate speed, headway and lane usage for optimal traffic flow. This information is used to control the vehicle speed automatically or to advice driver. The algorithms are designed to enable shorter time headways in order to improve traffic flow for a variety of traffic situations (e.g. lane merge/split). The vehicle type (i.e. truck or passenger car) is considered.
The optimal speed is calculated using motion data (i.e. position, speed and accelerations) of other nearby vehicles. The motion data acquired and sent by

individual vehicles (vehicle-to-vehicle (V2V) communication) and/or detection and communication is done using the roadside infrastructure (RSU) [source: DITCM 1.0, based on Spits].

2.3.2 I2V applications

Application	**Project(s)**
1. Incident Warning[1]	DITCM 1.0
2. Road Works Warning	ITS Corridor, DITCM 1.0
3. Traffic Jam Ahead Warning	A58
4. Red Light Violation Warning	DITCM 1.0
5. In Vehicle Signage	ITS Corridor, DITCM 1.0
6. Merging Assistant (for CACC)	DITCM 1.0
7. Shockwave Damping (via Speed Advice)	A58, DITCM 1.0
8. Green Light Optimal Speed Advice	MOBiNET, DITCM 1.0
9. Green Wave (via Speed Advice)	DITCM 1.0
10. Stopping Behaviour Optimization	DITCM 1.0
11. Pay How You Drive	MOBiNET, DITCM 1.0
12. Navigation related applications:	
a. Rerouting / Smart routing / Traffic Information	A58, PPA, DITCM 1.0
b. Intermodal Route Planner	MOBiNET, DITCM 1.0
c. Eco Route Planner	DITCM 1.0
d. EV Charging Point Planner	DITCM 1.0
e. Smart Parking Assistant	PPA, DITCM 1.0

2.3.2.1 Incident Warning (IW)

Application area: safety - project: DITCM 1.0
The objective of this function is to provide information about one or more incident locations (e.g. vehicle breakdowns) on the driver's route. The most relevant factor is to provide the information about the location of the incident as soon as possible after the event. It must be taken into account that the vehicles involved in the incident might not be able to send out any messages. Therefore, the challenge consists in the ability to detect incidents by recognizing its/their situation from the outside [source: DITCM 1.0, based on DriveC2X].

2.3.2.2 Road Works Warning (RWW)

Application area: safety - project: ITS Corridor, DITCM 1.0
Construction sites and temporary maintenance working areas are accident black spots, because static traffic signs are ignored or realized too late. In V2V enabled systems, the road operator can communicate directly with a driver by I2V communication about traffic information, road works, restrictions, instructions, advice etc. I2V communication enhances the operational integration of local traffic management and in-car systems to improve safety, traffic efficiency and helps to protect the environment. A Road Works Warning is sent by a roadside (or road works trailer) to approaching vehicles via cooperative communication. Road Works

[1] Incident Warning is a local real-time warning for drivers. Incident Information is global information service and is mostly part of Traffic Information Services (with traffic jams, predicted travel times, road works, etc.).

Information (RWI) is a related application used by road operators to inform road users – via service providers - on planned and actual road works for pre-trip and on-trip navigation. [source: DITCM 1.0, C2C-CC]

In the ITS Corridor project the application is described in detail in a functional specification [Message Set and Triggering Conditions for Road Works Warning Service, Amsterdam Group, version 1.1, July 2014]. In this document different types of road works are described with a reference to the specific road situation (with objects, road infrastructure, traffic control measures and traffic signs) and a translation to the corresponding I2V DENM message sets. The road works types are:

- Short term mobile road works
- Short term stationary road works
- Long term stationary road works

The roadside systems support either a **stand-alone service** where only limited information is available (e.g. position of trailer, arrow position etc.) and no connection to a back-end is used, or a **basic service** where information like reduced maximum speed, status of hard shoulder, position of works area (length, closed lane information, position of trailer) is available via a back-end system [source: ITS Corridor].

In the document no explanation is given how the back-end of the roadside systems is connected to back-office systems. This is left to the road operator.

2.3.2.3 Traffic Jam Ahead Warning (JAW)

Application area: safety – project: A58
The objective of this function is to provide information about one or more locations with traffic jam tail on the driver's route. The most relevant factor is to provide the information about the location of the tail of the traffic jam as soon as possible after the event. It must be taken into account that the vehicles involved in the traffic jam might not be able to send out any messages. Therefore, the challenge consists in the ability to detect traffic jams by recognizing its/their situation from the outside [source: A58].

2.3.2.4 Red Light Violation Warning (RLVW)

Application area: safety - project: DITCM 1.0
The Red Light Violation Warning (RLVW) service aims to increase drivers' alertness at signalized intersections in order to reduce the number and severity of collisions. Although the focus of the service is on red light violations, the service also addresses situations involving emergency vehicles as well as the various right of way rules [source: DITCM 1.0, based on Compass4D].

2.3.2.5 In-Vehicle Signage (IVS)

Application area: traffic flow - project: ITS Corridor, DITCM 1.0
Traffic signs are used for prohibitions, to inform, advice, or warn drivers. They can be temporary or permanent, and static or dynamic. In-vehicle signage brings part or all this information inside the vehicle, and thus can be personalized: only relevant information for the driver, at the moment it is relevant, can be communicated with the driver, in the most appropriate way. Significant costs are involved in installing

and maintaining all these traffic signs, and in-vehicle signage can reduce the costs related to the provisioning of the information to the driver: the aim of in-vehicle signage is to improve the effect of providing the information (safety, traffic flow, comfort, etc.) at a reduced cost. It is important to consider that complexity of the implementation is tightly coupled to the requirements. In-vehicle signage can be provided as an add-on service to a navigation service and requires no strict guarantees, but that is changed significantly if in-vehicle signage is aimed to be a replacement for (dynamic) traffic signs [source: DITCM 1.0].

2.3.2.6 Merging Assistant with CACC (MA)

Application area: traffic flow - project: DITCM 1.0
A vehicle wants to join the highway (example). An application at the RSU determines the positions of the vehicles on the highway via vehicles (FCD) and roadside sensors. The RSU determines the best way the vehicle can join the main road and sends speed or location/time advice to the vehicle. If the vehicle is not equipped with an OBU, the information can also be presented to the driver by a roadside system. In a more advanced version, the vehicles on the main road can also get speed advice [source: DITCM 1.0, based on Spits].

2.3.2.7 Shockwave Damping via Speed Advice (ShD)

Application area: traffic flow - project: A58, DITCM 1.0
Shockwaves occur on highly occupied roads when drivers react on spontaneous manoeuvres, resulting in a slow down or stopping of the traffic. The location where the vehicles stop or decrease speed can move upstream, causing a shockwave in the traffic flow. This use case will prevent or dissolve shockwaves by detecting shockwaves as soon as they arise and control the speed of approaching vehicles. [source: DITCM 1.0, based on Spits].

2.3.2.8 Green Light Optimal Speed Advice (GLOSA)

Application area: traffic flow - project: MOBiNET, DITCM 1.0
The traffic light is connected to a roadside unit (RSU). Via this connection the traffic light can broadcast information to nearby vehicles. This includes information about the topology of the intersection and the phase schedule of each traffic light signal. Approaching vehicles can receive this information and calculate the optimal approaching speed. At optimal approaching speed, energy-efficiency is improved and stops may even be completely avoided [source: DITCM 1.0, based on C2C].

2.3.2.9 Green Wave via Speed Advise (GW)

Application area: traffic flow - project: DITCM 1.0
Green Wave is a related application of GLOSA. A green wave is an intentionally induced phenomenon in which a series of traffic lights are coordinated to allow continuous traffic flow over several intersections in one main direction. Any vehicle travelling along with the green wave will see a progressive cascade of green lights, and not have to stop at intersections. A driver is informed about the approximate speed at which the vehicle should travel to be part of the green wave [source: DITCM 1.0, based on en.wikipedia.org].

2.3.2.10 Stopping Behaviour Optimization (SBO)

Application area: traffic flow - project: DITCM 1.0
This use case optimizes the way drivers stop at an intersection. Based on the signal phase and timing, the approach can be optimized, e.g. by reducing the driving

speed more gradually. While idling, 'time-to-green' information can be used for engine control and engine turn off. Start delay prevention support uses 'time-to-green' information to minimize time loss at the start of a green light phase due to reaction time etc. [source: DITCM 1,0, based on Compass4D].

2.3.2.11 Pay How You Drive (PHYD)

Application area: comfort – projects: MOBiNET, DITCM 1.0
Usage-based insurance, also known as pay-as-you-drive (PAYD) and pay-how-you-drive (PHYD) and km-based auto insurance is a type of automobile insurance whereby the costs of motor insurance are dependent upon type of vehicle used, measured against time, distance, behaviour and place [source: DITCM 1.0, based on en.wikipedia.com].

2.3.2.12 Navigation related applications (NAV)

Navigation is a basic application which can be extended with additional smart applications like smart routing and Point-of-Interest based applications like smart parking assistant. Automotive navigation uses a GPS navigation device to acquire position data to locate the user on a road on a map. Using the road database, it gives directions to other locations along roads in this database. Dead reckoning using distance data from sensors attached to the vehicle, a gyroscope and an accelerometer can be used for greater reliability, as GPS signal loss and/or multipath can occur due to urban canyons or tunnels [source: DITCM 1.0, based on en.wikipedia.org].

Traffic Information Service (TIS)

Traffic information Service (application area: comfort) empowers road users to make decisions on their traveling behaviour on the actual, or even predicted future, situation of the roads network. It enables the road user to limit their traveling time, reduce fuel consumption, change their traveling plans to prevent excessive traveling time, and improves their wellbeing by having control over their situation. Traffic information can be provided directly to the road user, or can be used in an advisory system like a navigation device.

Rerouting (RR)

Application area: comfort - projects: A58, PPA, DITCM 1.0
With Rerouting / Smart Routing a driver wants to drive to a specific destination and based on the origin and destination a specific route is determined, e.g. by a navigation device. Depending upon actual traffic information, e.g. traffic jams and road works, the optimal route may change during the trip. With rerouting, the navigation device and the driver are advised with a new route in case a new optimal route exists. Rerouting can take the vehicle type into account.

A related application is the Eco Route Planner (application area: environment).
Finding the most fuel efficient combination of vehicle, trailer, route, driver and system configuration based on mission information, traffic management data, truck and driver models and routing system. The application can also cover a use case to warn truck drivers when entering forbidden urban eco zones (with geofencing techniques) [source: DITCM 1.0, based on ECoMove].

Intermodal Route Planner (IRP)

Application area: comfort - projects: MOBiNET, DITCM 1.0

An Intermodal Route Planner is a computer system which can provide a traveller with an itinerary for an intermodal passenger transport journey. The system can provide timetable, routing and other travel information. A single journey may use a sequence of several modes of transport, meaning that the system must know about public transport services (bus, train, aero plane, tram, metro) and about transportation networks (roads, footpaths, cycle routes) for private transportation (automobile, walking, bicycle) [source: DITCM 1.0, based on en.wikipedia.org].

Electrical Vehicle Charging Point Planner (EVCP)
Application area: comfort – projects: DITCM 1.0
EV Charging Point Planner is Point-of-Interest based application. An EV Charging Point Planner is a route planner that takes into account the requirement of electric vehicles being charged periodically. The range of electric vehicles is more limited than of conventional vehicles, and depends strongly on the particular situation: weather conditions, congestion, driving speed, and road conditions can influence the range significantly. At the same time, the number of charging points is in general limited. Furthermore, charging can take significant time, potentially blocking a charging point for other vehicles, but also making the vehicle unavailable for the driver. An EV Charging Point planner takes all these aspects into account to provide the driver with an advice on how to schedule his trip, continuously updated based on changing situations.

Smart Parking Assistant (SPA)
Application area: comfort – projects: PPA, DITCM 1.0
Smart Parking Assistant is an example of another Point- of-Interest based navigation application. Part of congestion in urban environments is caused by people searching for parking places. The smart parking assistant can find a parking place in real-time. The driver can search for a parking place near his current location, or in the vicinity of a specific location. The smart parking assistant finds a parking spot based on current availability and provides the driver with a selection of parking places with static information, e.g. rates and hours

2.3.3 V2I applications

Application	**Project**
1. Probe Vehicle Data from cooperative cars	A58, ITS-Cor., DITCM 1.0
2. Probe Vehicle Data from connected cars	A58, PPA
3. Priority Request	DITCM 1.0

2.3.3.1 Probe Vehicle Data from connected and cooperative cars (PVD)
Application area: traffic flow – projects: A58, ITS-Corridor, DITCM 1.0
Traffic conditions, most notably traffic densities and average speeds, are traditionally measured by road sensors, like loop detectors or cameras. Instead of using road sensors to determine traffic conditions, it is also possible to use information provided by vehicles directly. Depending on the exact details on how the probe data is collected in the vehicle and aggregated, similar information as obtained from road sensors can be used, but also all kinds of additional information (road condition, sudden braking actions, etc.) can be collected. Probe Vehicle Data Collection (or Floating Car Data Collection) can be used as input for operational traffic management, but also for other usages of traffic information e.g. for tactical /

strategic purposes like maintenance planning. The Probe Vehicle Data could be used as additional traffic information or as substitute for traditional traffic information from cameras or road loops. Probe Vehicle Data can be collected from connected cars, via service providers, or via cooperative cars by collecting broadcast messages from these cars in cooperative roadside units, or in-vehicle units.

2.3.3.2 Priority Request (PR)

Application area: traffic flow (for specific class of vehicle) - project: DITCM 1.0
For safety, environment, traffic flow or other reasons it can be advantageous to give priority to specific classes of vehicles. The level of priority will depend on the type of vehicle. Emergency vehicles will get the highest priority, public transport can request priority, but also heavy goods vehicles could be granted some sort of priority to improve traffic flow and reduce environmental effects. In this use case, all these types of vehicles can request priority for an intersection, and the traffic light controller determines in what way it can and will honour the request. Optionally, the requesting vehicle is informed about the action taken by the traffic light based on the request. This reply can be used to assist emergency vehicles in passing an intersection, but would also allow for heavy goods vehicles to calculate their fuel consumption.

2.3.4 I2I applications

Application	**Project**
1. Local Traffic State Data	A58
2. Local Traffic Control Data	A58
3. e-Market place for service providers	MOBiNET, Converge
4. Cooperative Message Distribution	A58
5. Coordinated Traffic Management	PPA roadside

2.3.4.1 Local Traffic State Data (LTSD)

Application area: traffic flow – projects: A58
The traffic state data from the loop detectors (connected to roadside stations) is – via a traffic data provider – send to service provider. In A58 an information exchange interface is developed between one single road operator (RWS) and the data providers involved in A58. For deployment on other high-ways the information is send via a local interface could/should be provided via a centralized interface, to minimize implementation costs.

2.3.4.2 Local Traffic Control Data (LTCD)

Application area: traffic flow – projects: A58
See Figure 8-10. The traffic control measures from a road operator (dynamic speed limits) are sent to service providers [source: A58]

2.3.4.3 e-Market place for service providers

Application area: traffic flow – projects: MOBiNET, Converge
A B2B e-Market place for B2C service exchange is developed in several projects. With this market place service providers can publish their services in a service directory. Other services provider can discover these services and establish agreements on usage of these services with support from the market place on e.g. accounting and billing.

[source: MOBiNET, Converge]

2.3.4.4 Cooperative Message Distribution

Application area: traffic flow, comfort, safety – projects: A58
With this application communication providers can publish communication services and service users can send cooperative messages via different communication providers [source: A58].

2.3.4.5 Coordinated Traffic Management

Application area: traffic flow, comfort, safety – projects: A58
With this application profit (= less congestion, better traffic flow) can be gained by aligning the use of scarce road capacity of different road authorities via efficiently distributing traffic over their roads. Information on traffic state (sensing/detection) from geographically related road operators of e.g. high-ways and local roads is collected and used in centralized traffic management algorithms. The information of the algorithms is used to dynamically activate traffic flow control scenarios (actuation). With this application traffic management is coordinated between different road operators, and traffic measures (traffic light controllers, speed limits) are activated via pre-defined scenarios involving several road operators [source: PPA].

2.3.5 Vulnerable Road User applications

Application	**Project**
1. Intelligent Pedestrians Traffic Signal	VRUITS
2. Intersection Safety for VRU's	VRUITS
3. VRU warning via VRU Beacon System	VRUITS
4. VRU warning via Cooperative VRU Detection	VRUITS

The applications and sequence diagrams from VRUITS are described in [21]. In this section four selected applications are described based on the VRUITS D4.2 document. All applications in the VRUITS project rely on localization of VRU's via (i) vehicle or roadside sensors (camera, radar, etc.), (ii) a tag-based communication system (VRU-T with V-VLS, or R-VLS) or (iii) VRU's with a PID or VRU-OBU capable for ITS-G5 and/or cellular communication. The solutions differ in the system that performs situation assessment (i.e. roadside, vehicle or VRU) and in the road users that are warned i.e. driver and/or VRU.

2.3.5.1 Intelligent Pedestrians Traffic Signal (IPTS)

This application has been split into two variants:

a) IPTS with I2VRU communication (IPTS + I2VRU): in this use case of IPTS a pedestrian can activate green light demand via his smartphone and a traffic light controller provides information to the VRU via I2VRU communication on time-to-wait, pedestrian green times etc. The TLC can extend the pedestrian green phase for safety crossing, based on the user-specific profile of the pedestrian.
b) IPTS with I2V communication (IPTS + I2V): right-turning assistance for cars on a signalized intersection with simultaneous green for turning cars and pedestrians has a special focus on safety for pedestrians during allowed right turns. It warns the driver of the pedestrians' presence on crossings

where the car has no visibility. This scenario focuses on preventing collisions between right-turning cars with low/no visibility and pedestrians. A roadside sensor system, part of the Traffic Light Controller (TLC), detects the pedestrian and warns the driver of the approaching car about the presence of pedestrian crossing via I2V communication

2.3.5.2 Intersection Safety for VRU's

Intersection Safety assists the driver of a car in avoiding common mistakes which may lead to typical intersection accidents. It covers these functions: traffic light assistance, right-of-way assistance, as well as right- and left-turn assistance.

For left- and right-turn assistance, a roadside infrastructure detects the VRU, communicates this to the car which is turning right or left into the path of the VRU. The car driver is informed via a warning or the car automatically brakes, depending on the urgency of the situation. The roadside infrastructure also informs the VRU of a dangerous situation by e.g. flashing lights and / or making a sound.

For traffic light assistance or right-of-way assistance the roadside system at the intersection can detect a dangerous situation related to violation of red light or right-of-way by either VRU or car. In this scenario the car drives perpendicular to the path of the VRU. The roadside infrastructure detects the VRU crossing the intersection. The roadside system informs the car about the presence of the VRU. The RIS roadside system can also inform the VRU (via flashing lights/ sound) about the presence of the on-coming car.

Besides the above described roadside-centric solution also a car-centric solutions can be used for right-of-way assistance and right and left turn assistance, based on cooperative ITS technology: the car detects the VRU via cooperative ITS technology. Also another car at an intersection can assist in the detection of a VRU and send the position and / or path to cars in their vicinity (cooperative sensing).

2.3.5.3 VRU presence warning via VRU Beacon System (VBS)

The VRU carries a simple device (e.g. smartphone, or wearable tag in bags or clothes) that detects the presence and localizes the VRU by the roadside infrastructure or in-vehicle systems. The signal sent by the VRU device can be detected by a device installed in cars. The roadside or car is equipped with a VRU localization unit, to detect the presence or track the VRU.

The system can be used to detect the presence of a VRU close to a fixed roadside system (e.g. a signalized crossing) or can be used to locate the VRU for tracking. For this tracking function the VRU transponder system must send frequent updates. The car or roadside system calculates the trajectories of the detected VRU (target tracking) and assesses - in relation with the own car trajectory (host tracking) - the possibility of a collision between target and host. The driver is warned about a possible collision and in case of no response the system can brake autonomously to slow down the car.

A VRU beacon system can be used in several use cases on collision avoidance like Blind Spot Detection (for trucks, buses or person cars), in-vehicle Pedestrian Detection System with Automatic Emergency Braking, Bicycle-to-car communication, Roadside Pedestrian Presence, etc. For in-vehicle Pedestrian

Detection Systems the cooperative information of a VRU Beacon System is combined with in-car sensors like camera, laser, radar or infrared sensors. They warn the driver and may brake autonomously to anticipate on an impending impact (CAEB). At low speeds the system is likely to avoid a collision, at higher speeds the collision speed is at least reduced as far as possible. Cooperative information send from pedestrians or roadside systems can be included to extend the field-of-view.

2.3.5.4 VRU warning via Cooperative VRU Detection (CVD)

Through cooperative communications the field-of-view of cars can be improved by informing other cars about out-of-sight VRUs which may pose a threat. Examples of this application are VRUs at highways (e.g. person leaving a breakdown car), pedestrians walking along rural roads in low visibility circumstances, pedestrians crossing a road after a sharp turn. The detection of VRU's in some of the above use cases is based on an equipped VRU (tag, VRU-OBU or PID (i.e. smartphone)) that can be used to detect a VRU. The application Cooperative VRU Detection – or cooperative sensing - uses a system with V2V or V2I functionality in which information on unequipped pedestrians, bicyclists or PTW are forwarded to other cars. Information is relayed by cars or infrastructure to all cars within the range of interest.

2.4 ITS application types

The above described C-ITS applications can be grouped in several ways. One generic approach is to group on high-level objectives related to the application area. ETSI ITS uses three application areas in ETSI TR 102 638 (Basic Set of Applications) i.e. (i) road safety, (ii) traffic efficiency and (iii) other.

In this document this grouping is reused, with an additional split of "other" in 2 sub-categories i.e. environmental and comfort.

1. **Safety**: applications with the main objective to increase individual safety for all road users by informing/warning these road users, or directly interact with a vehicle (braking); safety warnings can be issued from individual cars via V2V communications or by infrastructure systems form road operators or
2. **Traffic flow**: applications with the main objective to increase the efficiency of the traffic flow and prevent traffic jams by informing/advising/instructing individual road users, either direct or indirect via navigation applications with rerouting; traffic flow can be influenced 'centrally' by road operators (traffic management measures via road signs) or on individually by in-vehicle navigation systems with smart routing functions;
3. **Environmental**: applications with the main objective to reduce the negative effects of traffic flow (CO_2 emission, noise, pollution). Government is often involved to define and enforce policies (e.g. via speed limits, eco-zones in city centres, etc.)
4. **Comfort**: applications with the main objective to increase the comfort of individual road users e.g. by providing up-to-date information on travel related comfort, e.g. in navigation.

The applications in the above areas will all – directly or indirectly - contribute to an increased economic profit of individual consumers, business companies or society.

Applications in the areas safety, traffic flow and comfort have often an implicit effect on the economic profit, e.g. preventing incident saves costs of repair, hospital etc.

Another way to order applications and use cases is on time and distance scale. Applications that are relevant on short time and distance scales should be handled on a local scale, e.g. avoidance via electronic brake systems are today implemented in vehicles only. The car acts as autonomous system with no (cooperative) interaction to other ITS systems.

In Figure 2-1 the C-ITS applications have been grouped by their relevant application areas (horizontal axis) and their relevant time and distance scale (vertical axis). As shown in this figure, time and distance scale are strongly correlated, i.e. a driver needs information on the road section he/she approaches in the same time scale related to his driving speed. As shown, C-ITS applications can be both related to more application areas and time scales.

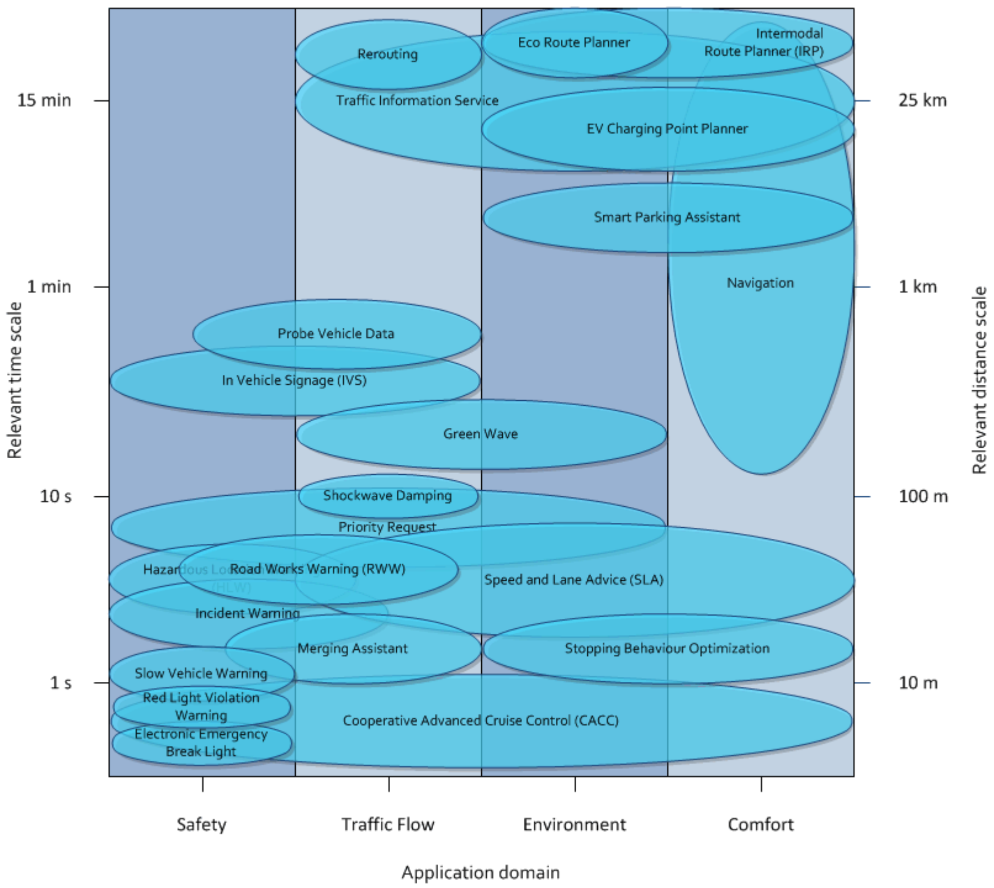

Figure 2-1 C-ITS applications per application area and time/distance scale [from DITCM 1.0]

3 Business Model Design

3.1 Introduction

The transport and mobility business domain is currently transitioning towards a service-dominant business setting. Before the transition, business settings used to be centred on the delivery of products or stand-alone services. After the transition, they will be centred on the provisioning of solution-oriented, integrated services to customers (either business organizations or individual consumers). Services may require the deployment of products, but these products become part of the delivery channel of services, not the focal point themselves. Ownership of products becomes a less relevant issue. The emphasis shifts from the value of the individual product or service to the value of the use of the product or service in an integrated context – the so-called value-in-use. A representative example of such a value-in-use is the transition from leasing a car (asset) to the provisioning of integrated mobility solutions, including public transportation, flexible work offices, etc. for a hassle-free relocation [23].

This transition though has consequences for the very basic characteristics of doing business. First, customers expect coherent solutions, not stand-alone solution fragments. Thus, solution-oriented services are of a complex nature that requires the integration of the capabilities of multiple service providers. This introduces the necessity of explicitly managed business networks, in which traditional mobility and transport service providers, equipment providers, authorities, and user organizations collaborate to co-create the value-in-use. Second, customer-driven requirements to solution-oriented services will evolve much faster than requirements to the underlying products. Rapid developments in information and transport technology will further reinforce this process. Thus, managing agility in service delivery will be a key factor in the market position of a service provider. Third, managing service complexity and business agility requires a tight integration between the structure of business strategy and models on the one hand and the structure of business operation and information management on the other hand. It is not only about what transport or mobility service to sell, but also about how to get it delivered.

Performing the transition to service-dominant business and managing its consequences is a formidable task for any non-trivial business organization. Taking a traditional top-down, business-strategy-to-operations approach will be too slow in the current fast pace of market developments. Taking a quick-win, opportunity-driven, bottom-up approach will result in isolated implementations and chaos in integration efforts. A visionary, industry-strength approach is required that is completely tuned to the service-dominant transition and that has the very basics of service business at its core. BASE/X[2] is such an approach [24].

[2] BASE/X is the acronym for Business Agility through Service Engineering in a Cross-Organizational Setting.

3.2 BASE-X framework

BASE/X is a business engineering framework for service-dominant business, i.e., business that puts service management at the forefront of its design and operation. BASE/X covers the entire spectrum from high-level business strategy definition to business information system architecture design, including elements like business model conception, business service specification and business process modelling. The very core of BASE/X is the understanding that to achieve truly agile service provisioning business, these elements cannot be treated in isolation.

To capture networked, service-oriented business, BASE/X has two core business principles:

1. Business services and the value-in-use they deliver to customers are the primary building blocks for contemporary business design and execution.
2. To deliver integrated business services as a solution to a customer, networks of providers of basic services are required. Given the volatility of many markets, these networks must be dynamic and explicitly orchestrated. Orchestration of networks is of paramount importance.

For the purposes of the current document, we focus mainly on the business design aspect of the framework, while information about business engineering principles like the organization design and IT platform design can be found in the full documentation of BASE/X [24].

3.2.1 Business Design in BASE/X

Business design in BASE/X is based on the observation that we need the distinction between business goals (the 'what' of business) and business operations (the 'how' of business) on the one hand and the distinction between the stable essence of an organization and its agile market offerings on the other hand. This leads to a model with four layers, as shown in the Figure 3-1 below.

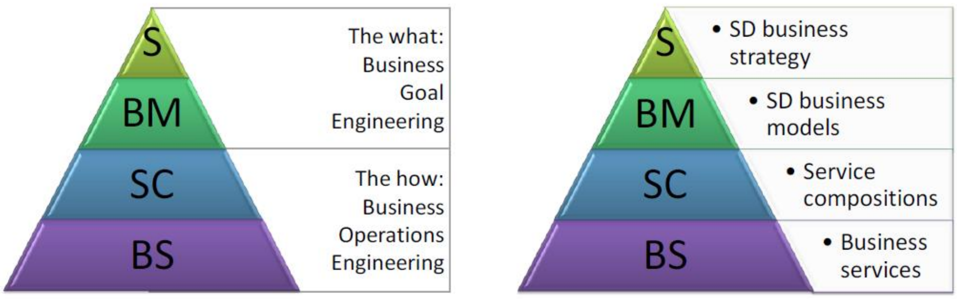

Figure 3-1 BASE/X Business Pyramids

As shown in the left side of the figure, the top half of the pyramid covers business goal engineering. As shown in the right of the figure, the top layer contains the service-dominant business strategy. This strategy describes the identity of an organization in a service-dominant market. The identity is relatively stable over time: the strategy evolves. The second layer contains service-dominant business models. Each business model describes a market offering in the form of an integrated, solution-oriented complex service: they describe a concrete value-in-use. Business models follow fluid market dynamics and are agile: they revolve – they are conceived, modified, and discarded as required.

The bottom half of the pyramid covers business operations engineering. The bottom layer contains business services, each of which contains a core service capability of the organization. As these capabilities are related to the resources of the organization (covering both personnel and large-scale technical infrastructures), they are relatively stable over time: they evolve. The third layer of the pyramid contains the service compositions. Each composition is a combination of business services to realize the service functionality required by a business model: they implement a concrete value-in-use. The combination includes business services from the organization's own set, but also business services of partner organizations in a business network. As service combinations follow business models, they are agile: they revolve with their associated business models.

In the current document we are focusing on the service-dominant *business model layer* since our aim is to provide guidelines on the design of business models for ITS applications.

3.2.2 Business Model Radar

A business model is a set of assumptions about how an organization will create value for all its stakeholders. The design of a business model is done by using tools like the Business Model Canvas (BMC) [25]. However, approaches like this are typically not focusing on service-dominant business and are organization-centric, not network-centric. Therefore, we use here a tool proposed in [26] that has a service-dominant starting point, called Service Dominant Business Model Radar (SDBMR) or Business Model Radar in short.

The Business Model Radar (depicted in Figure 3-2) uses as a central aspect the notion of Value Co-creation Proposition, which defines the proposed co-creation of value in terms of the solution to the customer's problem or customer's experience. Four concentric circles are framing this value proposition. The first one is the Networked Value Proposition, which defines a value proposition to co-create value by a co-creation actor to the solution for the benefit of the same or other actor within the ecosystem. Co-Creation Activities is the next elements defining the activities that each actor performs in the business for achieving the co-creation of value. In the business model, we also have to define the benefits/costs as the **financial and non-financial** gains/expenses of the co-creation actor participating in the value co-creation. Finally, we have the co-creation actors represented as radial regions covering all con-centric circles. These actors are the Focal Organization, Core and Enriching Partners and of course the Customer. The Focal Organization defines the role of co-creation actor that proposes the business model and participates actively in the solution or experience. A Core Partner defines the role of co-creation actor as a partner that participates actively in core of the solution or experience while an Enriching Partner element defines the role of co-creation actor as a partner that participates actively in enriching the solution or experience.

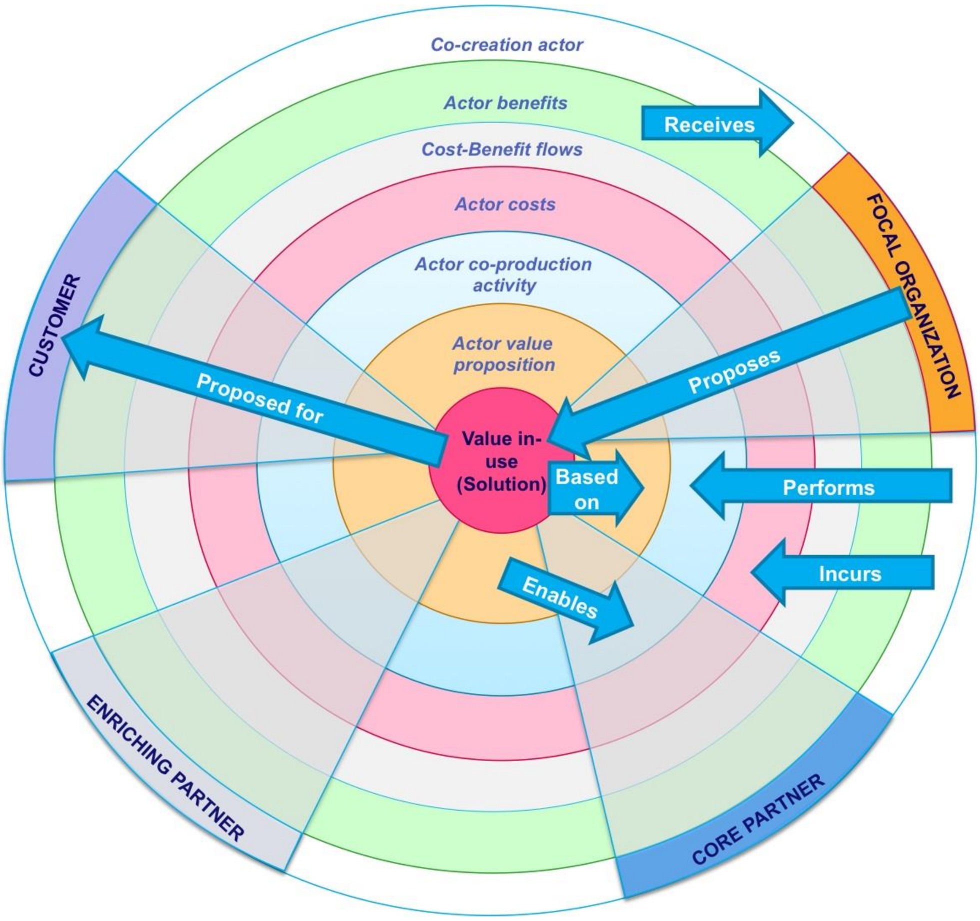

Figure 3-2 Service Dominant Business Model Radar

3.3 Stakeholders in the ITS landscape

The provisioning of mobility solutions involves many role categories with actors who play a direct or indirect role in multi-sided business models. In this section we present the main stakeholder of ITS applications, starting from general categories and specifying later more specific actors. Note here that an actor can play multiple roles in the same or different business models. For example, a company as a specific actor can act as a navigation provider and the traffic content provider in the same or in different business models.

In past projects (Compass4D [27] and MOBiNET [28]) role categories have been identified. In the current project, we enrich them in order to cover as many options as possible. For each of these role categories, we specify different types of actors that can play such roles. A complete, but non-exhaustive, list is as follows:

A. **Service Provider or Focal Organisation**: Represents the stakeholders that are contractually providing the service(s) directly or indirectly from the producers to the consumer(s). A Service Provider is the main interlocutor with the users and is directly related to the focal organisation in Figure 3-2. Usually a technological company or a navigation provider acts as a service provider. However, it could also be a different stakeholder, for example a public company owned by a consortium of cities of a region. Other typical service providers are a public transport information provider, a traffic information provider or a telematics provider. The service provider is the focal organisation in the Service Dominant Business Model Radar, shown in Figure 3-2. Also a public organisation (like a road operator) can act as a service provider by providing (safety-related or traffic flow) information directly to end-users.

B. **Customer or End-user**: Represents the stakeholders who are perceived as users of the service (Public, commercial or private) and who are willing to pay (indirect) the service provider for the service(s).
   - Driver: the real final individual user of the road network, either private or commercial, and a service. An extra distinction can be made for ITS-road users and non-ITS road users in order to take into account in some business scenarios any user who is not equipped with ITS-enabled devices.
   - Fleet manager: actor who manages a number of vehicles, such as buses, emergency vehicles, trucks or taxi cars.
   - VRU: any kind of vulnerable road user like a pedestrian or a cyclist.
   - Traveller: the individual user who travels with any kind of transportation means and uses a service.

The consumer or end-user of the service might also use the (information) service for free. In this case the service provider needs a business model were revenues are generated via stakeholders who have interest in the information provided to the end-user, e.g. a parking operator or a retailer who attract more visitors, based on the information provided by the service provider.

The Service Provider can make use of several **core and enriching partners** to provide services / technology to the focal organisation or to end-users e.g.

A. **Technology Supplier**: Represents the stakeholders that are supporting the producers of the functionality of the service(s) or the service provider with the necessary technology and devices. It can be any actor providing devices, HW platforms, SW applications, consulting services to all the other actors involved in the services e.g.:
   - RSU provider: provides complete RSUs and in some cases has the task to install and maintain the RSUs in the road infrastructure.
   - Road Sensor provider: provides any type of sensor (e.g. camera, speed sensor, location module, actuators) to be connected or integrated in a RSU in order to capture real data and information.
   - OBU provider: provides the OBUs to the car/truck maker or to retrofit installer in aftermarket scenarios.
   - Vehicle maker: represents the role of a maker of every kind of vehicle (cars, trucks, buses, ambulances, fire-fighters vehicles, etc.).
   - IT provider: provides HW and SW support for Back-Office operations.

B. **Service Enabler**: Represents the stakeholders that are supporting the service provider with necessary services and contents.
   - Data Provider or Content provider: finds and creates content (traffic data, information, basic services) to build useful services to end users (e.g. POI on maps). A data provider typically fuses data from several sources and distributes the enriched information as a service.
   - Communication (or connectivity) provider: provides the SIM card/module to be inserted into the OBU and RSU, connectivity services to users and other actors, other value-added services like location or identity management. A mobile operator is a typical example of a communication provider for mobile communication services. A similar role is needed for the provider of the RSU infrastructure (RSU infrastructure manager[3]) who has the task to provide and manage the infrastructure and to allow other actors to deploy services or to use the RSU communication infrastructure for communication services i.e. to send/retrieve information from vehicles.
   - Service Broker: plays the role of discovery and automatic integration of services via a B2B service platform. A broker can be used by consumers, service providers and service enablers (like data/information or communication providers) to discover the availability of services.

A specific type of service enablers are financial stakeholders.

C. **Financial service provider**: Represents the stakeholder(s) that are supporting the financial transactions within the business model and the assurances related to the services.
   - Payment provider: deals with the transaction management (i.e. micropayments) and any monetary compensation among actors.
   - Insurance company: allows the equitable transfer of risk of a loss or a damage in exchange for payment.

Besides the market-oriented service providers also public stakeholders have an important role.

D. **Policy Makers & Regulation:** Represents the stakeholders that are defining the policies and are monitoring the compliance with the regulation and legislation related to the services, e.g.:
   - Local/National/European Public Administration: they define the policies and monitor compliance with regulation that other actors should follow. They can provide free services to the users or, in some cases, they provide grants and funding to increase the use of ITS and to get indirect benefits.
   - Traffic Manager/Road Operator: supervises the traffic management of an area (i.e. a city or a highway) and is responsible for its optimization and for road safety.
   - Enforcement: monitoring authority and certification of violations of the "Code of the Road" and related law collections. It includes P.S.A.P.

[3] The Road Operator or Traffic Manager can act a RSU infrastructure provider for the road sections under his direct control.

(Public Safety Answering Point), that is, the collection center for emergency calls and rescue.
- Certification body: entity that certificates the adherence and compliance of products and services with standards and technical guidelines.

The following stakeholders are examples of organizations who are not directly related to traffic safety or management but might have interest that information is distributed by service or information providers, e.g. for event-related traffic and smart parking assistant applications.

A. **Event Location Provider**: Represents the stakeholders who own or hire facilities for event hosting.
   - Stadium provider: responsible (either owner or lessee) of a stadium that can hold an event (such as a concert, sport event, etc.).
   - Hall provider: responsible (either owner or lessee) of a (music) hall which can hold a music concert or an exhibition.
   - Cinema/Theatre provider: responsible (either owner or lessee) of a cinema/theatre.

B. **Event Organizer**: Represents those stakeholders who organize events and eventually gather people in a specific area or location.
   - Sports events organizer
   - Music events organizer
   - Exhibitions organizer

C. **Retailer**: Represents the stakeholders who provide facilities for accommodation or any leisure activities, attracting people in specific areas.
   - Hotel
   - Restaurant/Café
   - Shopping Mall/Shop: any owner of a shop, either individual or part of a large shopping mall in an area.

D. **Parking Operator**: Represents the stakeholders that own, manage and provide parking facilities and services. It can be either public actors, private business actors or both.

3.4 Business Models

Below we present *examples of* business model radars as blueprints for a representative set of ITS applications. In selecting the applications, we made sure that all application types regarding the area (traffic flow, safety, etc.) and application category (I2V, V2I, V2V, etc.), as well as the connection type (connected/cooperative) are represented to facilitate a broad support.

These sample radars can serve as starting point for developing concrete radars that target specific business models. This is the first step to put structure in the design of such models. Based on a number of explicitly stated assumptions, the key elements are identified (typically) in qualitative forms. The next step is to cover the full spectrum of the business side of ITS applications by performing market share analysis, time to market analysis, risk analysis and finally quantifying the cost/benefits for concrete application implementations.

For each type of ITS application below, we first selected the required stakeholders that contribute to a specific value-in-use. The focal organization and a customer segment is a crucial step in the design of a business model. After their selection, core and enriching partners complete the list of stakeholders. For each of them, we identified relevant value propositions, their co-creation activities based on their business capabilities and finally the costs/benefits (both financial and non-financial) related to the current business model.

A list of the applications is presented in Table 2 below.

Table 2. Selected list of ITS applications for which the Business Models are defined

Nr	Application Area	Application Category	Service	Cooperative/ Connected
1	Traffic flow	I2V/V2I/I2I	Traffic Information Service with Floating Car Data collection	Connected/ Cooperative
2	Traffic flow	I2V	Shockwave Damping	Cooperative
3	Safety/Traffic flow	I2V	Road Works Warning	Cooperative
4	Safety	V2V	Emergency Brake Light Warning	Cooperative
5	Comfort	I2V	Intermodal Route Planner	Connected
6	Environmental	I2V	Green Light Optimal Speed Advise	Cooperative
7	Environmental	I2V	Green Light Optimal Speed Advise	Connected
8	Environmental/ Comfort	I2V	Smart Parking Assistant	Connected
9	Comfort	I2V	Pay How You Drive	Connected

3.4.1 Traffic Flow: Advanced Traffic Information Service via Floating Car Data collection

In this business model, the co-created value in use is providing an informed driving experience through the advanced traffic information service. A Traffic Data Provider gathers traffic information from three different sources:

- Probe Vehicle Data from connected vehicles, provided by a Service Provider (usually a Navigation Provider)
- Probe Vehicle Data from cooperative vehicles, provided by a Communication Provider
- Local Traffic Information, provided by a Road Operator (info can be aggregated, or local data from loops)

After fusing all data, the enhanced traffic info is sold to a Service Provider who is the main interaction point with the Driver through an in-car application. The service for end-users can be free or charged (e.g. on a per-contract basis or on a fixed periodic fee (month/year). The radar is shown in Figure 3-3, and shows the option where an end-user is willing to be charged for the Informed Driving Experience.

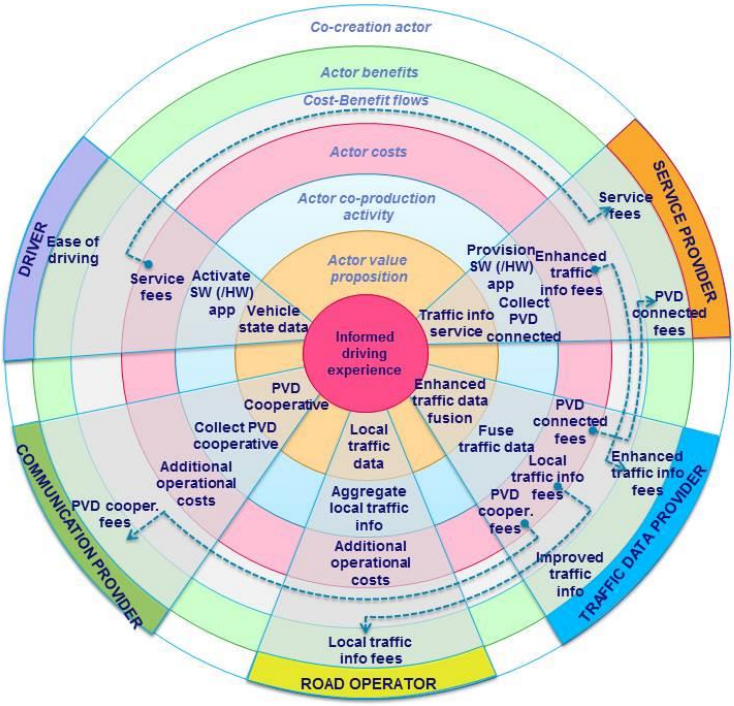

Figure 3-3 Business Model Radar for *Traffic Information Service* with FCD for Drivers with Connected/Cooperative Systems

3.4.2 Traffic Flow: Shockwave Damping

The value-in-use of the Shockwave Damping service is jam-free driving, which is achieved by attenuating the traffic jam. A Service Provider has the role of providing a speed advice to the driver. This is achieved with the help of Road Operators who have the right traffic information and calculate speed profiles. This information is sold to the Service Provider in terms of service fees. In turn, the Service Provider charges its users for the service, as part of an *informed driving experience* service. Other revenue models - not shown in Figure 3-4 - are possible e.g. a free service to end-users with revenue from selling collected data or aggregated information, or advertisements or a freemium model with a free basic service combined with premium paid service. Since the business model is for services using Cooperative systems, OBU and RSU providers are included for the communication part. OBUs can be paid by the Service Provider who may incorporate this expense into the service fees for the drivers. Of course, there is always an option that the Driver is exclusively responsible to acquire and pay the OBU. Also, an assumption that we make is that the RSUs are not provided by the Road Operator but from a separate RSU Provider. In that case, the Road Operator can finance the RSU equipment.

The business model radar is presented in Figure 3-4 below.

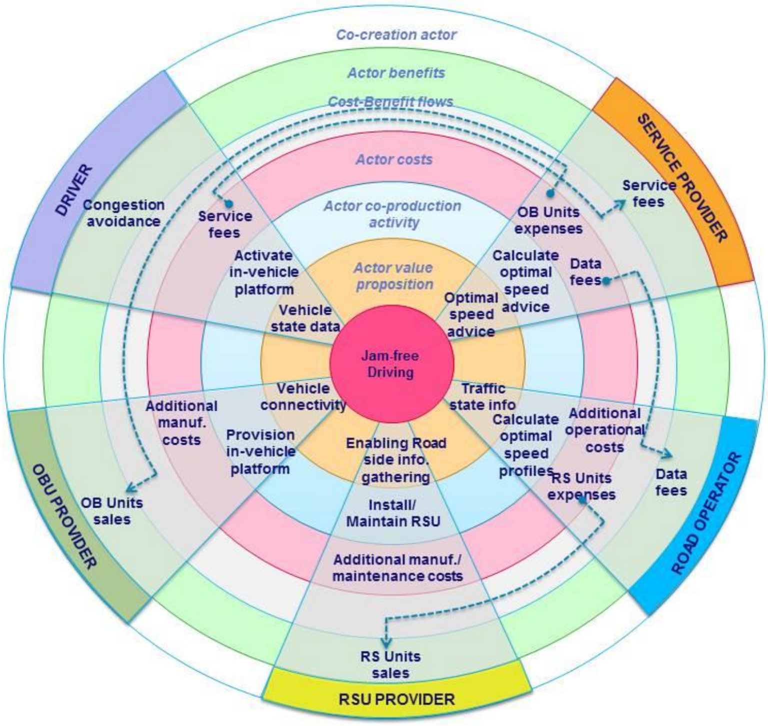

Figure 3-4 Business Model Radar for *Shockwave Damping* with Cooperative Systems

3.4.3 Safety/Traffic flow: Road Works Warning

By providing warnings about road works, this results in a safe driving solution for drivers. In order to achieve that, Road Operators provide information about road works to a Service Provider who is responsible to transmit warnings to Drivers. Road Operators offer road works data to the Service Provider, which in turn incurs from the Drivers for the provided information service. Assuming that the service is provided with Cooperative systems, OBU and RSU providers are included for the communication part. Similarly like in Shockwave Damping application, OBUs can be paid by the Service Provider. The business model radar is presented in Figure 3-5 below. Note that the service fees for Drivers in this figure are not for specific safety warnings, but for an *informed driving experience* service for safe and informed driving. Other revenue models - not shown in Figure 3-5 - are possible e.g. a free service to end-users with other indirect revenue streams.

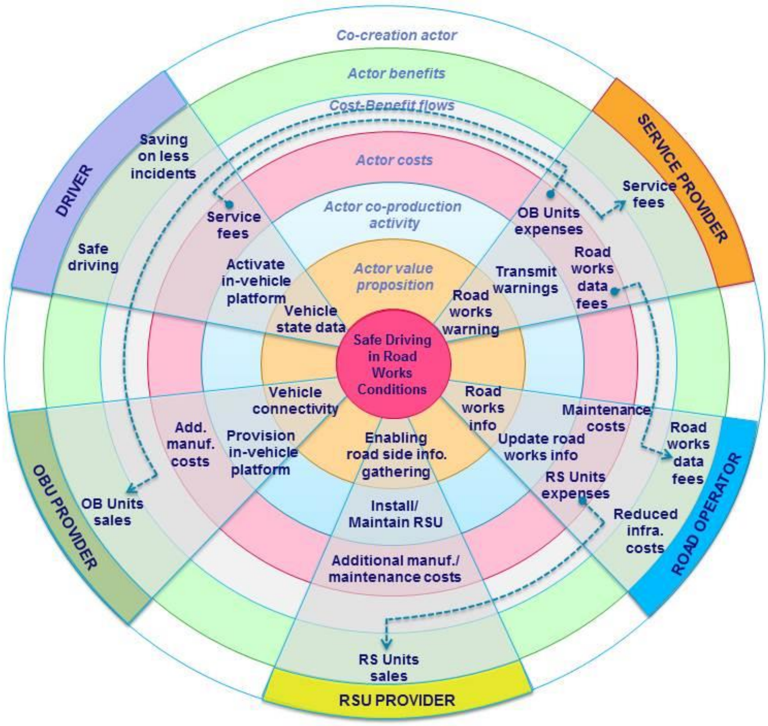

Figure 3-5 Business Model Radar for *Road Works Warning* with Cooperative Systems

3.4.4 Safety: Emergency Brake Light Warning

Safe driving is the value-in-use in this business model like the previous one, but different actors contribute to that. A main difference is that we need at least two drivers so the service has meaning. A Service Provider provides the SW/HW application to warn drivers about braking vehicles ahead of them. The main flow of money is the service fees that Drivers Pay to the Service Provider. An OBU provider is included for the communication in Cooperative Systems. Note here that since the application is V2V, a car manufacturer can undertake the role of the Service Provider. The business model is shown in Figure 3-6.

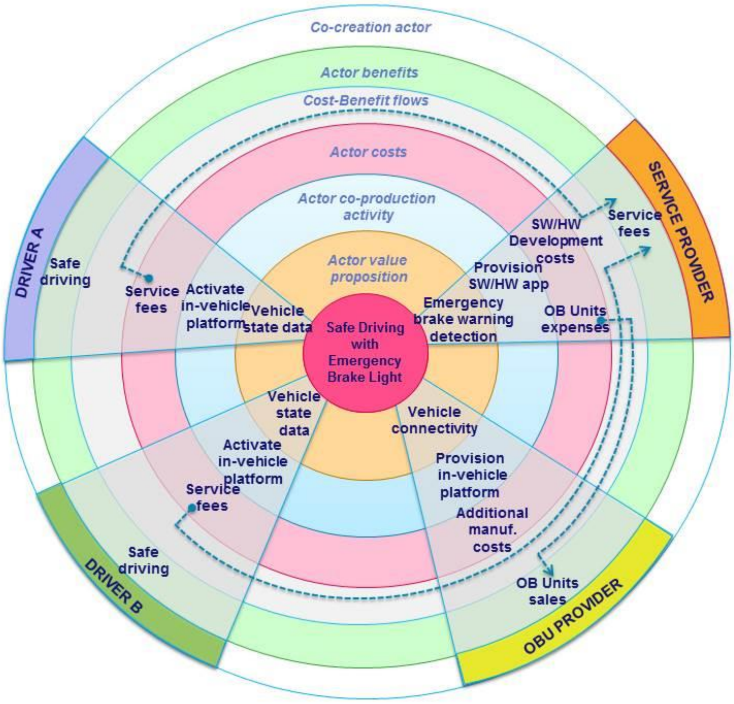

Figure 3-6 Business Model Radar for *Emergency Brake Light* with Cooperative Systems

3.4.5 Comfort: Intermodal Route Planner

Travellers care about convenient, reliable and fast relocation from a point A to point B. A service like an Intermodal Route Planner provides all the right information to support that value-in-use. A Service Provider gathers all information from Public Transport Information Providers and Traffic Information Providers in order to calculate the optimal route for a traveller. This route may contain all means of transport that use ITS, i.e. car, train, bus, tram, metro. After the route is planned, a Navigation Provider can guide the traveller to his destination. A main assumption we make here is that the Navigation Provider charges the Service Provider service fees in order to provide navigation. However, these fees are included in the service fees that the Service Provider charges its customers. The radar is presented in Figure 3-7.

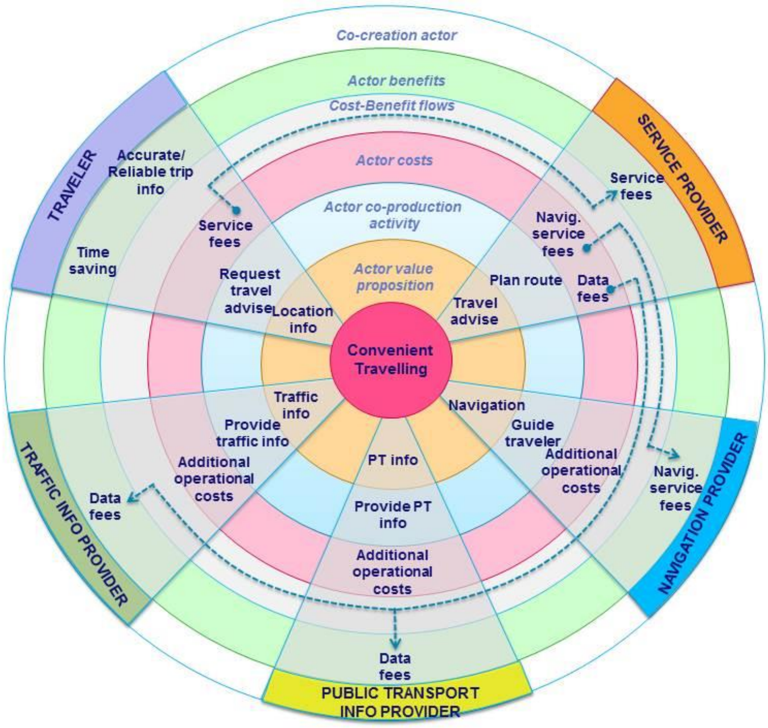

Figure 3-7 Business Model Radar for *Intermodal Route Planner* with Connected Systems

3.4.6 Environmental: GLOSA – Cooperative Systems

Road Operators manage the information of traffic lights and create optimal speed profiles. These profiles are forwarded to a Service Provider who has the task to calculate a speed advice to be sent out to a driver. OBU and RSU providers contribute to the business model by providing the right equipment. The radar is shown in Figure 3-8. Note that the service fees for Drivers in this figure are optional for an *informed driving experience* for safe and informed driving. Other revenue models - not shown in Figure 3-8 - are possible e.g. a free service to end-users with other indirect revenue streams.

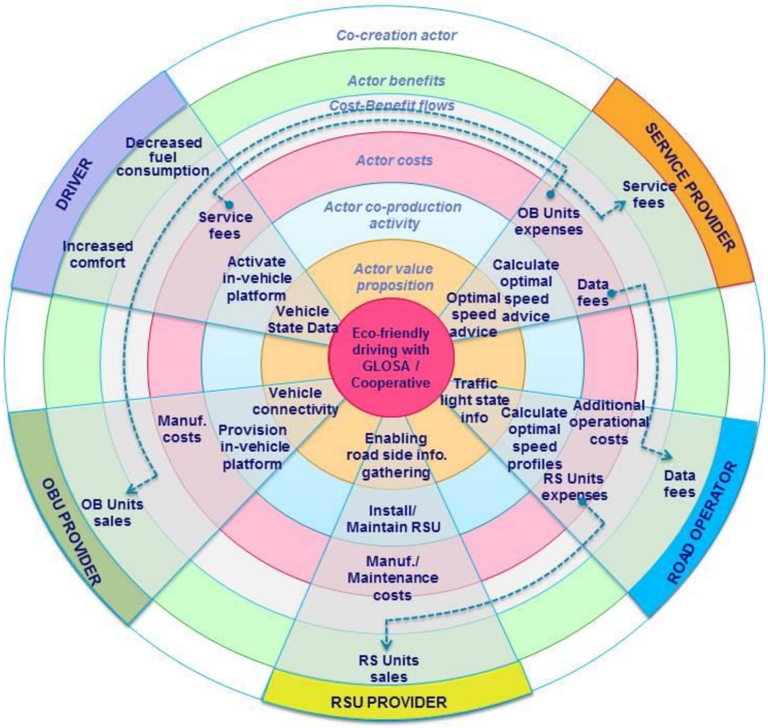

Figure 3-8 Business Model Radar GLOSA for Cooperative Systems

3.4.7 Environmental: GLOSA – Connected Systems

In case of Connected Systems, the OBU Provider can be excluded since the provisioning of the service to the Driver can be done through a mobile application. Road Operator, RSU Provider and Service Provider have the same roles as in the previous business model. The radar is presented in Figure 3-9. Note that the service fees for Drivers in this figure are optional for an *informed driving experience* for safe and informed driving. Other revenue models - not shown in Figure 3-9 - are possible e.g. a free service to end-users with other indirect revenue streams.

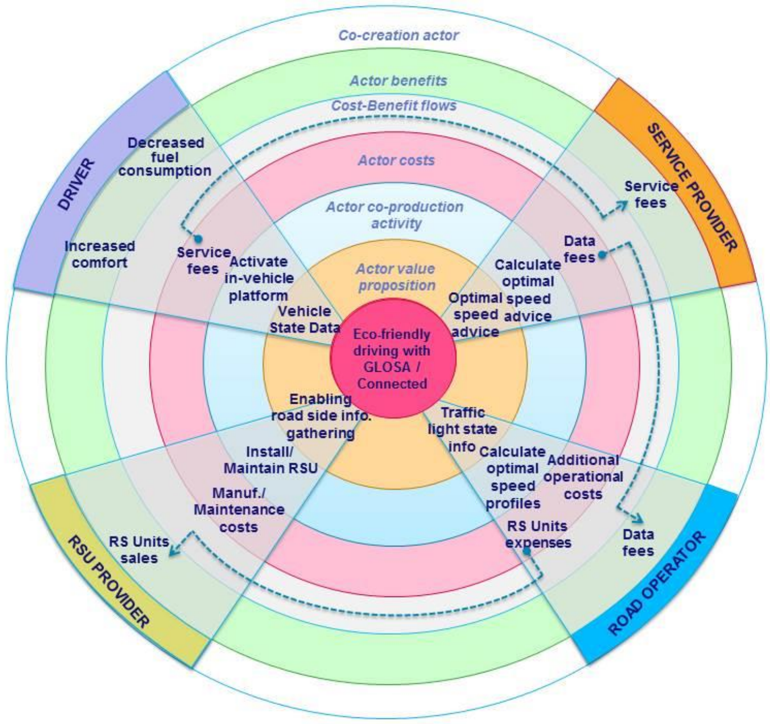

Figure 3-9 Business Model Radar for *GLOSA for Connected Systems*

3.4.8 Environmental/Comfort: Smart Parking Assistant

Parking in urban areas is a tough task and causes a lot of congestion problems. A service that will result in smart parking as a value-in-use requires a number of stakeholders. Assuming that the service is for advice on parking in parking areas and garages (and not in free slots along roads), the Parking Providers need to announce their free parking slots, thus selling their data to a Service Provider. This information is then used by the Service Provider to plan the route and advise the end user. A Navigation Provider is included for providing navigation towards the parking area. We make the assumption that the Navigation Provider charges the Service Provider for the navigation services (In case the Navigation Provider is the main Service Provider, then there is no need to distinguish these two roles). The business model radar is shown in Figure 3-10.

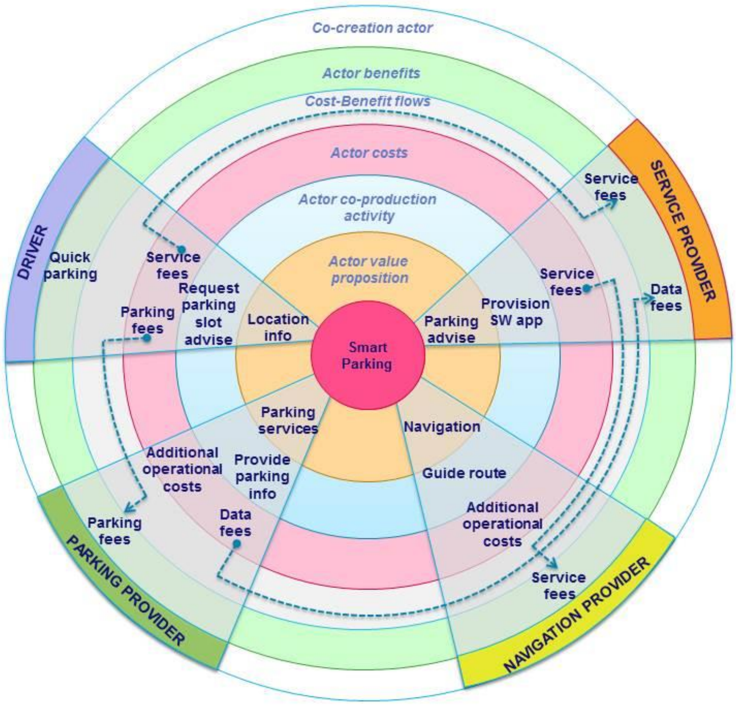

Figure 3-10 Business Model Radar for *Smart Parking Assistant* with Connected Systems

3.4.9 Comfort: Pay-how-you-drive

The idea behind this application is that the insurance costs of a vehicle are not fixed but depend on the type of vehicle, the covered distance, the measured time and other relevant parameters that depict the way of driving. In that way, “safe” drivers are rewarded based on present patterns of driving behaviour, rather than on a reflection of driving history. A Telematics Provider is responsible to gather all the right information from a vehicle and sell it to the Service Provider. The Service Provider will calculate the insurance formula and provide a customized insurance scheme per driver. OBUs can be paid by the Service Provider as an incentive for Drivers to install the appropriate equipment. This cost can however be incorporated in the insurance fees that Service Provider charges its customers. The business model radar is shown in Figure 3-11.

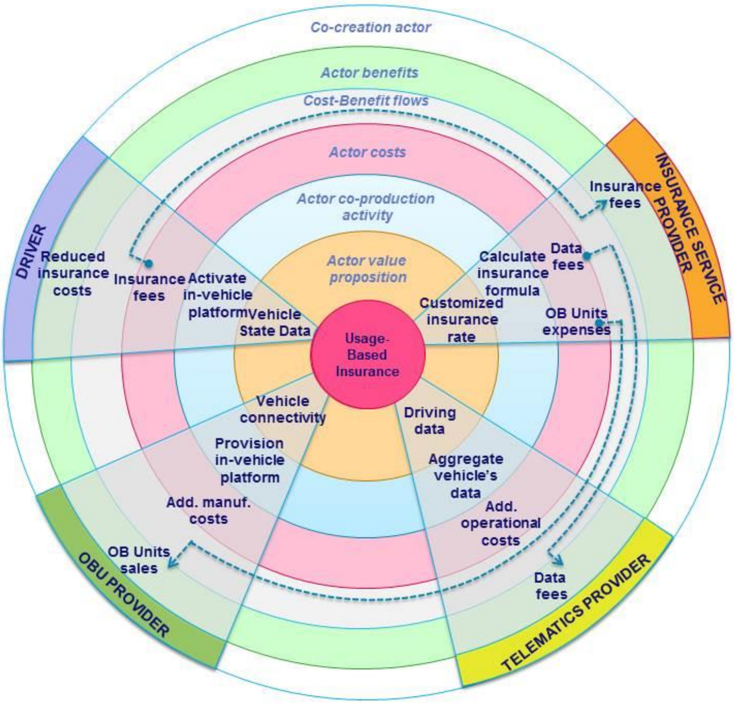

Figure 3-11 Business Model Radar for *Pay How You Drive* with Connected Systems

4 System architecture

4.1 Introduction

In this chapter the ITS system architecture is described. The system architecture is **descriptive** and not prescriptive, and is described with 'building blocks' in several dimensions. Before analysing the elements of an architecture, we need to understand that architectures of large information systems are large and complex themselves. It is necessary therefore to look at the architecture in a well-structured framework. In the current project, we make use of the framework which relies on a set of four architecture dimensions. These are:

- The aspect dimension, which describes a number of aspects from which we can view an architecture, providing a certain 'cross-section' of an entire architecture description.
- The aggregation dimension, describing the levels of aggregation which determine the level of detail of an architecture description – ranging from very coarse (few elements) to very detailed (many elements).
- The abstraction dimension, which describes the abstraction levels at which we describe an architecture, ranging from very abstract (i.e., few concrete choices have been made) to very concrete (i.e. all concrete choices have been made).
- The realization dimension, describing the spectrum from very business-oriented descriptions (no attention for IT elements) to very IT-oriented descriptions (no attention for business elements).

Each architecture model has a specific value with respect to the aggregation, abstraction and realization dimensions. Thus, we can say that each architecture model can be placed at a specific point in a design space consisting of these three dimensions. When performing an architecture design process, we have to traverse the design space. We start at an abstract, highly aggregated, business-oriented architecture specification. In a number of design steps, we need to arrive at a concrete, detailed, IT-oriented specification. To visualize this process, we make use of a three-dimensional design "cube", as shown in Figure 4-1 where each cell represents a specific combination of values along the aggregation, abstraction and realization dimension. Each cell of the cube may contain a number of architecture models.

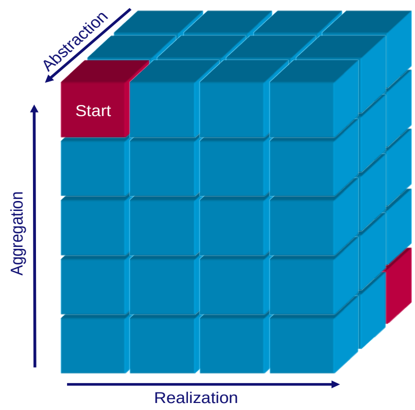

Figure 4-1 Three-dimensional design "cube"

Within an aspect dimension, the architectural models can be developed in a stepwise fashion along the abstraction, aggregation and realization dimensions. Performing a complete architecture design process for a specific aspect means going via a number of model transformations from the front top left cell (labelled “Start”) to the back bottom right cell. In the current document we follow the top down process to design more abstract and clustered architecture models.

The approach to describe the architecture is similar to the DITCM 1.0 architecture project and is extended with the applications in the selected projects as described in Section 2, as well as some external frameworks including the one by the US Connected Vehicle Reference Implementation Architecture (CVRIA) [29].

With respect to the *aspect* dimension, the architecture in this document is described in three views:

- Physical View: describes the physical sub-systems and the communication interfaces between these sub-systems;
- Functional View: describes the application objects (or functional components) that are attached to the physical objects as well as abstract functions (processes) within application objects and their logical interactions (data flows) between functions; ITS applications are selected from earlier EU and NL research and running deployment projects and are used as the basis for system architecture; The system architecture will support the functionality as described in the ITS applications, but the functional requirements are not included in this document
- Communications View: describes the interfaces between the physical and functional building blocks via a layered set of communications protocols that are required to support communications among the sub-systems. Also a reference to specifications or detailed descriptions of sub-systems and interfaces is given where applicable

In Figure 4-2 the relation between the three architecture dimensions is shown.

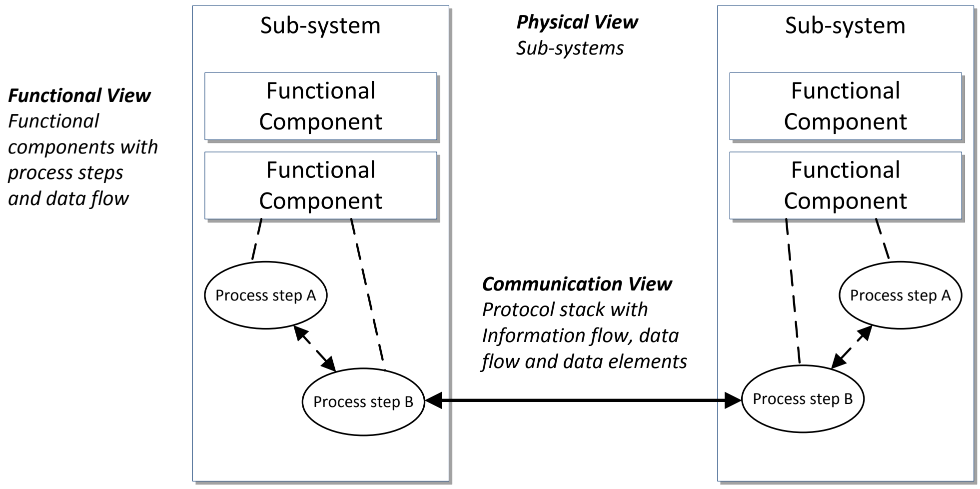

Figure 4-2 Architecture in several views.

In the next section the ‘building blocks’ within the views are defined to build an architecture.

4.2 Physical View

4.2.1 Introduction

In the Physical View the system architecture is depicted as a set of sub-systems that interact and exchange information to support the C-ITS applications described in Section 2. The system architecture is derived in a stepwise fashion by traversing the cube in Figure 4-1 along the aggregation dimension.

Sub-systems are defined to represent the major (physical) components of the connected vehicle environment. Sub-systems include functional components that define more specifically the functionality and interfaces that are required to support a particular connected vehicle application.

Information Flows depict the exchange of information between sub-systems and functional components. The information exchanges are identified by ‘triples’ that describe the source and destination sub-system and the information that is exchanged.

(Human) actors are treated as external entities that interact with the system (see Figure 4-3).

- *Vehicle Driver*: An actor driving in a vehicle. The vehicle is a motorized vehicle (car, bus, truck) and not a vehicle of a vulnerable road user (bike, moped, motor);
- *Vulnerable Road User* (VRU): A VRU is a human actor like a pedestrian, cyclist or powered-two-wheel driver (PTW); A motorcyclist is also an example of a PTW and is treated as a vulnerable road user in specific road hazard situations with other cars;
- *End User*: A human actor who uses a product or service as an individual, i.e. not on behalf of an organization;
- *Road Operator*: An actor responsible for the traffic management of a road network;
- *Service Provider*: An actor (organization) supplying services to one or more customers. Customers are either other organizations, including government (B2B / B2G / G2B / G2G) or end users (B2C / G2C). Typical examples of a service provider are a Navigation Provider as a service provider providing navigation services to end users or organizations or a Traffic Information Provider as a service provider that provides road traffic related information, like traffic jams, incidents, road works warning etc.

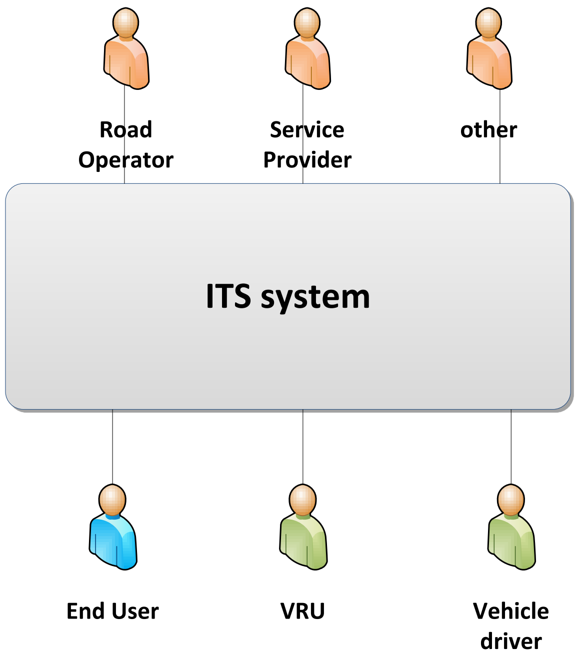

Figure 4-3 System architecture – aggregation level 0

4.2.2 Physical View – building blocks

The system architecture is based on best common practice in previous ITS projects i.e. a split in three main physical layers for Vehicle, Roadside and Central (or back-office). Two additional layers for Traveller / VRU and for Support are added. The system architecture is divided in five 'layers' as shown in Figure 4-4.

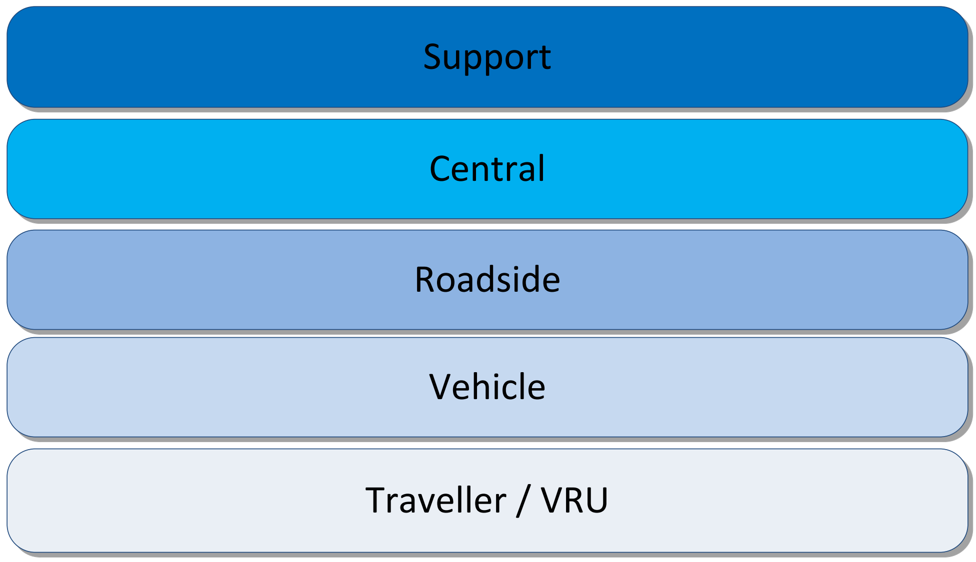

Figure 4-4 System architecture – aggregation level 1

1. Support layer: Sub-systems to support the overall system e.g. governance, test and certification management and security and credentials management;
2. Central (or back-office) layer: Sub-systems to support connected vehicles, field and mobile devices and to perform management and administration

functions. The sub-systems in this layer are typically virtual systems that can be aggregated together or geographical or functions distributed;

3. Roadside layer: Covers the ITS infrastructure on or along the physical road infrastructure, e.g. surveillance or control devices (signal/lane control, ramp meters, or systems to supply information to connected vehicles;
4. Vehicle layer: Covers the intelligent/cooperative on-board systems (advanced driver assistance / safety systems, navigation, remote data collection or information). Also specific sub-systems for fleet–type vehicles are included e.g. for signal priority, monitoring activities, fleet management or passenger services;
5. Traveller or vulnerable road user (VRU) layer: Covers both “personal” devices (e.g. mobile devices, navigation devices) and specific systems connected to vehicles of VRU’s or VRU’s itself (e.g. tags).

The identified ‘building blocks’ - physical objects or sub-systems in the five layers - are shown in Figure 4-5.

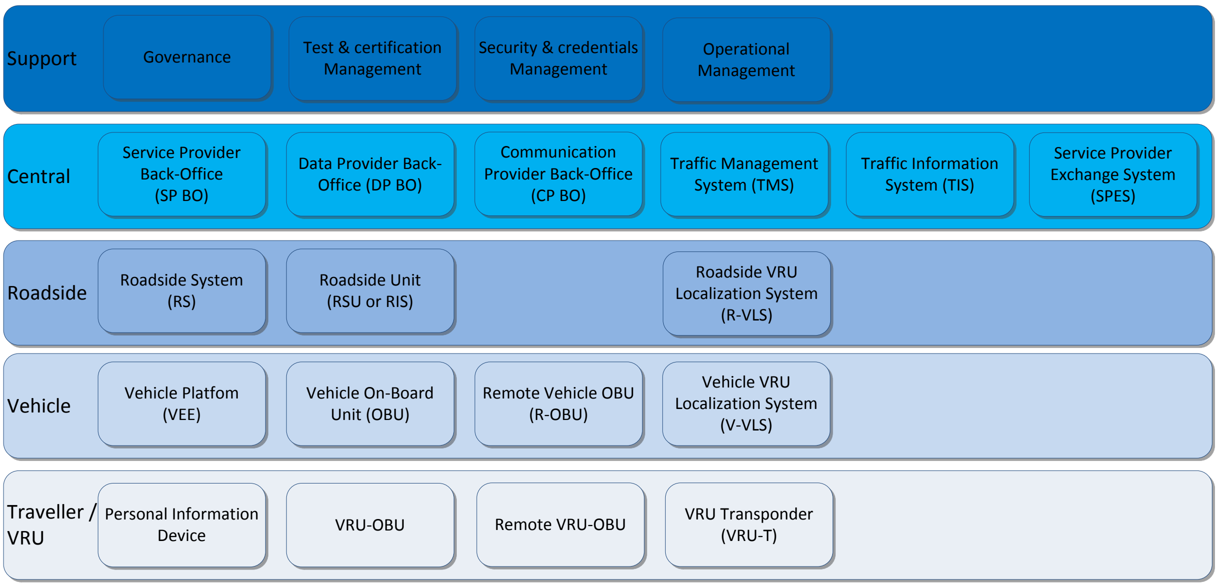

Figure 4-5 Building blocks for Physical View – aggregation level 2

At the traveller / VRU layer the following sub-systems are defined:

1. *Personal Information Device (PID):* A personal information device is typically a smart phone or personal navigation device used by an end-user. The PID provides the capability for travellers to receive formatted traveller information wherever they are. Capabilities include traveller information, trip planning, and route guidance. It provides travellers with the capability to receive route planning from the infrastructure at home, at work, or on-route using personal devices that may be linked with connected vehicle on-board equipment. A PID might include the communication functionality of a Personal ITS station, as specified in ETSI ITS specifications;
2. *VRU Vehicle OBU (VRU-OBU):* an on-board unit is a sub-system attached to a VRU vehicle (e.g. moped, electric bike) and needed for VRU assisted applications to inform / advise a driver via a HMI;

3. *Remote VRU OBU (R-VRU-OBU)*: Remote VRU Vehicle OBUs represent other VRU vehicles that are communicating with the host VRU vehicle. The host VRU vehicle on-board unit, represented by the VRU-OBU physical object, sends information to, and receives information from the Remote Vehicle OBUs to model all VRU related V2V communications
4. *VRU Transponder (VRU-T):* a VRU transponder is part of a tag-based communication system. A transponder can be active (=with own battery, sending data at constant time intervals), semi-passive (with own battery, sending message at request of an interrogator) or passive tag/chip (without own battery, responding to interrogator request). The tags communicate with an external interrogator, called VRU Localisation System, which can be integrated in a vehicle (car, bus, truck) or in a roadside system:
    - *Vehicle VRU Localization System (V-VLS):* A VRU Localization System is part of a tag-based communication system.
    - *Roadside VRU Localization System (R-VLS):* A VRU Localization System is part of a tag-based communication system. The VRU transponder carried by a VRU, is an active (=with own battery) or passive tag/chip that can respond on an interrogation signal (trigger) from the VRU Localisation System. A VRU Localization System can be integrated in, e.g., a Traffic Light to detect the presence of a specific user, e.g. a person with a disability.

   The VRU transponder carried by a VRU, is an active (i.e. with own battery) or passive tag/chip that can respond on an interrogation signal (trigger) from the VRU Localisation System. This transponder is different from a VRU OBU system, since the transponder is only able to send a limited amount of data (typically only ID and potentially some sensor values) and is not able of self-locating.

In the vehicle area the following sub-systems are defined:

1. *Vehicle Platform or Vehicle E/E system (VEE)*: The Vehicle Electrical and Electronic system (E/E) system includes all in-car sensors (speed, lights, etc.) and actuators (brake, etc.). The Vehicle Electrical and Electronic system provides sensor information (e.g. speed) from a vehicle to an external C-ITS system and optionally enables the control/actuation (e.g. speed control) of that vehicle by an external system. The Vehicle E/E must include safety measures to ensure the safe operation of the vehicle, independent of the interaction between the Vehicle E/E and external sub-systems. A further differentiation can be made per vehicle type, e.g. emergency vehicle, commercial vehicle or (public) transport/transit vehicle;
2. *Vehicle On-board Unit (OBU) or Vehicle ITS Station (VIS)*: An on-board unit is a sub-system attached to a car and needed for driver assisted applications to inform / advise a driver via a HMI. The OBU provides the vehicle-based processing, storage, and communications functions necessary to support connected vehicle operations. The radio(s) supporting V2V and V2I communications are a key component of the Vehicle OBU. Four different types of implementations are represented by the Vehicle OBU:
    a. Vehicle Awareness Device – This is an aftermarket electronic device, installed in a vehicle without connection to vehicle systems and is only capable of sending the basic safety message over

short-range communications. Vehicle awareness devices do not generate warnings;

b. Aftermarket Device – This is an aftermarket electronic device, installed in a vehicle, and capable of sending and receiving messages over a wireless communications link. The self-contained device includes GPS, runs connected vehicle applications, and includes an integrated driver interface that issues audible or visual warnings, alerts, and guidance to the driver of the vehicle;
c. Retrofit Device – This is an electronic device installed in vehicles by an authorized service provider, at a service facility after the vehicle has completed the manufacturing process (retrofit). This type of device provides two-way communications and is connected to a vehicle data bus to integrate the device with other on-board systems. Depending on implementation, the device may include an integrated driver interface and GPS or integrate with modules on the vehicle bus that provides these services;
d. Integrated System – This is a system of one or more electronic devices integrated into vehicles during vehicle production. The Integrated System is connected to proprietary data busses to share information with other on-board systems. The Integrated System may include many control modules.

In retrofit and integrated implementations, the Vehicle OBU interfaces to other on-board systems through a vehicle bus (e.g., CAN), represented as the Vehicle Platform, this interface provides access to on-board sensors, monitoring and control systems, and information systems that support connected vehicle applications. The vehicle bus may also be the source for GPS location and time, and the access point for the vehicle's driver-vehicle interface. Self-contained devices include an integrated GPS and driver interface that supports direct visual, audible, or haptic interaction with the driver. The Vehicle OBU includes the functions and interfaces that support connected vehicle applications for passenger cars and trucks. Many of these applications (e.g., V2V Safety applications) apply to all vehicle types including personal automobiles, commercial vehicles, emergency vehicles, transit vehicles, and maintenance vehicles. The Vehicle OBU is used to model the common interfaces and functions that apply to all of these vehicle types, i.e. also commercial, public transport or emergency vehicles;

3. *Remote Vehicle OBU (R-OBU)*: Remote Vehicle OBUs represents other vehicles that are communicating with the host vehicle. The host vehicle on-board unit, represented by the Vehicle OBU physical object, sends information to, and receives information from the Remote Vehicle OBUs to model all vehicle V2V communications.

In the roadside (or field) area the following sub-systems are defined:

1. *Roadside System (RS)*: Different types of existing roadside systems are identified:
   a. Roadside Substation (RSS): a system deployed along high-ways and includes sensors (loops), control logic and actuators. The system can run as a stand-alone closed loop system i.e. run stand-alone local traffic control functions (e.g. traffic jam tail detection and warning via Variable Message Signs) or can be controlled by the TMS;

   b. Traffic Light Controller (TLC): a TLC is a specific type of roadside system. It includes the input from loop detectors or other sensors, a control logic, and the actuation of the traffic lights. A TLC can be run as a stand-alone closed-loop traffic control system. A TLC can also be controlled by a central TMs, e.g. in green wave applications between different TLC's. A TLC is deployed on urban road or can be deployed at highway access roads for access control;

2. *Roadside Unit (RSU) or Roadside ITS System (RIS)*: A RSU/RIS is a cooperative roadside communication system responsible for the two-way communication functionality at a part of a road network (typically an intersection or a road section of 500m – 1km). This physical object is responsible for implementing communication functionality in the roadside layer and optionally also application functions. A RSU/RIS is included in the ITS reference architecture standardised by ETSI ITS. A RSU/RIS can be part of the roadside communication network with distributed radio units, and centralized functions in the Communication Provider Back-Office.

At the central layer the following sub-systems are defined:

1. *Traffic Management System (TMS*): A TMS is the functional back-office system of the responsible road operator to enforce legal actions on urban or high-way road sections or intersections based on real-time traffic data from loops, cameras, speed sensors, etc. or actions by traffic controllers. The real-time data that flows from the Traffic Info System is integrated and processed by the TMS (e.g. for incident detection), and may result in traffic measures (e.g. traffic routing, dynamic speed limits) with the goal of improving safety and traffic flow;
2. *Traffic Information System (TIS)*[4]: A Traffic Information System is the functional back-office system of a road operator to collect and process real-time traffic data from traffic data systems (e.g. roadside sensor systems (loops, cameras) or connected vehicles) and to distribute real-time and/or aggregated information on traffic state (speed, flow and travel times) or road state to TMS or external systems like a SP BO. In practice several distributed TIS from different road operators can be interconnected to a central TIS (e.g. from NDW), which provides aggregated information for the Netherlands;
3. *Service Provider Back-Office (SP BO)*: A generic back-office system of a service provider used for the specific services of the SP to connected drivers or end-users to inform end users or other SP BO systems from providers. A SP BO can be used to support personal information services for, e.g. navigation or traffic information applications on OBU/PID. A SP BO can also be used to gather floating car data from OBU/PID;
4. *Data Provider Back-Office (DP BO)*: A Data Provider BO system is a data system that collects and fuses floating car data and real-time traffic data from roadside sensor systems to increase insight in actual and expected traffic state (e.g. on traffic jams). The DS also distributes enriched

[4] A split is made between TMS and TIS. A TMS receives traffic information always via a TIS, and sends traffic actuation measures always to external systems via a TIS. In real world a TMS consists of several building blocks for traffic control.

(aggregated) information on traffic state (speed, flow and travel times) to service providers;

5. *Communication Provider Back-Office* (CP BO) or Central ITS System (CIS): A generic back-office system of a communication provider used for access at several communication layers from other BO systems (like SP BO, TMS, TIS etc.) to send and receive ITS information to/from vehicles or other road users;
6. *Service Provider Exchange System (SPES)*: an e-Market ('broker') system for discovery and exchange of ITS (end-user) services and ITS communication services; the SPES can support functions like service discovery, service authentication, authorization, accounting (AAA) and billing.

Other back-office systems can also be located at this layer depending on the type of application. One example is a Fleet and Freight Management System which provides the capability for commercial drivers and fleet-freight managers to receive real-time routing information and access databases containing vehicle and/or freight equipment locations as well as carrier, vehicle, freight equipment and driver information. Fleet and Freight Management Center also provides the capability for fleet managers to monitor the safety and security of their commercial vehicle drivers and fleet.

At the support layer the following sub-systems are defined:

1. *Governance system*: A system from policy makers for regulations & enforcement of the ITS system of environment / safety measures;
2. *Test and certification management system*: A system for registration of tested and certified communication systems for ITS (safety) applications;
3. *Security and credentials management system*: A high-level aggregate representation of the systems that enable trusted communications between mobile devices, roadside devices and centers, and protect data from unauthorized access. This sub-system will be implemented as an interconnected system of support applications that enable the secure distribution, use, and revocation of trust;
4. *Operational Management System*: A system for operational processes like fault, performance and configuration management of the sub-systems.

4.2.3 Architecture – physical view aggregated for all selected applications

The architecture is shown in the next figure. The detailed sequence diagrams in Section 8 are used to create this view.

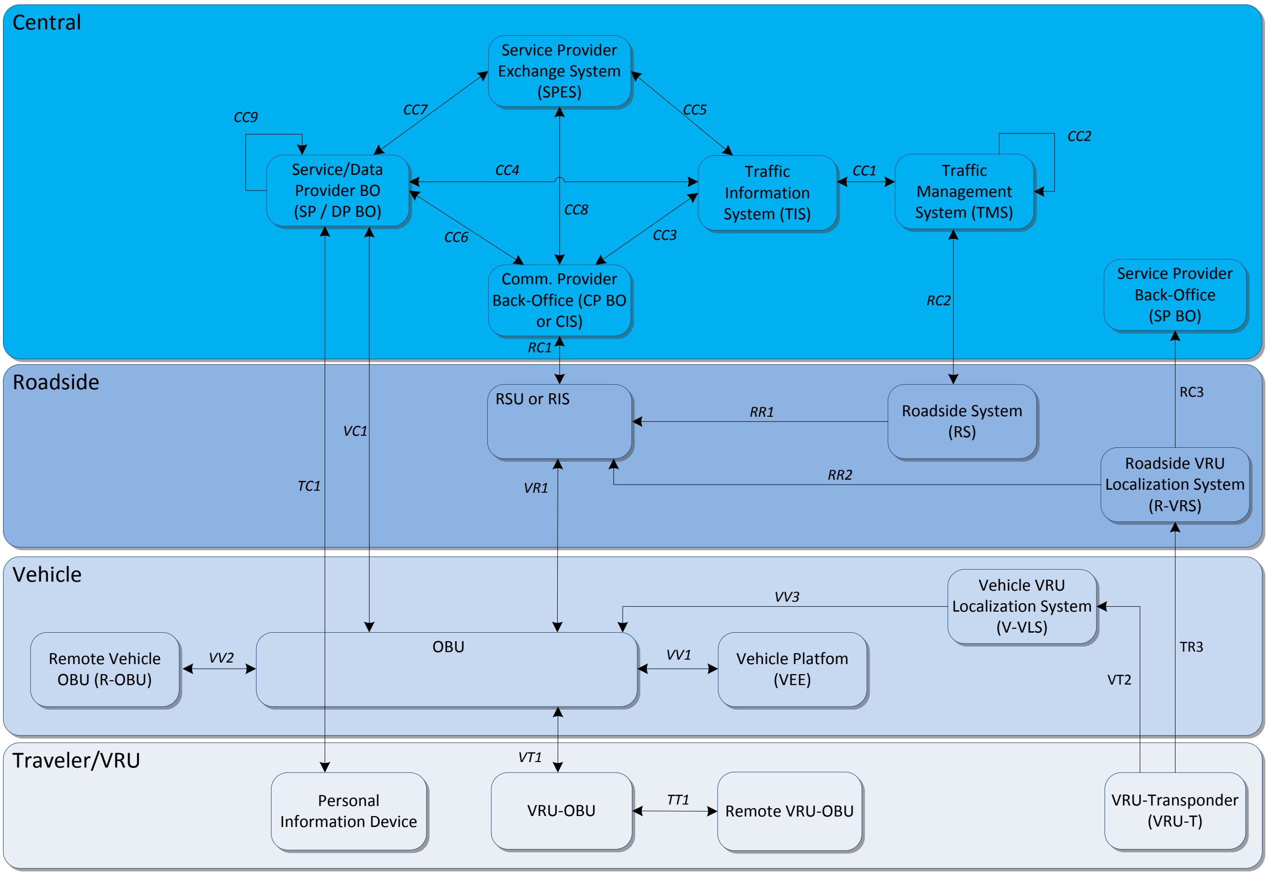

Figure 4-6 Architecture – physical view with sub-systems (16) and interfaces (24) – aggregation level 2. Note: the support layer is not included, for readability.

4.3 Functional View

4.3.1 Introduction

In the functional view functional components are attached to the sub-systems. The functional components define the functionality and functional data flow with interfaces that are required to support a particular ITS application. Information flows depict the exchange of information between sub-systems and their functional components. The detailed information flow is described in the sequence diagrams in Section 8.

4.3.2 Functional View – building blocks

The main system functions of the sub-systems are: sensing, communication, situation monitoring and situation assessment, acting and trust management. The hierarchic decomposition of these functions is based on geometrical and temporal scale of information and information abstraction. Cardinality (multiple entities with the same functionality) of the system is supported and dependent on physical limitations of sensors and actuators and heterogeneity of goals;
Each sub-system contains one or more of the following generic functional components:

- *Sensing Support* includes the collection of information from in-vehicle or road-side sensors included in the physical objects;
- *Communication Support* enables secure, reliable communications with other connected devices. It provides the communication functions that add

a timestamp, the message origin, and a digital signature in outbound messages and processes, verifies, and authenticates the same fields in inbound messages. It provides functionality to encrypt (outbound) and decrypt (inbound) sensitive data. Communication Support also includes information reception of formatted traffic advisories, road conditions, transit information, broadcast alerts, and other general traveller information broadcasts and presents the information to the traveller. The traveller information broadcasts are received by vehicle-attached or personal devices including personal computers and personal portable devices such as smart phones;

- *Situation monitoring and situation assessment* includes the processing of the information to determine a risk and to start actuation (e.g. a vehicle or road-side triggered event);
- *Acting Support* includes the option to present information to end-users via a HMI or to control in-vehicle (speed control) or road-side actuation systems (like variable message signs, traffic lights, etc.);
- *Trust Management* manages the certificates and associated keys that are used to sign, encrypt, decrypt, and authenticate messages. It communicates with the Security and Credentials Management System to maintain a current, valid set of security certificates and identifies, logs, and reports events that may indicate a threat to the Connected Vehicle Environment security.

Besides these *generic* components, application-specific support is also needed as the highest-level representation of the functionality required to execute a specific application, e.g. cooperative cruise control, rerouting, etc.

In Table 3 the functional components are listed that are required to support the ITS applications of Section 2. In the last column of Table 3 examples are given of (a group of) ITS applications that use the functional component.

Table 3 Functional components per sub-system

Layer	**Sub-system**	**Functional component**	**Example of application**
Vehicle	OBU	Vehicle V2V Safety	All V2V applications
		Vehicle Situation Monitoring	(Extended) Probe Vehicle Data
		Vehicle Roadside Information Reception	I2V applications with RSU
		Vehicle Traveller Information Reception	I2V applications with SP BO
		Vehicle Application Specific Support	CACC, Merging Assistant
Roadside	RSU	RSU Traffic Monitoring	V2I applications via V2V monitoring
		RSU Situation Monitoring	(Extended) Probe Vehicle Data
		RSU Vehicle Message Distribution	I2V applications with RSU
		RSU Application Specific Support	Priority Request, GLOSA
	RS	Roadway Traffic Monitoring	Incident Warning, Traffic Jam Ahead
		Roadway Traffic Control (e.g. via Variable Speed Limits or Signal Control status)	Shockwave Damping, GLOSA, In-Vehicle Signage
		Roadway Traffic Monitoring and Signal Control Distribution	Shockwave Damping, GLOSA, In-Vehicle Signage
Central	TMS	TMS Traffic Monitoring	Incident Warning, Traffic Jam Ahead
		TMS Traffic Control	Shockwave Damping, GLOSA
		TMS Traffic Information Distribution	Navigation related services

		TMS Application Specific Support	none
	SP/ DP/ TIS	BO Traffic Data Collection	(Extended) Probe Vehicle Data
		BO Traffic Information Distribution	Navigation related services
		BO Traveller Information Distribution	Navigation related services
		BO Application Specific Support	Smart Parking
	CP	BO Traffic Data Collection (from RSU Traffic and situation monitoring)	V2I applications with RSU
		BO Vehicle Message Distribution	I2V applications with RSU
Traveller	PID	Personal Pedestrian and Cyclist Safety	All VRU applications
		Personal Application Specific Support	Navigation related applications

4.3.2.1 Functional components at the Vehicle

The OBU / RV-OBU contain the following functional components:

1. *Vehicle V2V Safety* is the functionality to exchange current vehicle location and motion information with other vehicles in the vicinity. The information is used to calculate vehicle paths, and warns the driver when the potential for an impending collision is detected. If available, map data is used to filter and interpret the relative location and motion of vehicles in the vicinity. Information from on-board sensors (e.g., radars and image processing) is also used, if available, in combination with the V2V communications to detect non-equipped vehicles and fuse with connected vehicle data. This object represents a broad range of implementations ranging from basic Vehicle Awareness Devices that only broadcast vehicle location and motion and provide no driver warnings to advanced integrated safety systems that may, in addition to warning the driver, provide collision warning information to support automated control functions that can support control intervention. This function also includes vehicle control events that indicate a potential incident or other hazardous location warning extracted from on-board sensors (e.g. emergency brake light, slippery road, slow vehicle etc.)
2. *Vehicle Situation Monitoring* is the functionality required to collect traffic data and environmental situation data from on-board sensors and systems related to environmental conditions and sends the collected data to the infrastructure (V2I) as the vehicle travels. The collected data is a by-product of vehicle safety and convenience systems and includes ambient air temperature and precipitation measures and status of the wipers, lights, ABS, and traction control systems. Collected data is aggregated into snapshots that are reported when communications is available. Note that this application object supports collection of data for areas remote from RSUs or other communications infrastructure. A specific type of data monitoring is *Vehicle Emissions Monitoring* directly measures or estimates current and average vehicle emissions and makes this data available to the driver and connected vehicle infrastructure systems. This component is used in eco-based applications.
3. *Vehicle Roadside Information Reception* receives advisories, vehicle signage data, and other driver information and presents this information to the driver using in-vehicle equipment. Information presented may include fixed sign information, traffic control device status (e.g., signal phase and timing data), advisory and detour information, warnings of adverse road and weather conditions, travel times, and other driver information.

4. *Vehicle Traveller Information Reception* provides the capability for drivers to receive general traveller information including traffic and road conditions, incident information, maintenance and construction information, event information, transit information, parking information, weather information, and broadcast alerts.
5. *Vehicle Application Specific Support* is the representation of the functionality required in the vehicle to execute a specific application e.g. cooperative adaptive cruise control, rerouting etc.

The VEE supports the functional components

1. *Advanced Driver Assisted Systems* (ADAS) are vendor-specific assistance systems to increase safety and comfort of the driver. Examples are lane departure warning, automatic emergency brake, and advanced cruise control. These systems can in the near-future use cooperative information exchange to increase the field-of-view.
2. *Vehicle Monitoring* provides access to vehicle-specific sensor and actuator information systems of the vehicle.

4.3.2.2 Functional components at the Roadside

The RSU contains the next functional components:

1. *RSU Traffic Monitoring* monitors the Vehicle V2V safety messages that are shared between connected vehicles and distils this data into traffic flow measures that can be used to manage the network in combination with or in lieu of traffic data collected by infrastructure-based sensors. As connected vehicle penetration rates increase, the measures provided by this application can expand beyond vehicle speeds that are directly reported by vehicles to include estimated volume, occupancy, and other measures. This object also supports incident detection by monitoring for changes in speed and vehicle control events that indicate a potential incident.
2. *RSU Situation Monitoring* is a general application object that supports collection of traffic, environmental, and emissions data from passing vehicles. The data is collected, filtered, and forwarded based on parameters provided by the back office. Parameters are provided to passing vehicles that are equipped to collect and send situation data to the infrastructure in snapshots. In addition, this object collects current status information from local field devices including intersection status, sensor data, and signage data, providing complete, configurable monitoring of the situation for the local transportation system in the vicinity of the RSU.
3. *RSU Vehicle Information Distribution* receives information from the CP BO. Location-specific or situation-relevant information is sent to short range communications transceivers at the roadside. To support this function additional functions are needed in the communication network.
4. *RSU Application Specific Support* e.g.
    a. *RSU Intersection Management* uses short range communications to support connected vehicle applications that manage signalized intersections. It communicates with approaching vehicles and ITS infrastructure (e.g., the traffic signal controller) to enhance traffic signal operations.
    b. *RSU Intersection Safety* uses short range communications to support connected vehicle applications that improve intersection safety. It communicates with approaching vehicles and ITS

infrastructure to alert and warn drivers of potential stop sign, red light, and pedestrian crossing conflicts or violations.

c. *RSU Queue Warning* provides V2I communications to support queue warning systems. It monitors connected vehicles to identify and monitor queues in real-time and provides information to vehicles about upcoming queues, including downstream queues that are reported by the Traffic Management System
d. *RSU Restricted Lanes Application* uses short range communications to monitor and manage dynamic and static restricted lanes. It collects vehicle profile information from vehicles entering the lanes and monitors vehicles within the lanes, providing aggregate data to the back office center. It provides lane restriction information and signage data to the vehicles and optionally identifies vehicles that violate the current lane restrictions. These functions are performed based on operating parameters provided by the back office managing center(s).
e. *RSU Speed Management* provides infrastructure information including road grade, roadway geometry, road weather information, and current speed limits to assist vehicles in maintaining safe speeds and headways. It also provides speed recommendations to vehicles based on current conditions and overall speed limits and strategies established by the back office.
f. *RSU Speed Warning* notifies connected vehicles that are approaching a reduced speed zone, providing: (1) the zone's current posted speed limit and (2) any roadway configuration changes associated with the reduced speed zone (e.g., lane closures, lane shifts) if applicable. Configuration parameters that define the applicable speed limit(s), geographic location and extent of the reduced speed zone, and roadway configuration information are received from a center or provided through a local interface. This application object works in conjunction with the 'Roadway Speed Monitoring and Warning' application object, which uses traditional ITS field equipment to warn non-equipped vehicles.
g. *RSU Electric Charging Support* uses short range communications to coordinate with a vehicle that is being charged, receiving information about the operational state of the electrical system, the maximum charge rate, and the percentage-complete of the charge from the vehicle.
h. *RSU Infrastructure Restriction Warning* uses short range communications to warn vehicles of infrastructure dimensional and weight restrictions
i. *RSU Parking Management* monitors the basic safety messages generated by connected vehicles to detect vehicles parking and maintain and report spaces that are occupied by connected vehicles. It also uses short range communications to provide parking information to vehicles.

The Roadside systems contain functional components to support the RSU e.g.

1. *Roadway Traffic Monitoring* monitors traffic conditions using fixed equipment such as loop detectors and cameras.

2. *Roadway Signal Control* includes the field elements that monitor and control signalized intersections/ramps and dynamic roadway signs e.g.
    - *Roadway Variable Speed Limits* includes the field equipment, physical overhead lane signs and associated control electronics that are used to manage and control variable speed limits systems. This equipment monitors traffic and environmental conditions along the roadway. The system can be centrally monitored and controlled by a traffic management center or it can be autonomous, calculating and setting suitable speed limits, usually by lane. This application displays the speed limits and additional information such as basic safety rules and current traffic information to drivers.
    - *Roadway Signal Control* includes the field elements that monitor and control signalized intersections. It includes the traffic signal controllers, signal heads, detectors, and other ancillary equipment that supports traffic signal control. It also includes field masters, and equipment that supports communications with a central monitoring and/or control system, as applicable. The communications link supports upload and download of signal timings and other parameters and reporting of current intersection status. It represents the field equipment used in all levels of traffic signal control from basic actuated systems that operate on fixed timing plans through adaptive systems. It also supports all signalized intersection configurations, including those that accommodate pedestrians.
3. *Roadway Local Traffic Monitoring and Signal Control Distribution* receive information from the *Roadway Traffic Monitoring* and send this information via a RSU to vehicles or BO systems.

4.3.2.3 Functional components at the Center

The TMS contains the next functional components:

1. *TMS Traffic Monitoring* remotely monitors traffic sensors and surveillance equipment (cameras), and collects, processes and stores the collected traffic data. Actual traffic information and other real-time transportation information are also collected from other centers. The collected information is provided to traffic operations personnel and made available to other centers. The collected information is used in scenario management in TMS Application Specific Functions to decide on traffic control measures.
2. *TMS Traffic Control* controls driver information system field equipment including dynamic message signs, managing dissemination of driver information through these systems.
3. *TMS Traffic Information Distribution* disseminates traffic and road conditions, dynamic speed limits, closure and detour information, incident information, driver advisories, and other traffic-related data to other centers, the media, and driver information systems. It monitors and controls driver information system field equipment including dynamic message signs and highway advisory radio, managing dissemination of driver information through these systems.
4. *TMS Application Specific Functions*, e.g.
    a. *TMS Dynamic Lane Management* remotely monitors and controls the system that is used to dynamically manage travel lanes, including temporary use of shoulders as travel lanes. It monitors

traffic conditions and demand measured in the field and determines when the lane configuration of the roadway should be changed, when intersections and/or interchanges should be reconfigured, when the shoulders should be used for travel (as a lane), when lanes should be designated for use by special vehicles only, such as buses, high occupancy vehicles (HOVs), vehicles attending a special event, etc. and/or when types of vehicles should be prohibited or restricted from using particular lanes. It controls the field equipment used to manage and control specific lanes and the shoulders. It also can automatically notify the enforcement agency of lane control violations.

b. *TMS Incident Dispatch Coordination* formulates and manages an incident response that takes into account the incident potential, incident impacts, and resources required for incident management. It supports dispatch of emergency response and service vehicles as well as coordination with other cooperating agencies. It provides access to traffic management resources that provide surveillance of the incident, traffic control in the surrounding area, and support for the incident response. It monitors the incident response and collects performance measures such as incident response and clearance times.
c. *TMS Infrastructure Restriction Warning* controls and monitors RSUs that support Infrastructure Restriction Warnings. It configures the RSUs to define tunnel/bridge geometry and design and temporary size and weight restrictions. Information that is currently being communicated to passing vehicles and the operational status of the field equipment is monitored by this application.
d. *TMS Intersection Safety* controls and monitors RSUs that support stop sign, red light, and pedestrian crossing violations. It configures the RSUs for the current intersection geometry and traffic signal control equipment at the intersection. Information that is currently being communicated to passing vehicles and the operational status of the field equipment is monitored by this application.
e. *TMS In-Vehicle Signing Management* controls and monitors RSUs that support in-vehicle signing. Sign information that may include static regulatory, service, and directional sign information as well as variable information such as traffic and road conditions can be provided to the RSU, which uses short range communications to send the information to in-vehicle equipment. Information that is currently being communicated to passing vehicles and the operational status of the field equipment is monitored by this application. The operational status of the field equipment is reported to operations personnel.
f. *TMS Roadway Warning* remotely monitors and controls the systems used to warn drivers approaching hazards on a roadway. It monitors data on roadway conditions from sensors in the field and generates warnings in response to roadway weather conditions, road surface conditions, traffic conditions including queues, obstacles or animals in the roadway, and any other transient events that can be sensed.

g. *TMS Variable Speed Limits* provides center monitoring and control of variable speed limits systems. It monitors data on traffic and environmental conditions collected from sensors along the roadway. Based on the measured data, it calculates and sets suitable speed limits usually by lane. It controls equipment that posts the current speed limits and displays additional information such as basic safety rules and current traffic information to drivers
h. *TMS Work Zone Traffic Management* coordinates work plans with maintenance systems so that work zones are established that have minimum traffic impact. Traffic control strategies are implemented to further mitigate traffic impacts associated with work zones that are established, providing work zone information to driver information systems such as dynamic message signs.

The next functional components can be used on several central systems like TIS, SP BO, DP BO:

1. *BO Traffic Data Collection* collects, processes and stores the traffic data. Current traffic information and other real-time transportation information are collected from several sources like TMS, and connected vehicles.
2. *BO Traffic Information Distribution* disseminates traffic and road conditions, closure and detour information, incident information, driver advisories, and other traffic-related data to other centers and the media (e.g. radio, service providers). Location-specific or situation-relevant traveller information is sent to short range communications transceivers at the roadside.
3. *BO Traveller Information Distribution* disseminates traveller information including event information, transit information, parking information and weather information. Also information such as lodging, restaurants, and service stations can be distributed. Tailored traveller service information is provided on request that meets the constraints and preferences specified by the traveller. This application also supports reservations and advanced payment for traveller services.

The Communication Provider BO contains the next functional components:

1. *CP Traffic Data Collection* collects, processes and stores the traffic data from RSU traffic and situation monitoring. Current traffic flow information and other real-time information are collected from equipped cooperative vehicles passing the roadside station of the communication provider.
2. *CP Vehicle Information Distribution* receives information including traffic and road conditions, incident information, maintenance and construction information, event information, transit information, parking information, and weather information. Location-specific or situation-relevant information is sent to short range communications transceivers at the roadside.

The SPES contains the next functional components:

1. *Service Directory* (SD) provides basis capabilities to manage and search service descriptions
2. *Identity Manager* (IM) provides capabilities to manage common identities and to handle all security and privacy related concerns
3. *Billing* is a support system that handles all financial transactions and provides a neutral instance which monitors the transactions between different parties.

4.3.2.4 Functional components for Traveller / VRU

The PID contains the next functional components

1. *Personal Pedestrian and Cyclist Safety* improves pedestrian and cyclist safety by providing pedestrian and cyclist location information to the infrastructure that can be used to avoid collisions involving pedestrians/cyclists. The application may also alert the pedestrian/cyclist of unsafe conditions, augmenting or extending information provided by signals and signs. The information provided and the user interface delivery mechanism (visual, audible, or haptic) can also be tailored to the needs of the user that is carrying or wearing the device that hosts the application.
2. *Personal Application Specific Support* e.g Personal Interactive Traveller Information provides traffic information, road conditions, transit information, yellow pages (traveller services) information, special event information, and other traveller information that is specifically tailored based on the traveller's request and/or previously submitted traveller profile information. The interactive traveller information capability is provided by personal devices including personal computers and personal portable devices such as smart phones.

The VRU OBU contains similar application objects as Vehicle OBU, but with specific VRU vehicle parameters for the functional components.

4.3.3 Architecture – functional view with functional components and interfaces aggregated for all applications

The architecture from a functional view is shown in Figure 4-7. Compared to Figure 4-6, this architecture gives more detail on the functionality of the physical components, so this architecture is at a more concrete level of abstraction than the physical architecture in Figure 4-6.

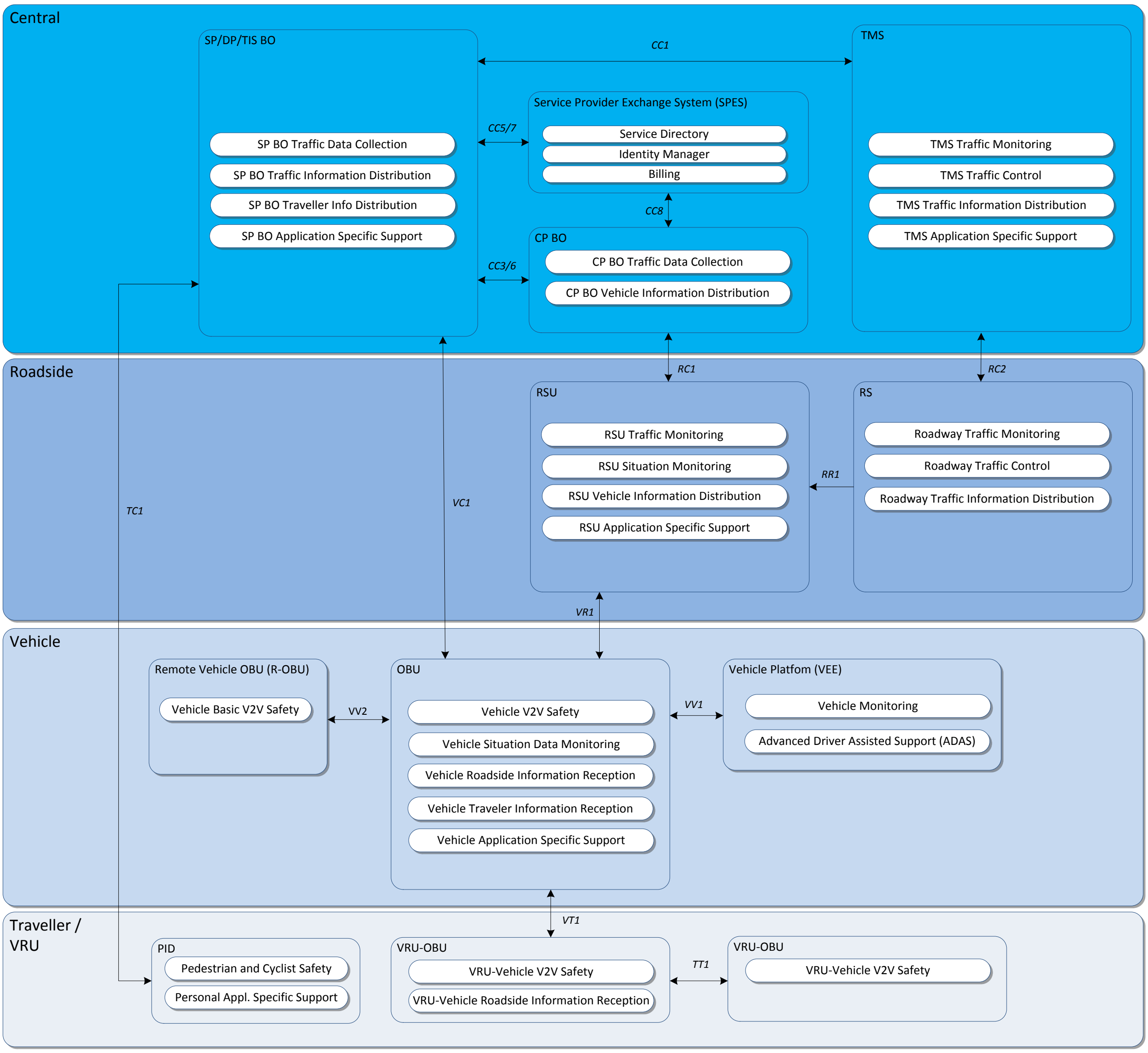

Figure 4-7 Detailed architecture functional view with sub-systems, functional components and interfaces – aggregation level 2[5].

4.4 Communication View

4.4.1 Introduction

The Communication View shows the interfaces between sub-systems and the data flow between the processes within the functional components. In Figure 4-6 and Figure 4-7 these interfaces are shown. In Section 8 the data flow is explained in the sequence diagrams, with an explanation of the information exchanged.

In this section technical descriptions are given on ITS-G5 based deployments for:

1) V2V with single vehicle unit
2) V2V with split in application and communication unit.

---

[5] The VRU elements for VRU localization (VRU Transponder and Vehicle and Roadside VRU Localization systems are for readability not included, see Figure 4-28 for these elements).

3) I2V with stand-alone infrastructure unit
4) I2V with back-office integration via
    a. Facility Layer Gateway
    b. Access Layer Gateway
    c. Proxy Layer Gateway

A general communications reference architecture for the ITS system is described in ETSI EN 302 665. The ITS station reference architecture is shown in Figure 4-8. This reference communication architecture is valid for all ITS systems, i.e. OBU, RSU and BO systems. In the ETSI definitions these elements are named Vehicle ITS, Roadside ITS and Central ITS.

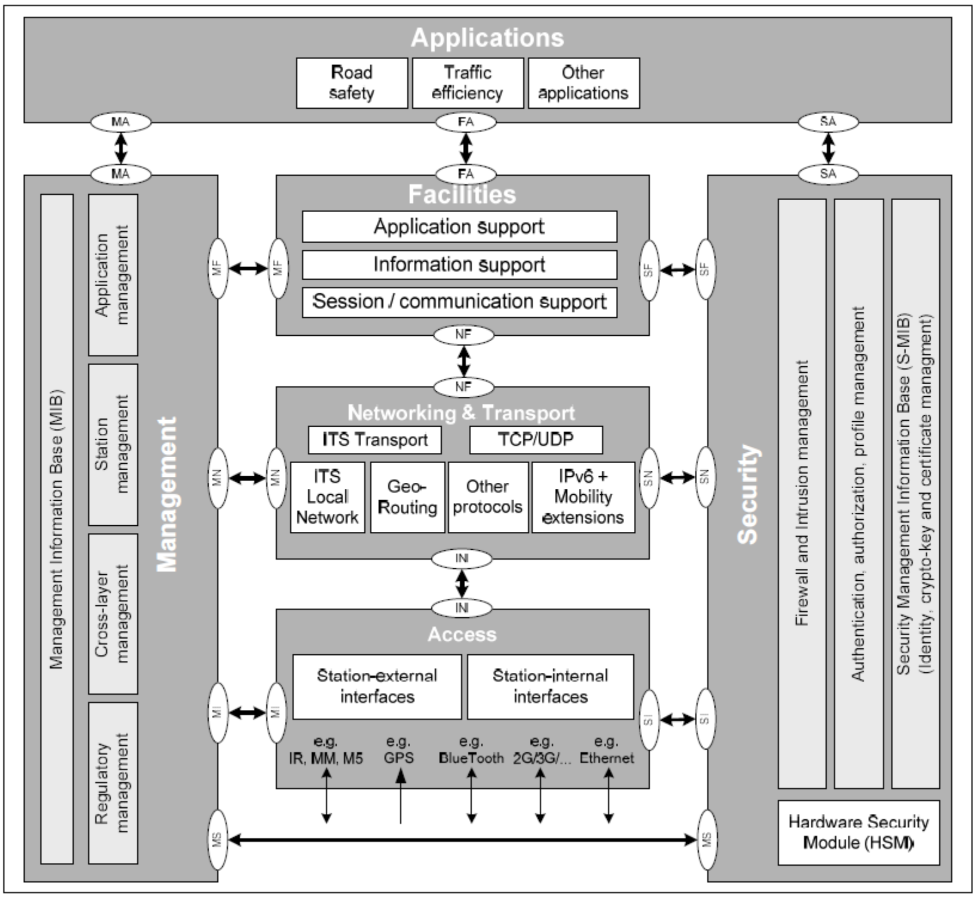

Figure 4-8 ITS station reference architecture / ITS-S host with examples of possible elements

The ETSI communication reference architecture defines six generic entities:

1. Applications: This entity presents the ITS-S applications making use of the ITS-S services to connect to one or more other ITS-S applications. An association of two or more complementary ITS-S applications constitutes an ITS application which provides an ITS service to a user of ITS;
2. Facilities: This entity represents ITSC’s communication specifications at OSI layers 5, 6 and 7, e.g. Cooperative Awareness Basic Service (for CAM, ETSI EN 302 637-2), Decentralized Environmental Notification Basic Service (for DENM, ETSI EN 302 637-2) and Location Dynamic Map (LDM, ETSI EN 302 895);

3. Networking & transport: This entity represents ITSC's communication specifications at OSI layers 3 and 4, e.g. GeoNetworking, IPv6 over GeoNetworking and IPv6 with mobility extensions. To connect to systems via other protocols (e.g. IPv4) a gateway is needed;
4. Access: This entity represents ITSC's communication specifications at OSI layers 1 and 2, e.g. on 5,9 GHz spectrum usage, Decentralized Congestion Control (DCC) and coexistence of ITS and EFC (CEN DSRC) services in the 5,8 GHz and 5,9 GHz bands;
5. Management: This entity is in charge of managing communications in the ITS station. This entity grants access to the Management Information Base (MIB);
6. Security: This entity provides security services to the OSI communication protocol stack, to the security entity and to the management entity. "Security" can also be considered as a specific part of the management entity.

The architecture of Figure 4-8 can be mapped to the OSI model as shown in Figure 4-9.

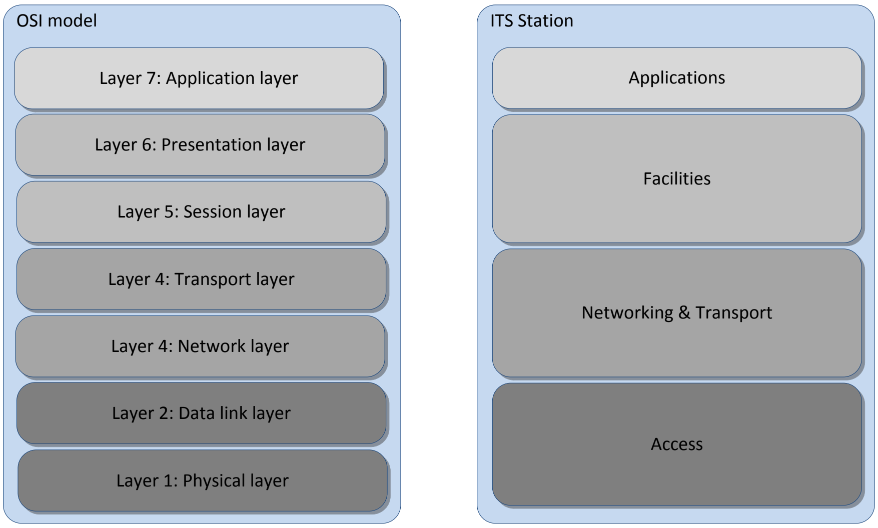

Figure 4-9 ETSI ITS station reference architecture mapped on OSI model

This ITS station communication reference architecture is used to define different 'types' of ITS-Stations (ITS-S): ITS-S host, ITS-S gateway and ITS-S (border) router. The ITS station architecture can also be used to define the communication interfaces between ITS-S hosts and towards non-ITS-S station at Application, Facilities or Network and Transport layer through so-called SAP reference points (IN-IN, NF-NF, FA-FA, see Figure 4-8). It should be noted that most of the reference points are defined as internal reference points and are not designed with interoperability in mind, e.g. the specification of these interfaces is informative and additional design effort is needed to implement them.

The following paragraphs describe specific deployment scenarios of ITS stations in different scenarios. Note that the communication with non-ITS elements like vehicle on-board systems, traffic lights, roadside actuators etc. is considered out-of-scope.

4.4.2 V2V communication

In Figure 4-10 a direct V2V communication scenario is depicted. The applications of the two vehicle stations communicate with each other using facilities (for example CAM or DENM message handlers and Local Dynamic Map (LDM)) and GeoNetworking over the ITS-G5 medium. Also note that in this communication scenario, the Vehicle ITS station is implemented in a single physical entity.
Below a schematic representation of the exchanged data format between the ITS stations is depicted. Note that the security entity adds its own header to the communication which is added at the GeoNetworking level.

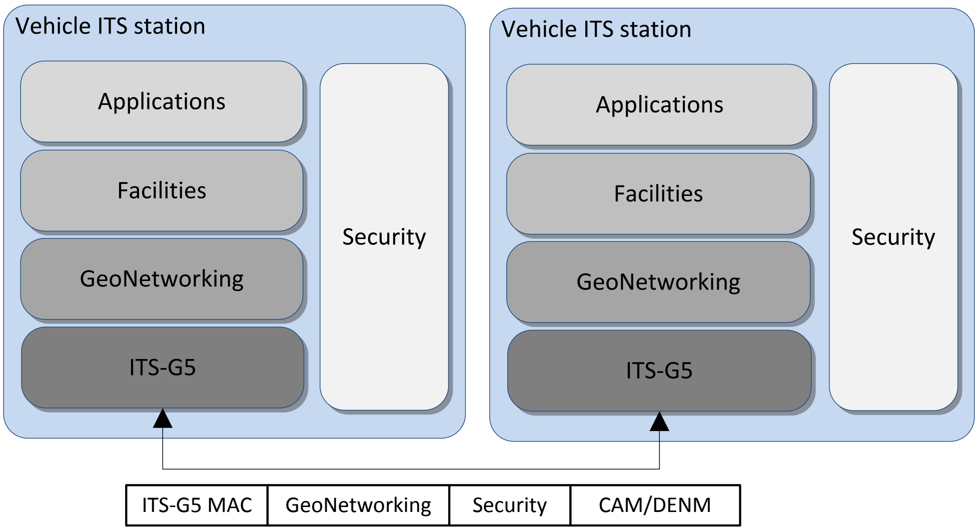

Figure 4-10 V2V communication in the single station deployment scenario

In Figure 4-11 a V2V deployment scenario encountered in e.g. Spits, DriveC2x and A58 is depicted. In this scenario, the ITS Station is split between two physical units: a communication unit and an application unit. The transfer of information between the application and communication unit is currently not standardized at ETSI. However, most implementations employ the informative BTP-SAP or NF-SAP specifications and implement a proprietary communication protocol around these specifications.

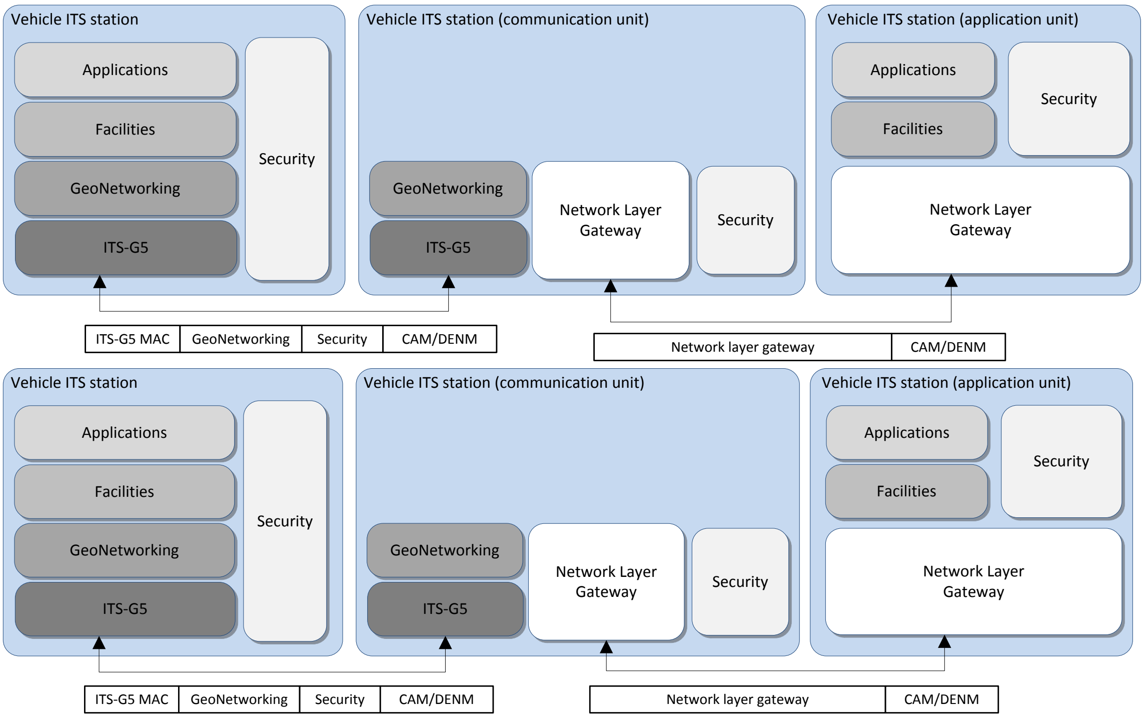

Figure 4-11 V2V communication in the split station scenario

4.4.3 V2I communication

The V2I communication over the air (e.g. directly between the roadside station and the vehicle) is similar to the V2V communication (Figure 4-12). There are some differences in the roles the stations take in respect to the implementation of the different message sets (a roadside station will broadcast an intersection alert, a vehicle will process it). Hence, the communication view for a standalone roadside ITS Station is not different from the V2V communication view.

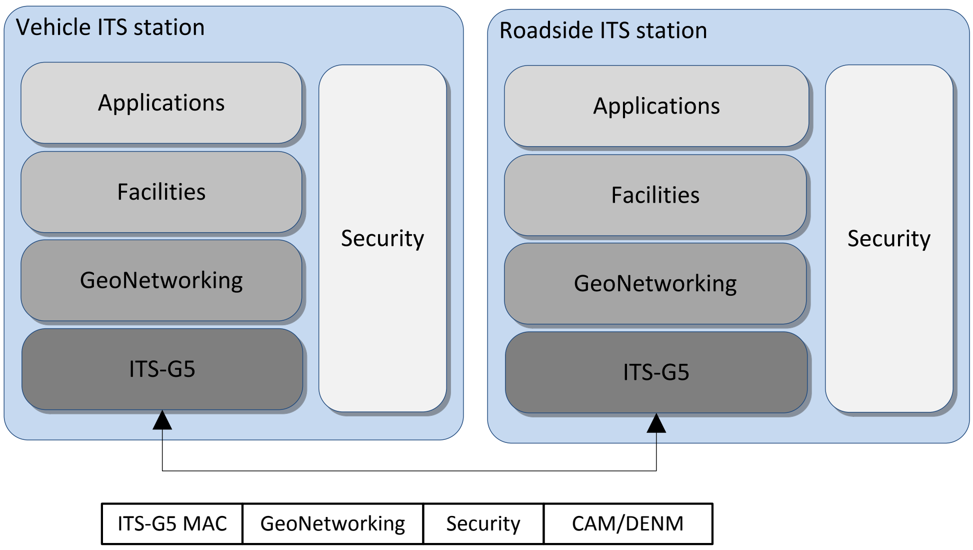

Figure 4-12 Standalone V2I deployment

A RIS can be stand-alone, i.e. operate without communication to a central element, a back-office system like a CIS. RIS systems can be fixed (e.g. installed at a fixed position) or mobile (e.g. connected to a trailer). A fixed RIS can be interconnected to central systems (CIS) via both mobile or fixed (e.g. optical fibre) communication networks. The choice for network type will depend on the requirements of the specific applications on information flow, time constraints and availability and costs of the communication infrastructure. A mobile RIS can be interconnected to central systems (CIS) via mobile networks.

The inclusion of central elements like a CIS in the communication view is challenging as there are many deployment options from which none are currently standardized. The following paragraphs 4.4.3.1 to 4.4.3.3 illustrate the different deployment scenarios to include communication between roadside (RIS) and central systems (CIS).

4.4.3.1 Facility Layer Gateway deployment

In this deployment scenario, the communication between a centralized component and roadside station is implemented by a Facility Layer Gateway. The benefit of this approach is that the application developers do not need to provide their own implementation of the Facilities and GeoNetworking (and ITS-G5) layer of the ITS communication stack. Multiplexing between different roadside ITS stations is done by the facility layer gateway (Figure 4-13).

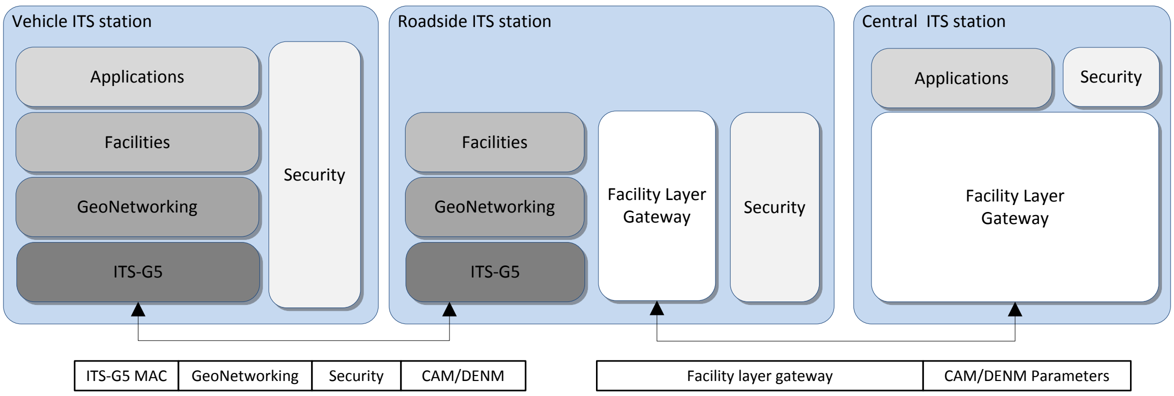

Figure 4-13 Facility Layer Gateway deployment[6]

As the security specifications of ITS dictate that the messages are to be signed at the GeoNetworking level, the certificates of the roadside ITS station provider are used for signing.

Facility Layer Gateways are currently not standardized. Facility Layer Gateway deployment is currently being implemented in the *Shockwave Traffic Jams A58* project.

4.4.3.2 Access Layer Gateway deployment

In the Access layer Gateway deployment scenario, GeoNetworking frames are tunnelled (for example over IP) to the different roadside stations connected to the central ITS station and then threated as a normal GeoNetworking frame (Figure

[6] The C-ITS station can also be another R-ITS station

4-14). This approach is different from the facility layer gateway as in that case the internal interface between the Facilities and the applications is used.

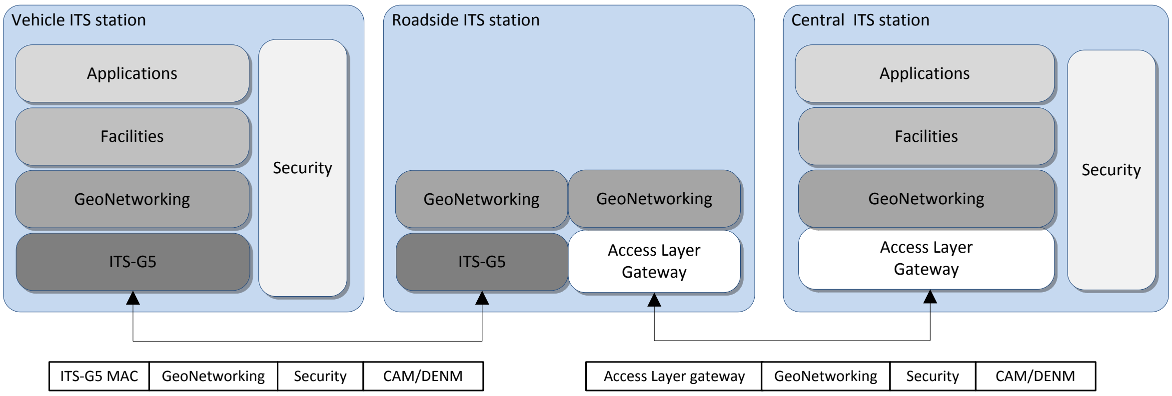

Figure 4-14 Access Layer Gateway deployment[7]

The advantage of the Access Layer Gateway scenario is that the new facilities and applications can easily be introduced at vehicle and central ITS station components without interference of the roadside ITS network. Also the security certificates of the implementer of the application can be used to sign the GeoNetworking frames.

The tunnelling of GeoNetworking frames over IP (or other transport methods) is currently not standardized. The Access Layer Gateway deployment is currently being implemented in the Converge project.

4.4.3.3 Proxy Access Layer Gateway deployment

In the Proxy Access Layer gateway deployment scenario the same tunnelling mechanism as in the Access Layer Gateway deployment scenario is used (Figure 4-15). In this case an additional station is introduced (Proxy ITS station) that directs tunnelled GeoNetworking messages to the right roadside ITS stations.

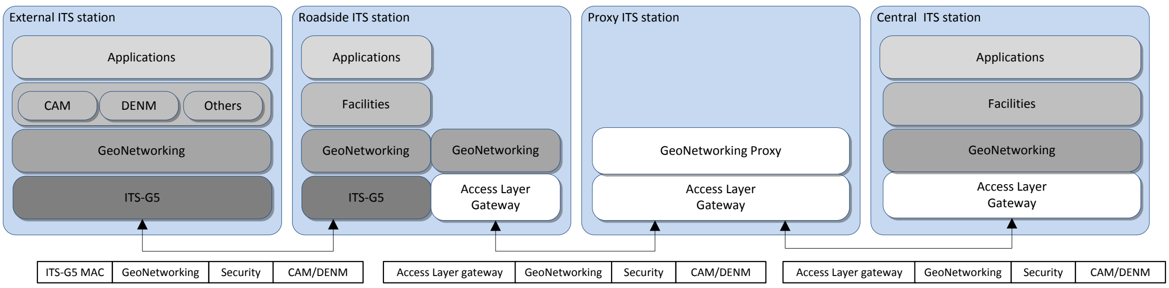

Figure 4-15 Proxy Access Layer Gateway (Tunnel) deployment

Multiple proxies can be chained together, as shown in Figure 4-16, to create a tree-like hierarchic structure - similar to DNS - from which wider geographic areas can be addressed. This concept is also explained in more detail in section 4.5.6.

[7] The C-ITS station can also be another R-ITS station

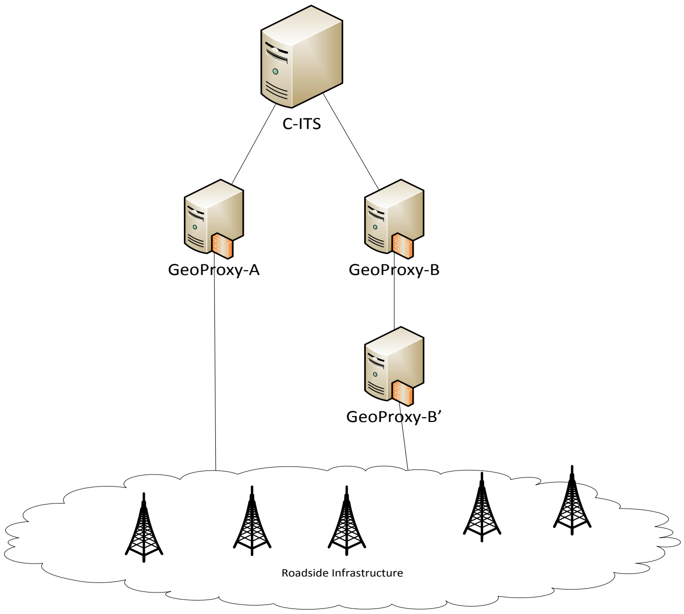

Figure 4-16 Hierarchic structure of GeoProxy servers

This approach is scalable. However, the inherent latency issues of this approach need to be taken into account.

4.5 Architecture View for typical application groups

In Section 2.3, we present the selected applications and grouped them into categories of V2V, V2I, I2V, I2I and VRU. In this section architecture views are provided for each set of these categories. Each view is a subset of the detailed architecture in Figure 4-7 that targets the specific category of applications.

4.5.1 V2V applications

The selected V2V applications are:

- Hazardous Location Warning
- Emergency Brake Light
- Slow Vehicle Warning
- Cooperative Adaptive Cruise Control

The architecture view for these V2V applications is shown in Figure 4-17.

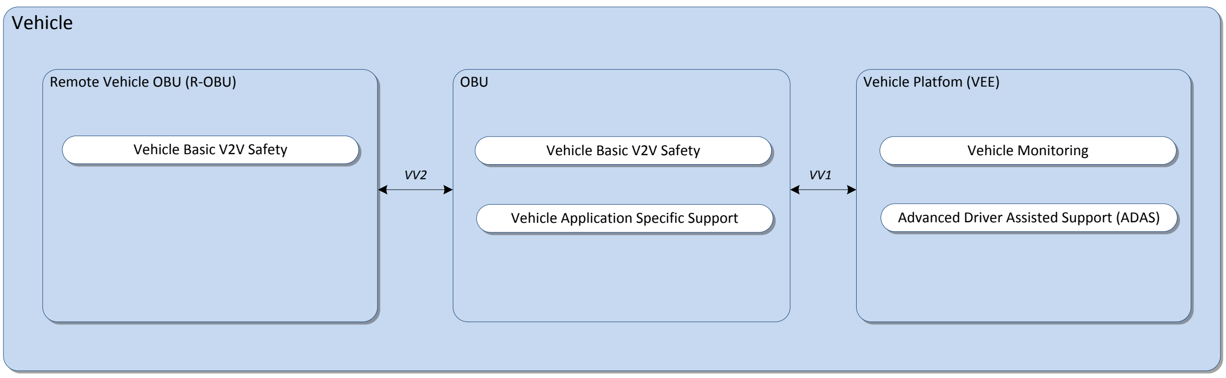

Figure 4-17 Architecture view for V2V applications

The interfaces and the information exchange are shown in Table 4.

Table 4 Interfaces with reference for selected V2V applications

Id	Source	Destination	Information Type	Reference	Remark
VV1	VEE	OBU	Vehicle State	EOBD standard	OEM specific
VV1	OBU	VEE	Risk	none	OEM specific
VV2	OBU	R-OBU	Situation Awareness	ETSI CAM	ETSI EN 302 637-2
VV2	OBU	R-OBU	Warnings	ETSI DENM	ETSI EN 302 637-3
VV2	R-OBU	OBU	Situation Awareness	ETSI CAM	ETSI EN 302 637-2
VV2	R-OBU	OBU	Warnings	ETSI DENM	ETSI EN 302 637-3

The DENM cause codes and sub-cause codes for the selected V2V application are specified in ETSI EN 302 637-3 and examples are shown in Table 5.

Table 5 DENM cause codes for selected V2V applications

Application	Cause code	Sub-cause code
Hazardous Location Warning	Traffic Condition (1) – traffic jam Accident (2) Hazardous location (9-12) Adverse weather (6,17,18) Collision Risk (97)	divers
Emergency Brake Light Warning	Dangerous situation (99)	Emergency electronic brake lights (1)
Slow Vehicle Warning	Slow vehicle (26)	

With DENM many type of V2V and I2V safety messages can be realised with the cause codes. However, the integration with vehicle or existing information systems is not specified. This is left to corresponding parties (e.g. Car2Car Consortium, Amsterdam Group) to include in application white papers and/or profiles.

4.5.2 V2I applications

The selected V2I applications are:

1. Probe Vehicle Data from cooperative cars
2. Probe Vehicle Data from connected cars
3. Priority Request

The aggregated architecture view for these V2I applications is shown in Figure 4-18. This architecture gives an example with physical and functional components to support the Probe Vehicle Data application via connected and cooperative communication. With connected communication information is exchanged directly from OBU to the Data Provider BO, whereas with cooperative communication information is exchanged from OBU via an RSU and Communication Provider BO to the Data Provider BO. This figure illustrates how the PVD application can be created by combining a limited number of functional components and which interfaces are required. This figure also illustrates that if the connected variant of PVD is implemented, the physical component roadside is not needed. Optionally other “probe vehicle” data from loops connected to RS can be distributed via TMS and TIS (shown in Figure 4-18 via interfaces CC2 and CC4) can be integrated to improve traffic monitoring.

For priority request CAM messages of a specific type of vehicles (public transport, emergency vehicle) can be used to initiate a priority request for a signalized intersection).

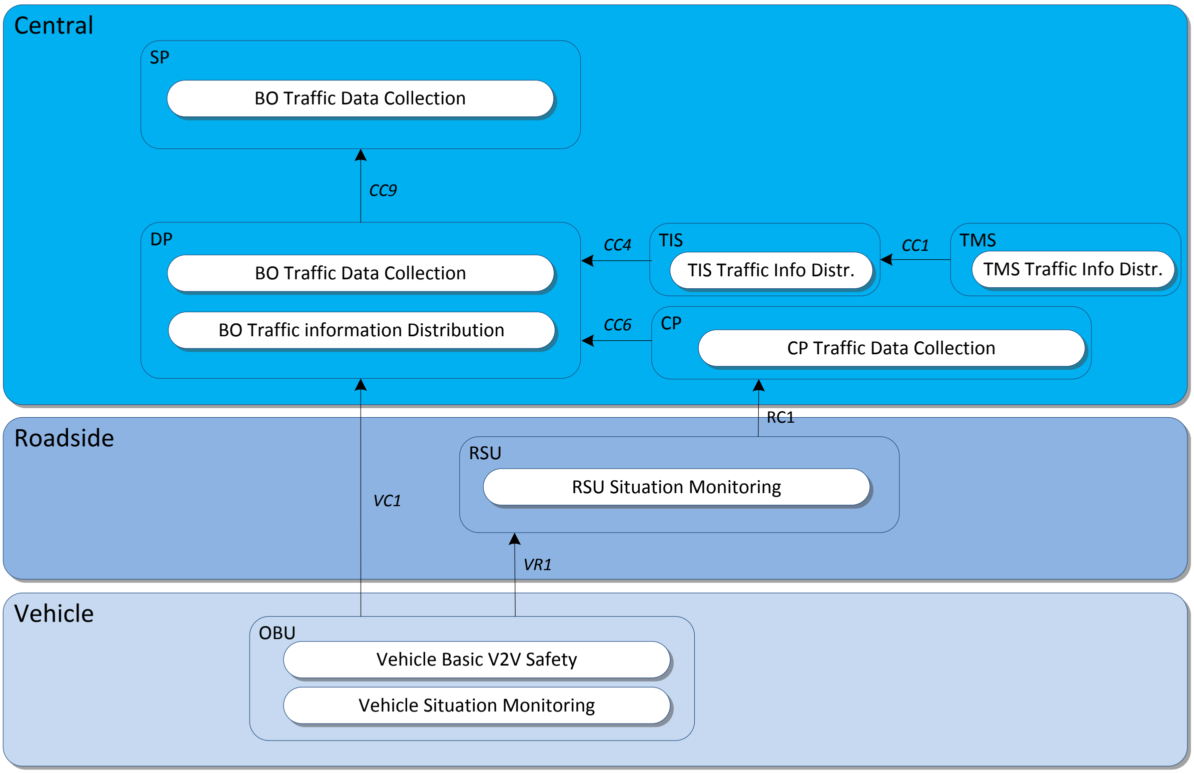

Figure 4-18: Architecture View for V2I applications for Probe Vehicle Data

The interfaces and the information exchange are shown in Table 6.

Table 6 Interfaces with reference for selected V2I applications

Id	Source	Dest.	Information Type	Reference	Remark
VR1	OBU	RSU	Situation Awareness	ETSI CAM	ETSI EN 302 637-2
VR1	OBU	RSU	Warnings	ETSI DENM	ETSI EN 302 637-3
VR1	OBU	RSU	Warnings	ITS Corridor	Eco-AT IF4 spec. plus profiles for RWW and other Hazardous Location Warnings
VC1	OBU	DP BO	Probe Vehicle Data	project A58	A58 spec. G
RC1	RSU	CP BO	Probe Vehicle Data	project A58	A58 spec. F / F*
RC1	RSU	CP BO	Probe Vehicle Data	ITS Corridor	Eco-AT IF3 spec; CAM aggregation (minute); DENM aggregation
CC1	TMS	TIS BO	Local Traffic State Data	project A58	A58 spec. H*
CC4	TIS	DP BO	Local Traffic State Data	project A58	A58 spec. H*
CC6	CP BO	DP BO	Probe Vehicle Data	project A58	A58 spec. G
CC9	DP BO	SP BO	Traffic Info (macro/micro)	project A58	A58 spec. A / A*

4.5.3 I2V applications for intersections

For I2V applications information is distributed to vehicles from infrastructure objects (back-office or roadside systems). To support this location-based information distribution several options exist to use hybrid communication networks. In this section, the intersection-based applications with traffic light controllers (TLC) on urban roads are shown. For this a stand-alone RSU-RS system can be used for applications like:

1. Green Light Optimal Speed Advice
2. Green Wave (via Speed Advise)
3. Stopping Behaviour Optimization
4. Red Light Violation Warning

An example architecture for the GLOSA application is depicted in Figure 4-19. The GLOSA application contains the Roadside System, which provides signal state data via the RSU to the OBU. This architecture shows a cooperative solution with a stand-alone roadside system.

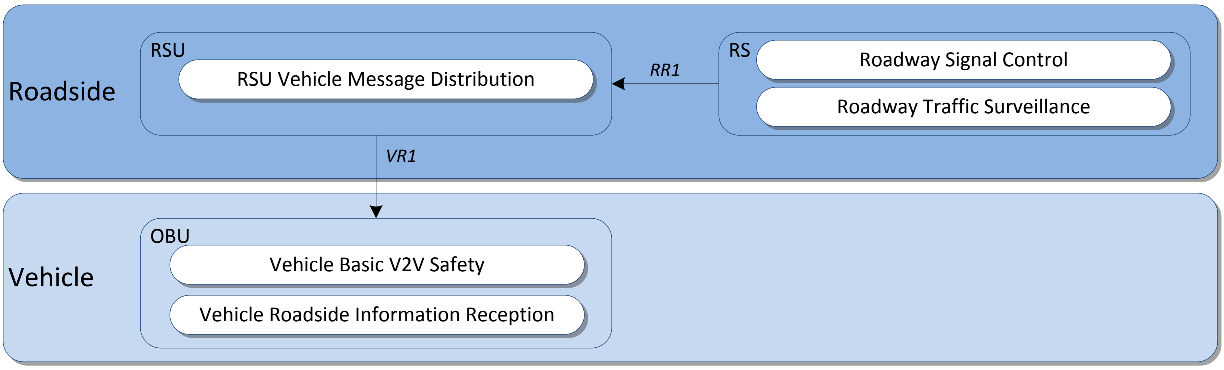

Figure 4-19 Architecture View for cooperative I2V applications for intersections with stand-alone RS-RSU

Optionally, the signalling phase (part of Roadway Signal Control information) from the TLC can be distributed via back-office systems to Service Providers, and - depending on the time constraints - this information can be used for connected applications. This is shown in Figure 4-20.

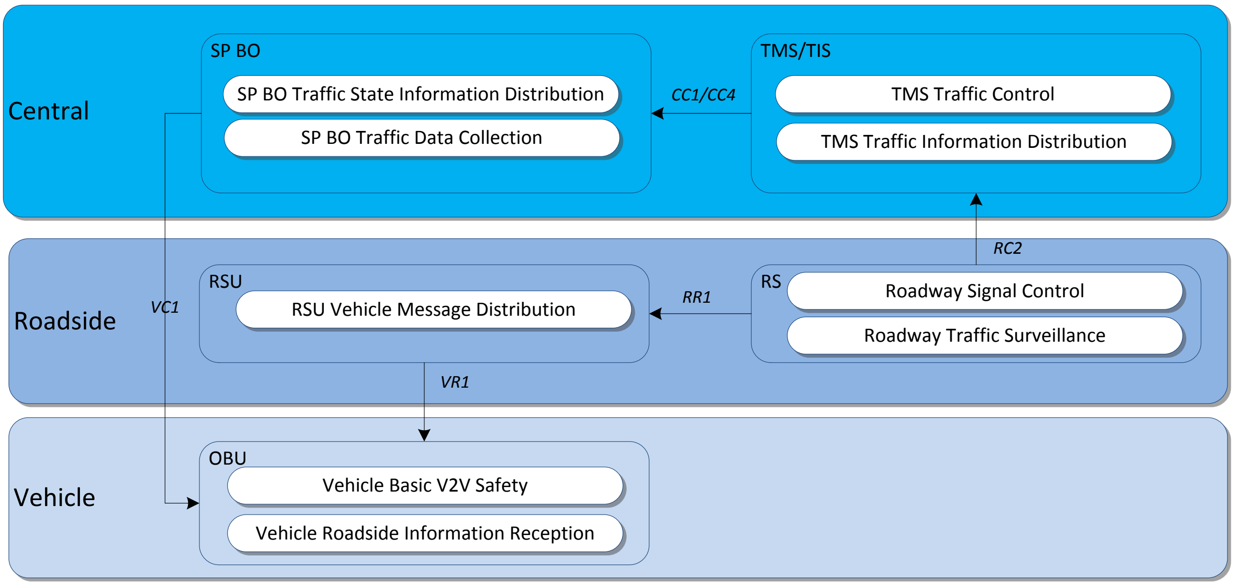

Figure 4-20 Architecture View for I2V applications for intersections with BO integration

The interfaces and the information exchange are depicted in Table 7.

Table 7 Interfaces with reference for selected I2V applications

Id	Source	Destination	Information Type	Reference	Remark
VR1	RSU	OBU	Road Topology of intersection	ETSI MAP	in progress
VR1	RSU	OBU	Signalling Phase and Time	ETSI SPAT	in progress
VR1	RSU	OBU	Warnings	ETSI DENM	ETSI EN 302 637-3
RR1	RS/TLC	RSU	Green time	IVERA/OCIT	candidates
RR1	RS/TLC	RSU	Green time	Eco-AT IF6	Proprietary interface to TLC
RR1	RS/trailer	RSU	Warnings	Eco-AT IF7	Proprietary interface
RC2	RS	TMS	Green time	IVERA	
RC2	RS	TMS	Warnings	ETSI DENM	ETSI EN 302 637-3
CC1/ CC4	TMS (via TIS)	SP BO	Green time	none	
VC1	SP BO	OBU	Green time	none	

4.5.4 I2V applications for road segments / highways

In this section the architecture for the remaining I2V applications is shown:

1. Incident Warning
2. Road Works Warning
3. Traffic Jam Ahead Warning
4. In Vehicle Signage
5. Shockwave Damping (via Speed Advice)

In this architecture, it is assumed that the TIS is the central provider generating the safety warnings for incidents, road works and traffic jam ahead. For speed advice in shockwave damping or in-vehicle signage a service provider might generate advises to individual end-users.

Figure 4-21 gives an example how the architecture for road work / incident / traffic jam ahead warning can be composed out of physical and functional components, where we combined the cooperative and connected versions into a single architecture. The difference is that the connected version communicates directly between SP BO and OBU, whereas the cooperative version communicates via CP and RSU to OBU. Additional to the information also contained in Table 3, this figure also shows the flow of the communicated data and thereby the interfaces between the physical and application objects. This architecture shows the required functional components, their interfaces and the flow of data only directed towards the OBU.

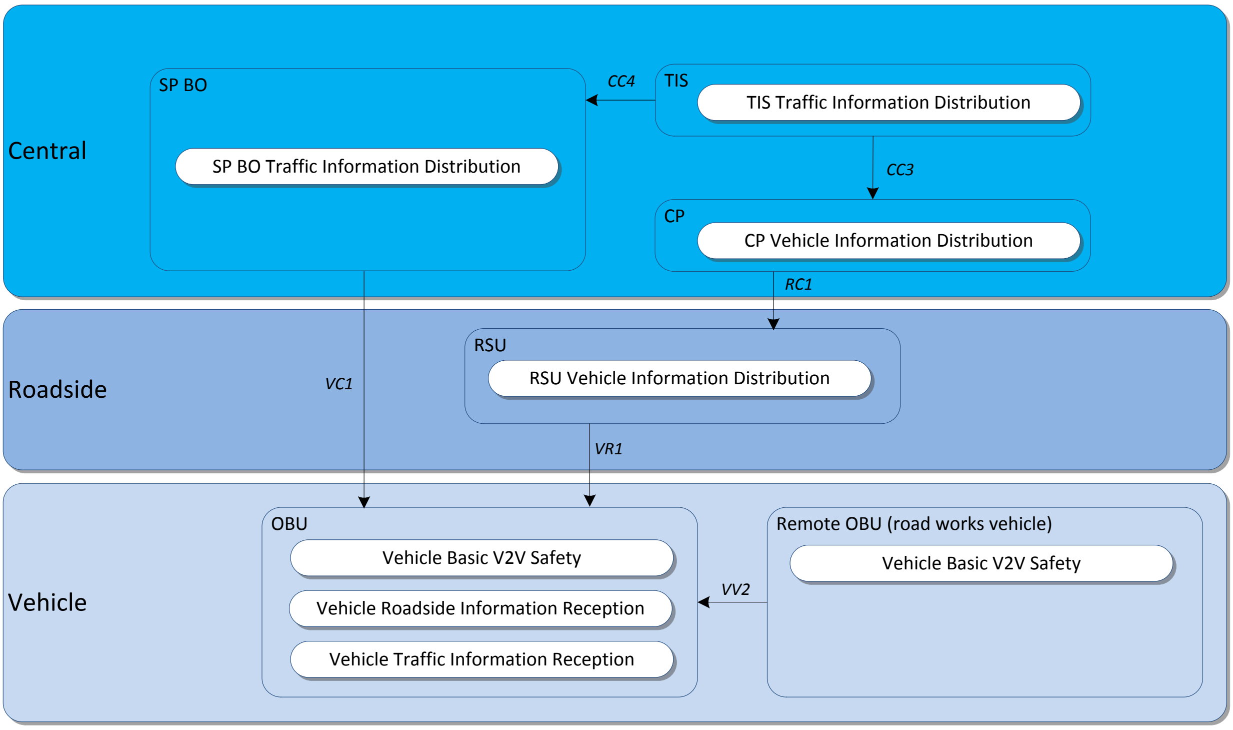

Figure 4-21: Architecture view for I2V applications for road segments/high-ways

The interfaces and the information exchange are depicted in Table 8:

Table 8 Interfaces with reference for I2V applications for high-ways

Id	Source	Destination	Information Type	Reference	Remark
VR1	RSU	OBU	Warning	ETSI DENM	ETSI EN 302 637-3
VV2	R-OBU	OBU	Situation Awareness	ETSI CAM	ETSI EN 302 637-2
VV2	R-OBU	OBU	Warning	ETSI DENM	ETSI EN 302 637-3
RC1	CP	RSU	Warning	ETSI CAM	ETSI EN 302 637-2
RC1	CP	RSU	Warning	ETSI DENM	ETSI EN 302 637-3
RC1	CP	RSU		ITS Corridor	ECo-AT IF3 spec.
CC3	TIS	CP BO	Warning	ITS corridor	ECo-AT IF1 spec. (DatexII-to-DENM)
CC4[8]	TIS	SP BO	Warning	NDW	DatexII
VC1	SP BO	OBU	Warning, Speed Advise	project A58	A58 spec. B (speed advise, JAM)

Other I2V applications can also be supported by the architecture in Figure 4-21, but only require the interface between SP BO and OBU:

1. Navigation related applications:
    a. Rerouting / Smart routing / Traffic Information
    b. Intermodal Route Planner
    c. Eco Route Planner
    d. EV Charging Point Planner
    e. Smart Parking Assistant

[8] The Dutch Ministry of I&M has initiated a Data Top 5 project to improve data quality on road works information, dynamic and static speed limits, dynamic traffic management measures, expected resolve time after incidents and map accuracy (via OpenLR).

2. Pay How You Drive

4.5.5 I2I architecture for e-Market place

To support a scalable and open eco-system with multiple service providers, data providers and communication providers and distributed Service Provider Exchange System (SPES) is needed. It should be noted that both public (e.g. road operator) and private entities (e.g. commercial company) can fulfil the different roles of service provider, data provider and/or communication provider. The split in roles – with corresponding interfaces – enables a flexible eco-system with a split in roles and underlying business models.

This SPES system is described in projects like MOBiNET (MOBiCENTER) and Converge (Service Directory in Car2X network). On the SPES platform service providers can publish their (ITS) services and subscribe to other services. These services are registered in a (distributed) service directory, which provides a search interface to lookup relevant services. This concept is globally shown in Figure 4-22.

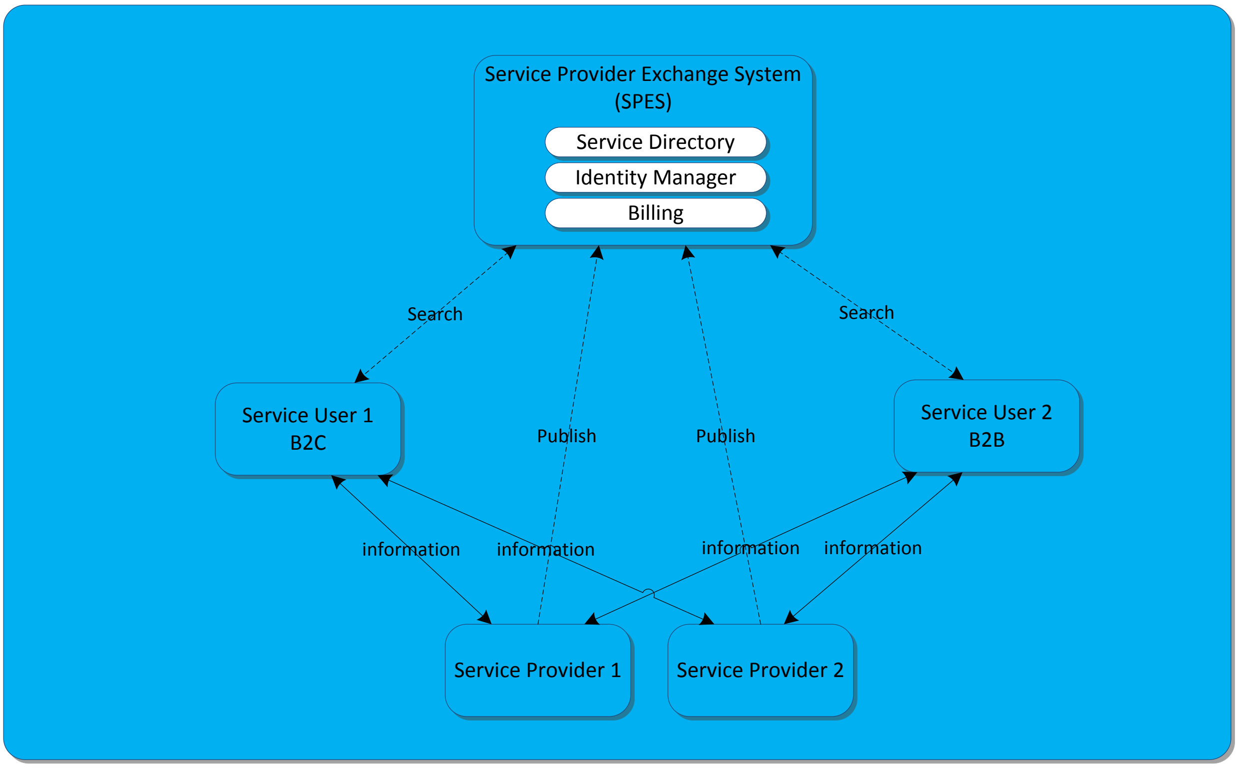

Figure 4-22 Architecture for Service Exchange.

Service Providers publish their ITS services in a Service Directory. Service Users (both B2C and B2B) can search this Service Directory and subscribe to these services (either in the Service Directory, with Billing option) or with Service Provider directly. After a subscription information can be exchanged between Service Provider and Service User. A Service Description and Information Model is needed to publish and search services. In both MOBiNET and Converge concepts of these (USDL-based) models are presented.

In Figure 4-23 this model is applied in an eco-system with several BO systems, related to different business roles. These interfaces can be established by prearranged bi-lateral agreements or be based on the above concept with a (distributed) service directory.

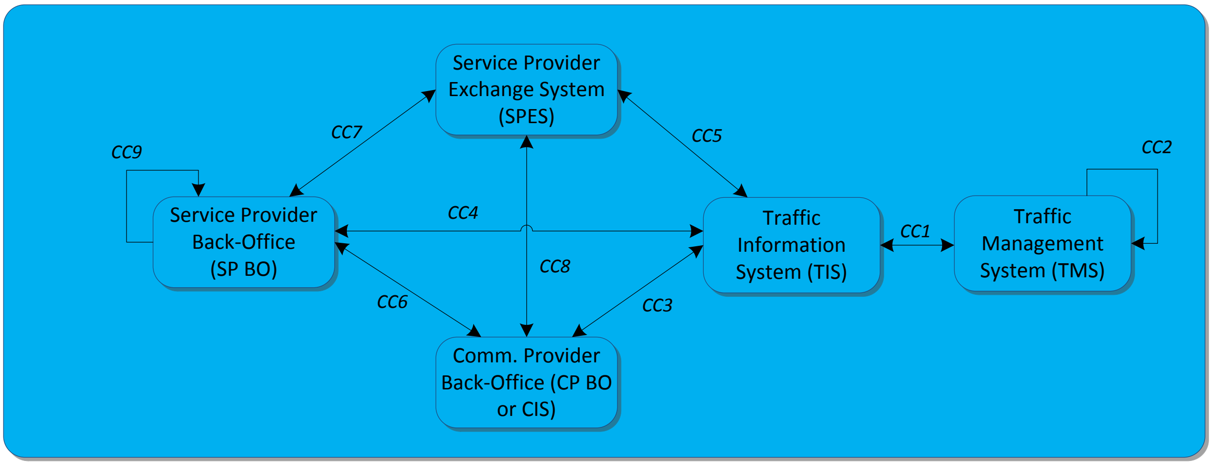

Figure 4-23 Architecture with different business roles

In the above figure also the Communication Provider of the road-side ITS network publishes his communication services (i.e. the supported messages types, applications and the geo-graphical coverage). In this figure it is assumed that a (central) Traffic Information System is the interface to and from Traffic Management Systems of road operators. A TMS can also – via a TIS – use the Communication Provider network to receive and send messages from cooperative vehicles.

Examples of the interfaces and information exchange are:

Table 9 Interfaces with reference for selected I2I applications

Id	Source	Dest.	Information Type	Reference	Remark
CC1	TMS	TIS	Traffic Info	DATEX-II	See NDW
CC1	TMS	TIS	Local Traffic State Data	project A58	A58 spec. H* (loop data)
CC1	TMS	TIS	Local Traffic Control Data	project A58	A58 spec. H (dynamic speed limits)
CC1	TIS	TMS	Traffic Info	DATEX-II	See NDW Data Fusion Project
CC2	TMS	TMS	Coordinated Traffic Management info	DVM-Exchange	See PPA roadside
CC3/6	CP	TIS/SP	Probe Vehicle Data	project A58	A58 spec. F/F*
CC4	TIS	SP	Traffic Info	DATEX-II	See NDW
CC4	TIS	SP	Local Traffic State Data	project A58	A58 spec. H* (loop data)
CC4	TIS	SP	Local Traffic Control Data	project A58	A58 spec. H (dynamic speed limits)
CC5/7/8	TIS	SP	Publish/Search/Subscribe	Project MOBiNET/ Converge	See project documents
CC9	SP BO	SP BO	Any	none	

4.5.6 I2I architecture for distributed cooperative networks

For a scalable communication infrastructure with multiple CPs and SPs different architecture options are possible. A CP with an RSU-based network can ‘disclose’ this network to external service providers, including road operators, in several ways:

1. Single CP, multiple SPs: multiple SPs have access to one single CP, where the CP sends his topology (area of reach) to the SP. Based on this info a SP can decide to send message to cooperative cars via the CP GeoMessaging server (Geom-S, see [20]). This Geom-S is aware of the internal topology of the RSU-based network and forwards messages to the correct RSU. A SP can also send peer-to-peer messages to connected OBUs via cellular networks.

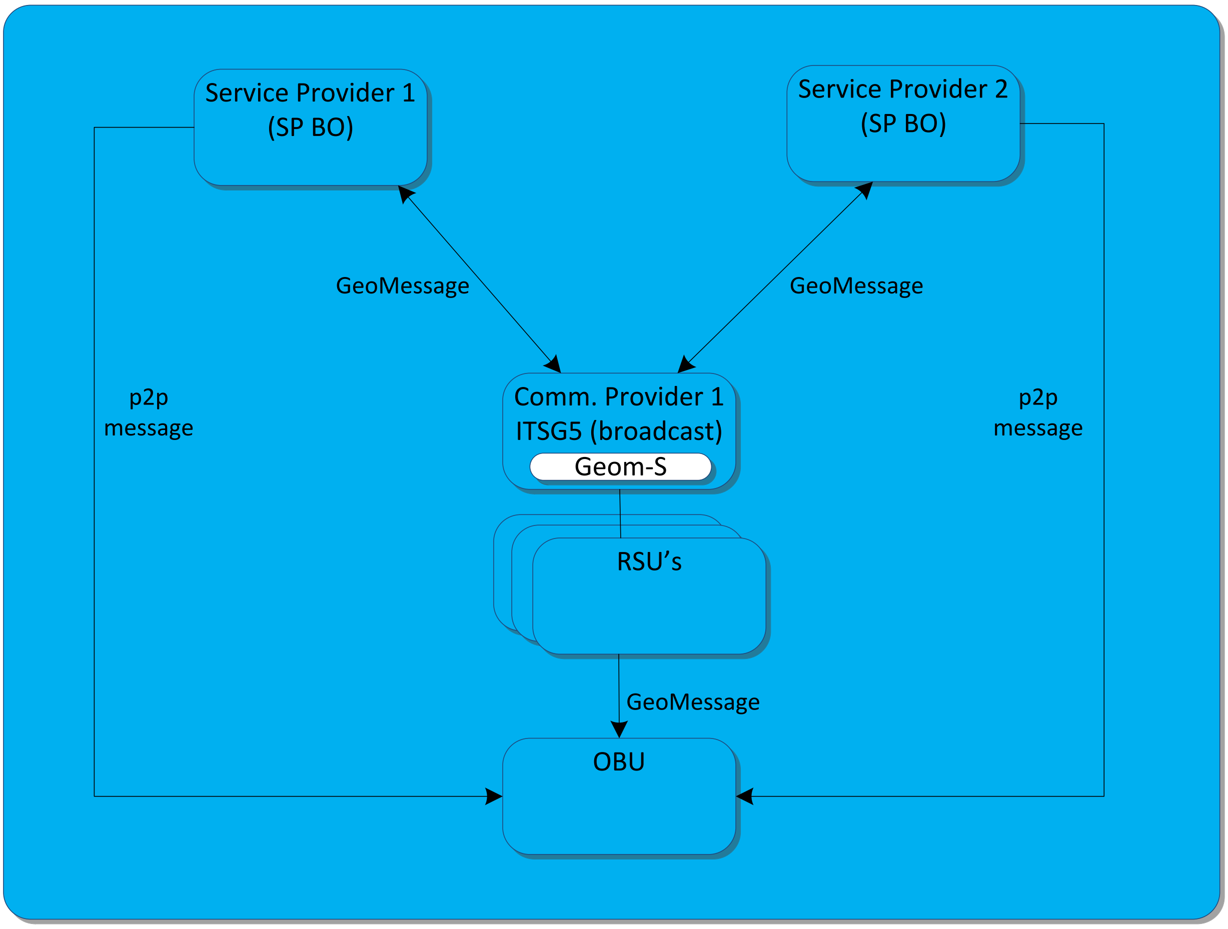

Figure 4-24 Architecture for single CP - multiple SPs

2. Multiple connections between SPs and CPs, without service directory: a SP has access to multiple CPs. The CPs send their topology (area of reach) to the SP. The SP’s stores this info and uses an own GeoMessaging Proxy (Geom-P) to send message to the correct Geom-S of the CP. Also other non-ITS-G5 broadcast networks of mobile network operators (e.g. with LTE broadcast) can be integrated in this concept, as shown by CP 1 and CP 4 in the next figure.

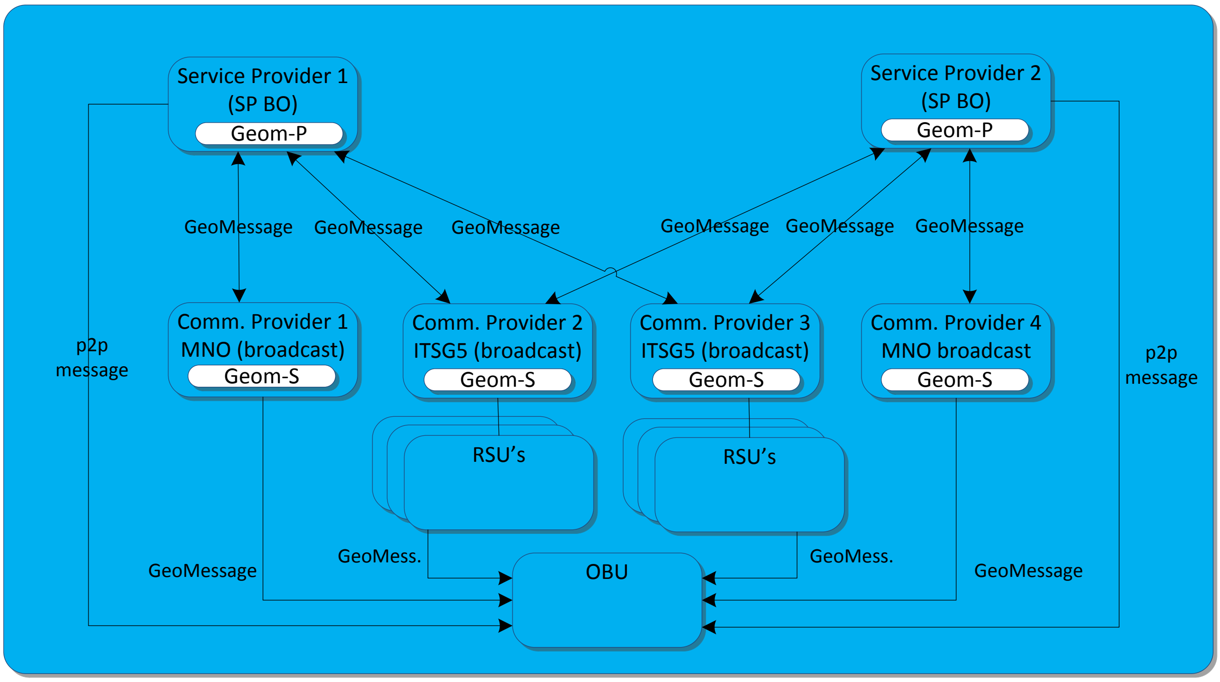

Figure 4-25 Architecture for multiple CPs - multiple SPs, without service directory

3. Multiple connections between SPs and CPs, with Service Directory: a SP has access to multiple CPs. The CPs send their topology (area of reach) to the central SD. The SP's retrieves this info and uses a GeoMessaging Proxy (Geom-P) to send message to the correct Geom-S of the CP.

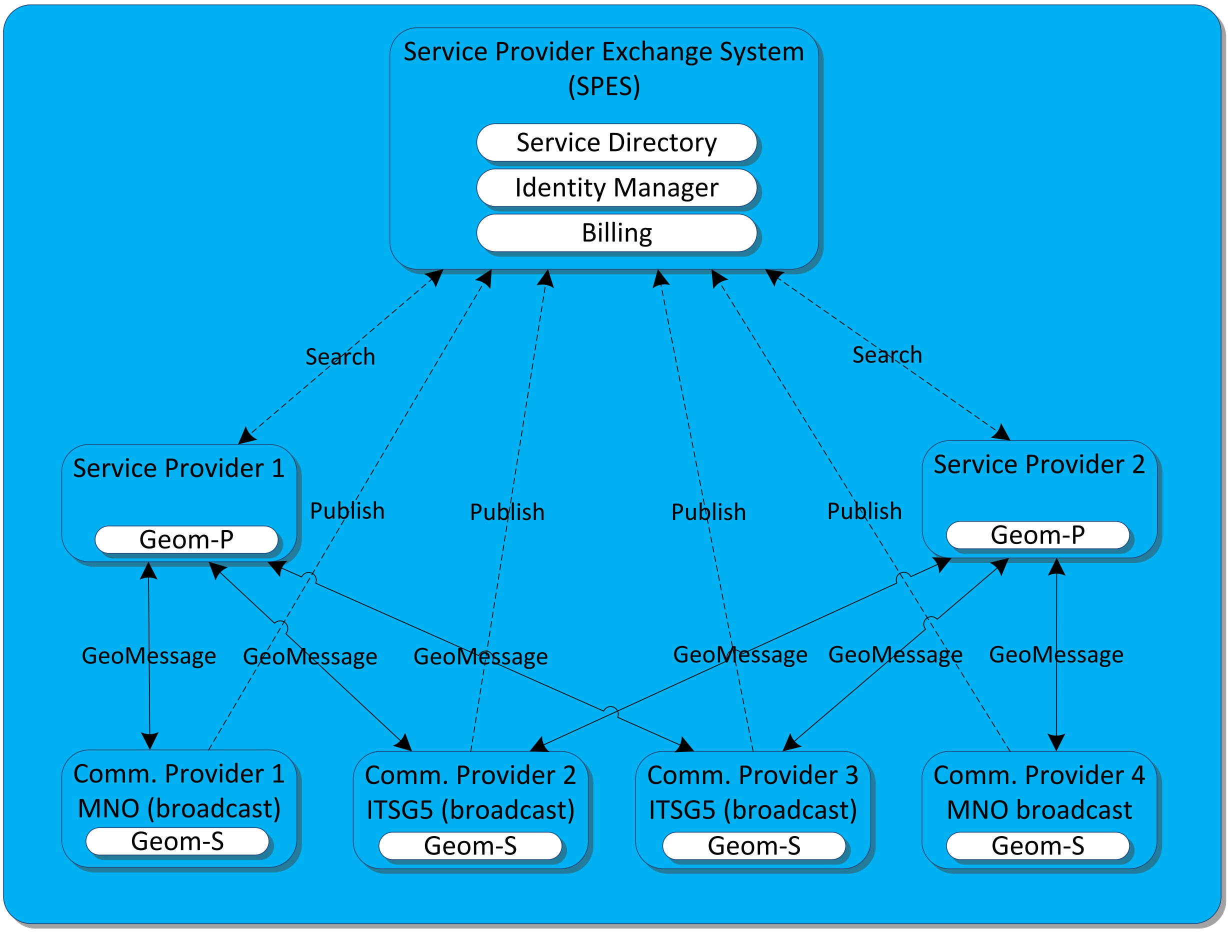

Figure 4-26 Architecture for multiple CPs - multiple SPs, with service directory

4. Multiple connections between SPs and CPs, with a central CP: a SP has access to multiple CPs via a central CP. This CP acts as communication broker for all SPs. The CPs send their topology (area of reach) to the central CP. The SP's forward all message via the central CP.

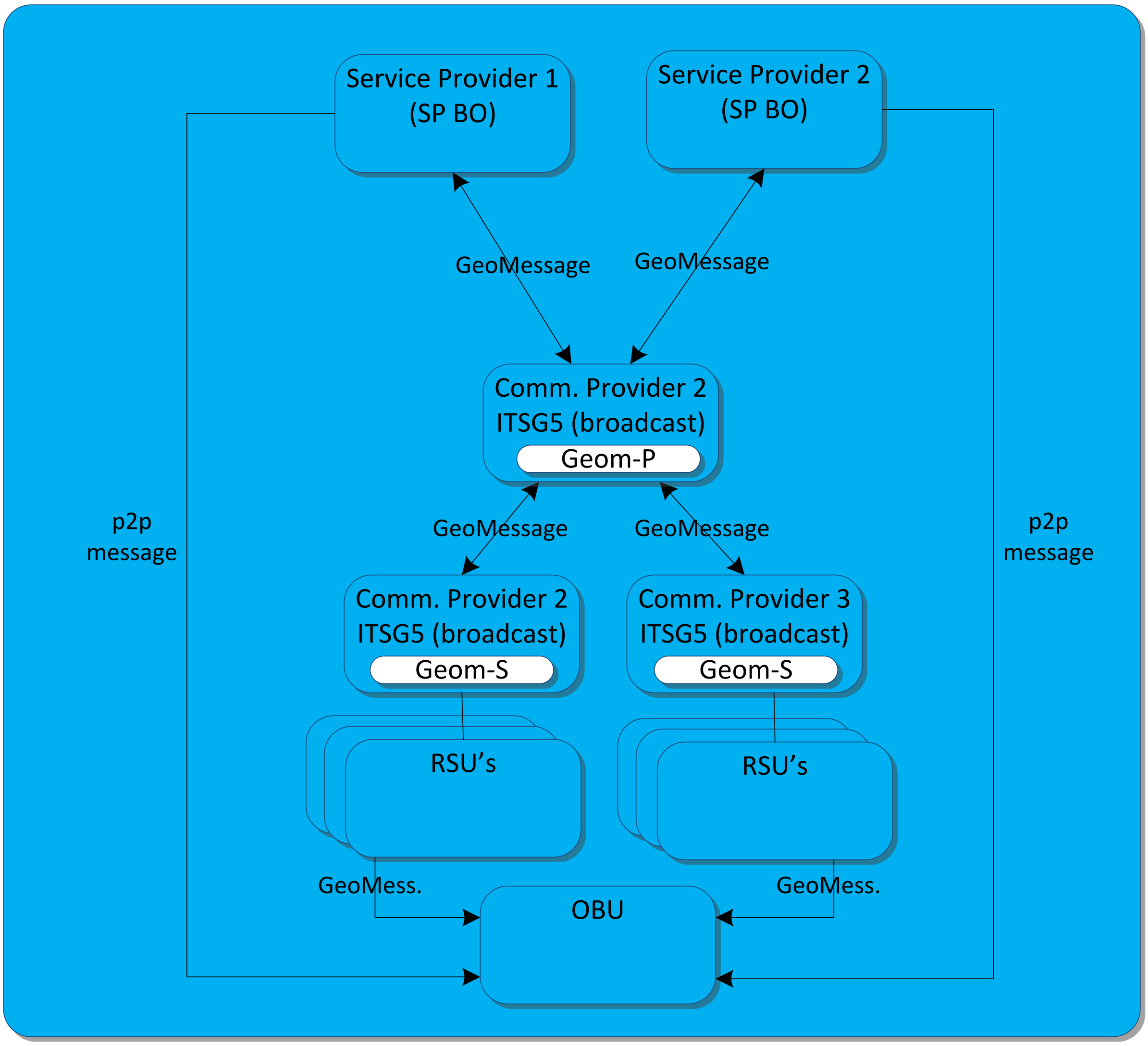

Figure 4-27 Architecture for multiple CPs - multiple SPs, with central CP proxy

4.5.7 Architecture for VRU applications

The VRU safety applications rely on accurate localization of VRU's via either (i) in-vehicle or roadside sensors (camera, radar), (ii) a tag-based system (VRU-transponder with a vehicle or roadside VRU localization system) or (iii) VRU's with a VRU-OBU capable for ITS-G5 communication or a personal information device.

The solutions differ in the system that performs situation assessment (i.e. roadside, vehicle or VRU) and in the road users that are warned i.e. driver and/or VRU. The aggregated architecture for the selected VRU applications is shown in Figure 4-28.

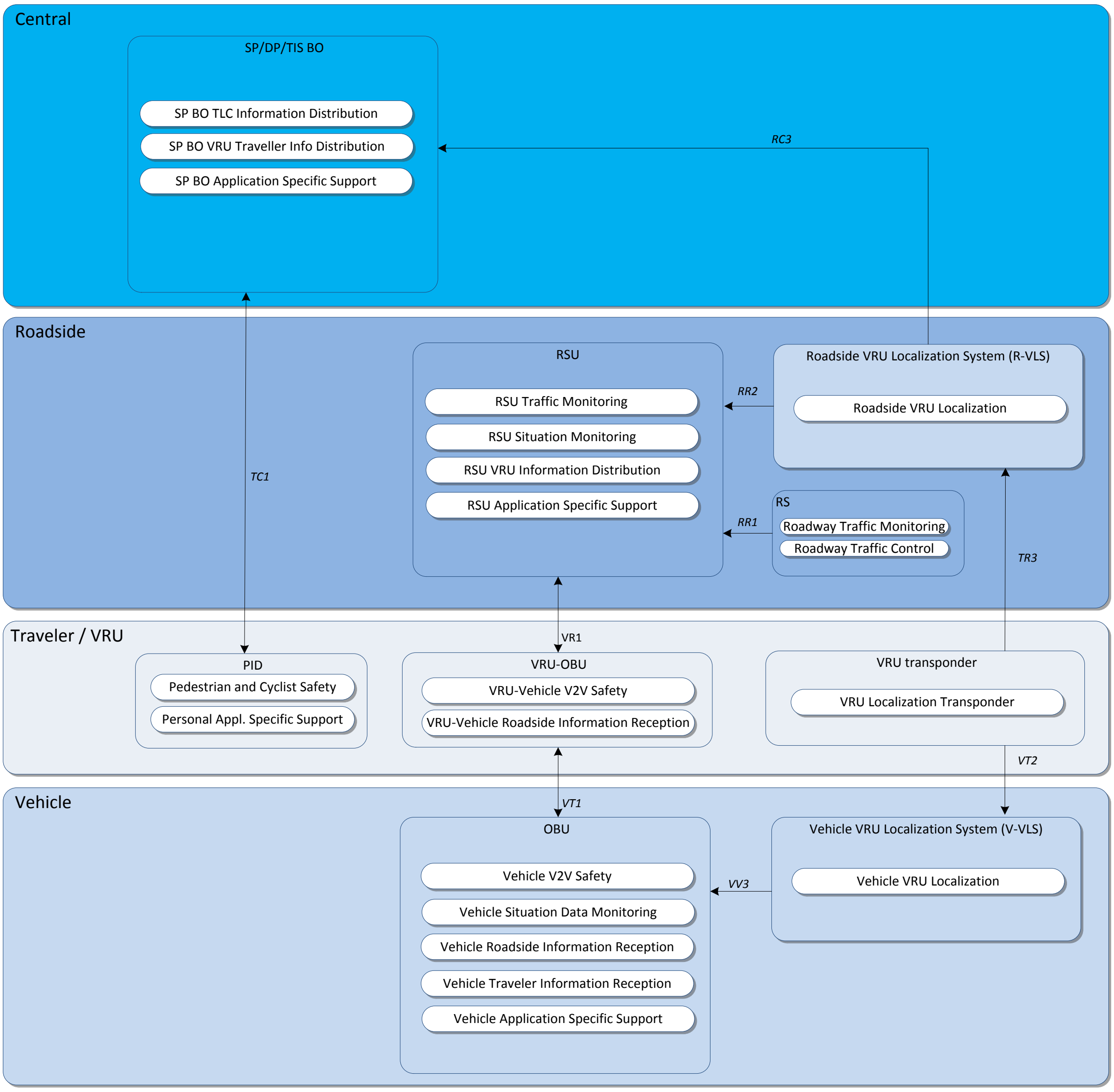

Figure 4-28 Architecture for VRU applications

Examples of use of the interfaces are depicted in Table 10.

Table 10 Interfaces with reference for selected VRU applications

Id	Source	Dest.	Information Type	Reference	Remark
VT1	OBU	VRU-OBU	Vehicle State/Warning	ETSI CAM/DENM	
VT1	VRU-OBU	OBU	Vehicle State/Warning	ETSI CAM/DENM	
VT2	VRU-T	V-VLS	VRU Location	Project VRUITS	
VR1	RSU	VRU-OBU	Warning, Intersection State	ETSI DENM, SPAT, MAP	
VR1	VRU-OBU	RSU	Vehicle State	ETSI CAM	
TR3	VRU-T	R-VLS	VRU Location	Project VRUITS	
RR1	RS	RSU	Intersection State, Detected VRU	Project VRUITS	
RR2	R-VLS	RSU	Detected VRU	Project VRUITS	
VV3	V-VLS	OBU	VRU Location	Project VRUITS	
TC1	PID	SP BO	Extended green time request	Project VRUITS	

TC1	SP BO	PID	Intersection Info	ETSI SPAT/MAP	
RC3	R-VLS	SP BO	VRU Location	Project VRUITS	
RC3	SP BO	R-VLS	Extended green time request		Similar to Priority Request

4.6 Standards

A separate project is defined by DITCM and Connecting Mobility on standards in C-ITS. The results of this project are not included in this document, since it is still work-in-progress.

The ETSI standards framework is applicable for the cooperative sub-systems, and is today mainly focussed on specification for V2V and V2I communication. Some specifications on interconnection of IP-based and GeoNetworking-based networks are missing, e.g. GeoNetworking-over-IP. This specification is relevant for roadside to back-office connections.

In [10] an overview is given on interfaces and protocols between cooperative systems and existing vehicle, roadside and central systems. Different specifications were identified, e.g. E-OBD, IVERA, WKS/LIB, VLOG, DVM Exchange and Datex-II.

A summary of the standards:
E-OBD: for in-vehicle OBU systems CAN-bus can be used to retrieve information on vehicle state from VEE. The standards are OBD-II (with EOBD) and FMS. Vendor-specific extensions are needed today to send requests to the VEE to adjust speed or to present warnings or risks on the in-car HMI.

IVERA: Today, no EU standards exist to exchange data between legacy roadside systems. In the Netherlands the IVERA protocol was developed by the IVERA platform (www.ivera.nl) to exchange information between TLC and TMS of different vendors. This protocol (version 3.01, July 2014) can be reused as interface between RSU and TLC to exchange information on intersection state. The IVERA protocol can also be used to exchange information between different TMS and to other systems like parking information systems. In Germany a similar protocol is developed by OCIT (www.ocit.org). Other protocols - like VLOG - are less suited to retrieve dynamic data, since they are used for log data for off-line analysis in tactical or strategic traffic management.

WKS/LIB: To retrieve information directly from roadside systems along highways of Rijkswaterstaat the interfaces as defined in the WKS (*Wegkantsysteem voor Signaleren en Monitoren*) can be used. The LIB (*Lokale Info Bron*) interface can be used e.g. to retrieve the actual information displayed on road-side systems. Information from roadside sensors are collected and aggregated by collection servers. This information is sent with a one-minute time interval to central systems, by proprietary protocols or by DATEX-2. This information cannot be used in use cases where traffic state information is needed at a smaller time scale of 0.1-10s.

DVM Exchange: is an application protocol (based on SOAP/HTTP) to send requests for dynamic traffic management (e.g. to increase traffic flow via different TMS and DVM (*Dynamisch VerkeersManagement*) systems). The current version of this standard is 2.5 and can be found on www.dvm-exchange.nl. DVM Exchange can be used in static (i.e. predefined measures at predefined location at fixed or variable time) or dynamic scenario's (i.e. ad-hoc request to increase traffic flow) between road authorities.

DATEX II: DATEX II is a multi-part standard, maintained by CEN Technical Committee 278, CEN/TC278. DATEX II is often being used to exchange information at the central layer between Traffic Management and Information Systems. It appears as a logical step to continue applying this standard for information exchange. However, it is not yet clear whether implementations of DATEX II based systems can meet real-time requirements imposed by cooperative applications. DATEX II is typically used for periodic updates of the traffic status and has a large message overhead, where many cooperative applications would benefit from an event-based approach with messages with a small overhead.

4.7 Security

A separate project is defined by DITCM and Connecting Mobility on security in C-ITS. The results of this project are available in a white paper [30], and therefore not included in this document. In this section we briefly discuss the organization of security measures, followed by the physical and functional security components. Note that privacy is not covered in this section.

As shown before, the ITS applications require functional and physical sub-systems to achieve their functionality, security also requires functional and physical sub-systems. Security serves a goal and requires organization of the security measures for the application, about which the developers and providers of the application should agree.

4.7.1 Organization of Security Measures

For a system or application the developers should agree upon the required level of security for the whole system or application and the implication for the separate physical and functional components and interfaces. The requirements should be formulated, such that it can be verified that a new provider of a physical or functional component satisfies these requirements. If a new provider satisfies the requirements, security material can be provided to him, possibly via functional and physical components and the already trusted providers in the system know thereby that they can trust this new provider.

Note that a system can be larger than a single project or application. Consider for example cooperative systems, where the OBUs can be expected to support different applications, thus being shared among different applications, thereby potentially complying with the different security requirements of these systems. This raises the questions if the security requirements upon which there is agreement for a system, are compatible with the other systems.

In the Converge project [31] a governance architecture is defined at the top of the system that consists of an *initialization body* a *service test and certification institution* and a *contract supervision authority*. These are organizational processes that are supported by functional components in the form of an *enrolment authority* and a *root certification authority*. The initialization body offers the providers that want to participate a legal framework, to which they have to agree, thus requirements that they agree with. The service test and certification institution verifies that the provider satisfies the requirements for the implemented physical or functional components and interfaces, this also includes security requirements. Note that these requirements can also be non-function, for example relating to OBUs being tamper proof. The contract supervision authority grants entrance to a provider if it agreed upon the legal framework and satisfies the requirements, thereby granting the provider access to use the functional components. This enables a provider to enrol via the enrolment authority and get a certificate signed by the root certification authority.

4.7.2 Physical and Functional Security components

A physical component will typically contain the generic application component *Trust Management.* This application component is able to generate keys and manages the certificates and associated keys that are used to sign, encrypt, decrypt, and authenticate information. It therefore has to exchange information with a physical component called the Security and Credentials Management System, to maintain a valid set of security certificates and credentials. Additionally, the trust management logs, identifies, and reports events that may indicate a threat to the Connected Vehicle Environment security. The application component trust management assist in security measures, but its usage is probably one of the taken security measures. Another security measure that may to be taken is assuring that the trust management is executed by a secure element, such that the key data inside is securely stored.

Trust management can be used to apply security for interfaces or for the application component itself. Below these two cases will be discussed, after which the required central security provider is discussed in detail.

Interface security

Application and physical components communicate information via communication channels. During the design for each interface the choice has to be made if the channel has to be secured, for example by using TLS, if the communicated data is signed or encrypted, or that no security measures are required. Depending on the selected security measures, key material may have to be exchanged with a physical element called a central security provider.

Application security

Functional components are executed by a physical component, for which it is desirable to assure that the correct application component is executed and that the used configuration information is correct, where both application and information are not altered. The choice regarding security measures and requirements will be made by the designers of the cooperative ITS system. The choice may mean that applications also require key material and certificates, which has to be exchanged with a central security provider.

4.7.2.1 Central Security Provider

For the security functionality described above additional functionality will be required to distribute, generate and store key and security data. Therefore we introduce the physical components *central security provider (CSP),* as shown in Figure 4-29. This CSP needs to be a trusted entity for all providers.

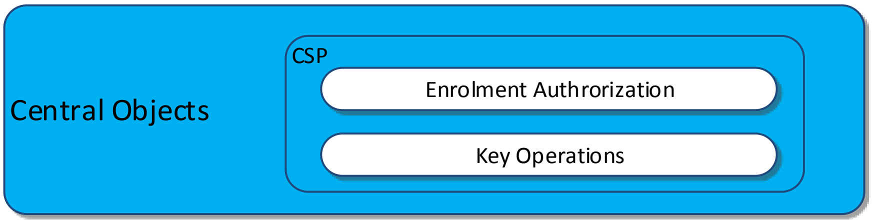

Figure 4-29: Physical component Central Security Provider

Functional components that can be implemented by this *central security provider*, depending on the required security measures for the system, are:

- Enrolment authorization: This grants a physical component access to the other security Functional components, preferably after they complied with the legal frame work and succeeded for the tests. With this access the Physical component can request certificates and keys from the Key Operations;
- Key operations: This application component can generate, store, revocate and distribute keys for a PKI infrastructure. For example, after obtaining access via the enrolment authorization, it can generate and sign certificates for a given functional component.

4.8 Traversing the Design Cube

In Section 4.1, we introduced a framework and the three-dimensional design cube to explain the process of traversing the design space in performing an architecture design process. Performing a complete architecture design process means going via a number of model transformations from the front top left cell to the back bottom right cell. Figure 4-30 shows the path that was followed in designing the architecture presented in this document (white arrow through the red cells). Accordingly, first two realization transformation steps were made (through the business model design), and next; three refinement steps were made to increase the level of detail along the aggregation dimension (through the system architecture design) and to reach to the cell that represents the architecture presented in this document.

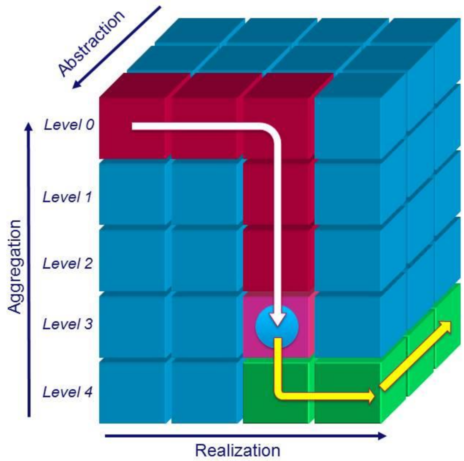

Figure 4-30 Path followed through the design cube

The figure also shows an *exemplary* path (yellow arrows through the green cells) that can be followed by taking the cell that represents the architecture as the starting point. In this path, first, a step is taken along the aggregation dimension, which is followed by a realization step, and finally two concretization steps are taken along the abstraction dimension.

4.9 Mapping Business Architecture to System Architecture

In Section 3, we discussed the business view of ITS applications by introducing a framework for business modelling. Business model design, with the help of the Business Model Radar conceptual tool, is the approach to concretize the strategic abstract value-in-use, to identify stakeholders, their value-propositions, the activities they perform and the costs and benefits they incur and receive respectively. According to BASE/X, a business model of the second layer of the pyramid is operationalized by a service composition in the third layer. This composition is the aggregation of business services provided by the focal organization and the other parties that are involved in the business model.

We have already mentioned that the BASE/X framework does not cover only the business design, but provides also support for the organization and information technology platform design. Organization design provides the organizational operationalization of the elements in the business pyramid covering both automated organizational processes and manual processes. The design of the information technology platform in BASE/X provides the blueprint for the IT platforms that are required for the execution of the elements identified in the organization pyramid. This leads to the three-pyramid model as shown in Figure 4-31.

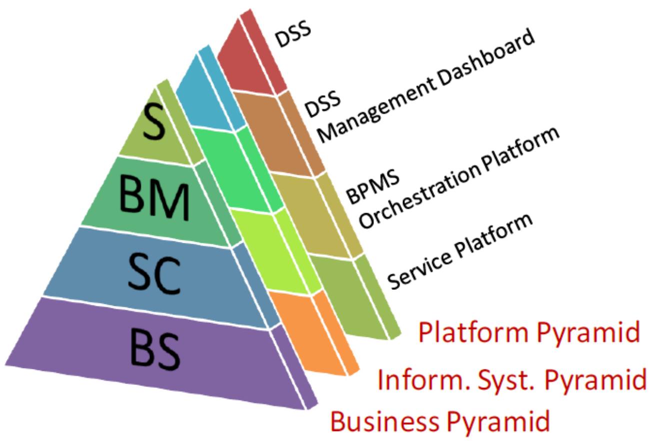

Figure 4-31 BASE/X 3-Pyramid Model

The support of the Service Composition layer is done with the help of the Business Process Management discipline. The conceptual design of service compositions in the business pyramid can be formulated with the design of business process models in the second pyramid. Many approaches, techniques and languages have been developed to design business processes. In this document, we use the Business Process Model and Notation (BPMN), Version 2.0[9] to model how the

[9] http://www.omg.org/spec/BPMN/2.0/

different co-production activities of each stakeholder in the business model are organized to realize the value-in-use.

We present in Figure 4-32 below an example of a business process model, more specific the TIS with FCD application. The co-production activities represented as high-level activities of each stakeholder can be further decomposed into detailed tasks.

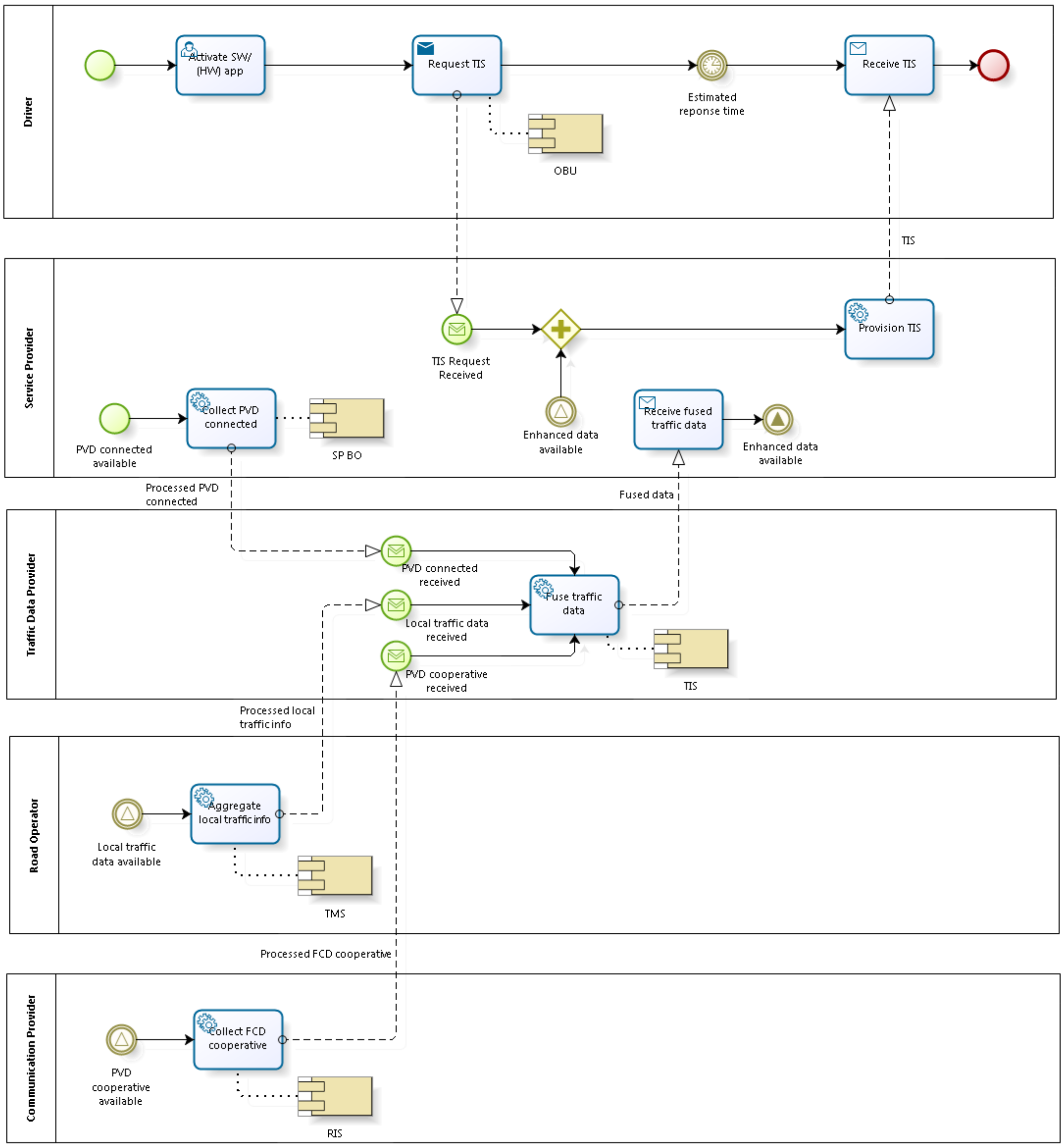

Figure 4-32 Business Process Model TIS with FCD

The process consists of two main parts. The first part is the collection of the data and their fusion from the Traffic Data Provider. The second part is the request from a Driver from Traffic Information Service.

It is assumed that the collection of data takes place prior to the driver's requests for the service. In addition, it should be considered as an iterative process. Assuming that PVD are available, a Service Provider gathers connected data. Moreover, triggers indicate that local traffic data and cooperative data are available to be gathered by the Road Operator and the Communication Provider respectively. All these three types of data are sent to the Traffic Data Provider who has the task to fuse them. After fusing, the enhanced fused data are sent to the Service Provider, who is responsible to inform the driver about the traffic.

After the Driver activates his in-car navigation system, his OBU requests the service. As soon as enhanced data are available, the service is provisioned back to the driver by the Service Provider.

The core activities in the above business process model can be supported by the elements of the functional architecture as shown in the model. We see for example how the collection of PVD from connected vehicles is supported by the Service Provider BO object.

5 Implementation architecture of selected projects

5.1 Introduction

In this section the method described in the previous chapter is applied on the applications of two selected projects.

5.2 NL-DE-AT ITS corridor

System architecture

The project team of Austria in ITS Corridor – called the European Corridor - Austrian Testbed for Cooperative Systems (Eco-AT) project [32] – has released in Jan. 2015 a first set of specifications on system definition (WP2), i.e. use case descriptions of the Amsterdam group Day-1 applications and a high-level system overview. This set of specifications has to be updated by the Dutch ITS Corridor project team in Jan. 2015.

In the use case descriptions the following ITS applications are described in detail:

1. Road Works Warning (RWW) [33]: several implementation options are described for both ad-hoc/short-term and long-term road works and the type of RSU systems used with trailers that are controlled with/without back-office integration. A ‘profile’ is defined based on the ETSI DENM specification;
2. Probe Vehicle Data (PVD) [34]: information from vehicles with CAM broadcast is collected by a RSU and - via CAM aggregation – send from RIS to CIS. The aggregation is performed by the RSU and identical to the current traffic information collection via existing loops. Additional information on e.g. individual vehicle information on position/speed is e.g. not forwarded in the current specification.
3. Intersection Safety (ISS) [35]: three use cases on intersection safety are described i.e. (i) vehicle speed optimization approaching an intersection based on signal status, (ii) fast pre-emption of traffic due to traffic light signal change (red to green) and (iii) red light violation
4. In-Vehicle Information [36]: information on dynamic and static signals is send via ETSI IVI messages, based on ISO/TS19321. The specification also describes the Austrian specific implementation to distribute the IVI information to external parties;
5. Other Road Hazard Warnings (other DENM [37]): existing road hazard warnings that are distributed today via digital audio broadcast radio (RDS-TMC) are also distributed from TCC via CIS and RIS to vehicles. The main Datex-II codes used today for road hazard warnings are mapped to DENM codes.

Other specifications on e.g. roles & responsibilities, security architecture and convergence strategy for ITS-G5 and cellular) and detailed descriptions with functional requirements for all individual system components (TCC, RSU, OBU, security) will be

In the system overview [38] the high-level architecture is defined and shown in Figure 5-1

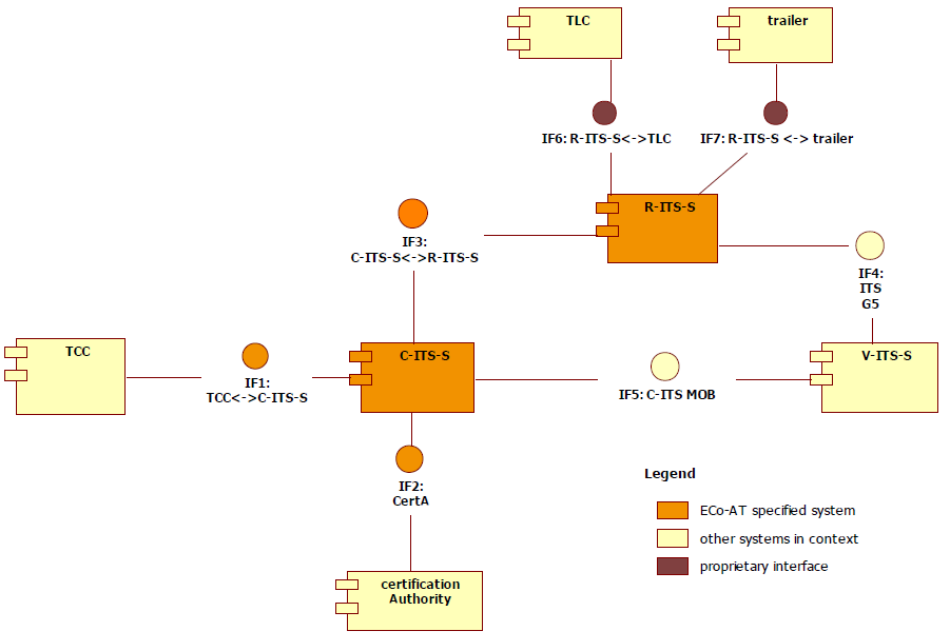

Figure 5-1 High-level Architecture ITS Corridor [source ECo-AT project]

A road works vehicle can also send CAM (special vehicle) or DENM messages (stopped vehicle, slow vehicle) to approaching vehicles, but this is not included in the ECo-AT specification today.

The following table shows a mapping of the ECo-AT interfaces IF1 to IF7 to the interfaces in the architecture as defined in Figure 4-6. All interfaces of ECo-AT project are addressed in the architecture and the specification can be re-used or need to be updated to the specific Dutch context.

ECo-AT interface	Interface	Source	Dest.	Information Type
IF1	CC9	DP	SP	Enriched Probe Vehicle Data
IF2	VC1	SP BO	OBU	Service provider specific information
IF3	VC1	OBU	SP BO	Service provider specific information, probe vehicle data
IF4	CC6	SP	CP	ETSI DENM, ETSI TSM
IF5		CIS	VIS	Not in scope of ECo-AT
IF6	VR1	OBU	RSU	ETSI CAM, ETSI DENM
IF7	CC6	CP	DP	Aggregated Probe Vehicle Data
G	CC9	SP	DP	Aggregated Probe Vehicle Data
H	CC1/CC4	TMS (via TIS)	DP	Macro Traffic State / Control Data e.g. Dynamic Speed Limits, loop/camera data
H*	CC1/CC4	TMS (via TIS)	DP	Micro Traffic State / Control Data
H'	CC2	SP	TMS (via TIS)	Speed advise

Business Model Design
In the ECo-AT architecture the focus is on safety-related applications via a system under full control by the road operator, i.e. the road operator acts as communication

provider (via RSU) and data provider to external parties, similar to today's situation in Austria, and acts as service provider to road users with for I2V safety-related information. There is no role foreseen for private entities to fulfil the role of communication or data provider, or give service providers and/or car manufacturers access to the RSU to send messages to vehicles.

5.3 Shockwave Traffic Jams A58

The approach of this project is market-driven i.e. with a vision on horizontal market dynamics and service versatility. Three horizontal market roles are defined - service provider, data provider and communication provider of a cooperative ITS roadside network - and supported by the system architecture by the definition of well-defined interfaces to exchange information between the market roles to support the market dynamics. However, the individual market parties have the freedom to develop differentiated applications, to have a differentiated service offering compared to competitors and will therefore depend on a suitable individual business model.

The architecture for this project is based on the following requirements:

- Support for different roles in the value chain ('horizontal' split) and open to enable market competition; less focus on specific use cases / ITS applications
- Several entities (both public and private) can fulfil same business role: multiple instances of the same application are possible
- Enable access to data at different levels (i.e. raw, fused, enriched)
- "Talking Traffic": synergy between connected and cooperative communication
- Support of a broad set of use cases

These requirements have led to the following project choices to support the 'horizontal' split in business roles:

- Hosting function on roadside communication system: applications/facilities run on hosted system, part of the CP BO; data exchange between applications (of different service/data providers) on local hosting system is used to reach time constraints for local advises/warning;
- Central access to roadside communication system; different types of access (via interfaces D1/2/10/11, see Figure 5-2) are possible, i.e. direct ETSI-based message (DENM, TSM, IVI) or other data messages to hide complexity of ETSI formats with related PKI-based authentication schemes;
- Road operator becomes an entity that can support different roles and is no longer the central / integral entity.

System architecture

For the *Shockwave Traffic Jams A58* project the architecture is modelled with the defined building blocks and shown in Figure 5-2.

In this figure the interface markings as defined by A58 [39] are plotted in the figure. The functional components are plotted in the sub-systems. With this architecture the applications in A58 are supported.

It should be noted that in the A58 project the role of the road operator is limited to providing information to data / service providers on traffic flow (local loop data) and traffic measures (dynamic speed limits). The architecture supports however also other roles for the road operator, e.g. sending safety warning (like road works warning). In this case the road operator fulfils the business role of service provider.

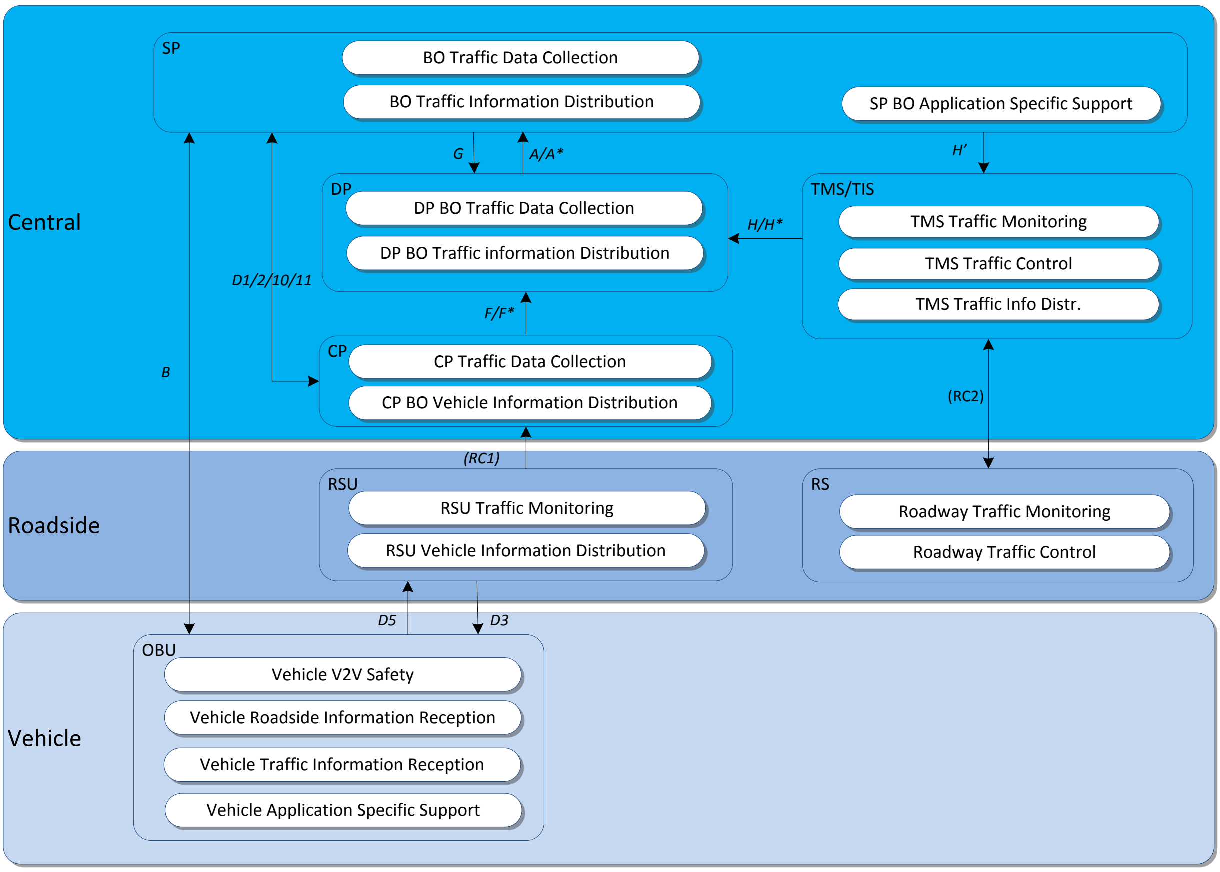

Figure 5-2 Architecture View of *Shockwave Traffic Jams A58*

The interfaces of the A58 project are shown in Table 11[10].

Table 11 Interfaces with reference between A58 and architecture.

Id A58	**Id**	**Source**	**Dest.**	**Information Type**
A / A*	CC9	DP	SP	Enriched Probe Vehicle Data
B	VC1	SP BO	OBU	Service provider specific information
B	VC1	OBU	SP BO	Service provider specific information, probe vehicle data
D1/2/10/11	CC6	SP	CP	ETSI DENM, ETSI TSM
D3	VR1	RSU	OBU	ETSI DENM, ETSI TSM
D5	VR1	OBU	RSU	ETSI CAM, ETSI DENM
F/F*	CC6	CP	DP	Aggregated Probe Vehicle Data
G	CC9	SP	DP	Aggregated Probe Vehicle Data
H	CC1/CC4	TMS (via TIS)	DP	Macro Traffic State / Control Data e.g. Dynamic Speed Limits, loop/camera data
H*	CC1/CC4	TMS (via TIS)	DP	Micro Traffic State / Control Data
H'	CC2	SP	TMS (via TIS)	Speed advise

[10] The interface specifications of the A58 project are available via the project.

Within the A58 project four different types of interfaces (D1/2/10/11) are defined between SP and CP. The interfaces D2/10/11 rely on a ‘hosting’ model were the service provider needs to install his application on the roadside hosting system.

Business Model Design

The project aims to support an open horizontal architecture rather than a vertical stovepipe architecture. In this approach functions are split, i.e. end-user services from service providers, data information services from data providers and road-side communication services from communication providers (via ITS-G5 roadside network(s)) and interfaces between these functions are defined to support this ‘horizontal’ split. In this architecture a provider can focus on a certain layer of the system, e.g. a roadside communication network, rather than focusing on end-user applications, which would require implementations of all parts of the system. The project leaves options open on the roles of the road operator, i.e. as responsible for law-enforcement and safety-related information distribution to road users.

6 Conclusions

Today's society is challenged with ensuring mobility while reducing its negative impact on the environment, economy, and quality of life. To address these challenges, various governmental, academic and industrial stakeholders have worked on the C-ITS systems for many years and advanced on the technology to improve several mobility concerns, such as safety and traffic efficiency. With the aim to provide guidance to future ITS deployment projects in the Netherlands, this report presents the results of the efforts in developing an ITS architecture in a Dutch context, through consolidating and synthesizing the outcome from several relevant initiatives. The architecture consists of two main elements: a business model design and a system architecture description.

We introduced a business model design to guide and facilitate the development of business models for ITS applications. First, a stakeholders' analysis is presented to provide structure in the long list of parties who are involved in ITS applications. The categorization of these stakeholders is done at the high level of roles, leaving the decision of which specific business actors will undertake these roles up to the board of each of the selected projects.

Next, we selected a representative set of ITS applications for which we design blueprint business models. The design is developed with the help of a conceptual tool called business model radar, which is part of a business-engineering framework for service-dominant business. In each of these business models, we present the actors involved, their value proposition and coproduction activities, and the costs and benefits associated with the deployment of a specific solution.

The business architecture described in this document is a prototyping approach of business modelling and acts as a guideline for further, concrete design of business models. Also, the relation between business architecture and system architecture can be explored in more detail in further work.

The system architecture described in this document is based on cooperative ITS applications from selected EU research projects and Dutch deployments trials. In this architecture, the 'building' blocks and sequence diagrams are defined to create a high-level Physical View, Functional View and a Communication View of the integrated cooperative ITS architecture. The main conclusions are:

- The architecture and the underlying 'building blocks', interfaces and sequence diagrams are meant to be **descriptive** and provide a common language in which all the underlying projects are captured in a consistent way. A design tool and/or templates will be useful to support future projects in defining their solutions with the use of a common framework of terminology, architecture views and data models/elements.
- In a next step, this architecture should be simplified to enable guidance for future projects. Simplification should be realized by limiting the design freedom that results from the integration process of the underlying projects, and from the ad-hoc decisions made in these projects due to the specific constraints. Such a next step should be supported by all stakeholders to enable the successful adoption of the resulting reference architecture.

- Technical system and interface specifications need to be developed in the projects. For the interfaces in the communication view a reference is given to specifications from EU (ETSI, Datex-II) or Dutch standards (IVERA, DVM-Exchange). System design specifications are not in scope of this architecture document since this is left to the specific implementation choices.
- Information exchange between vehicles and between vehicle and infrastructure (and vice versa) can be realised via short-range (ITS G5) and long-range (cellular) networks. To be effective safety-related information should reach as many end-points as possible i.e. both drivers and road operators. Improved information exchange between private and public organizations – via open data interfaces - and the integration of communication networks - via open network interfaces - would allow creating better and cheaper solutions and/or new functionalities. How to realise this improved information exchange and hybrid communication between vehicles and infrastructure will in the initial phase mainly depend on how vehicle ITS systems will be deployed. In the architecture options are described to support open interfaces and communication via hybrid networks.

The deployment phase (research, trial, deployment) of the ITS applications differ per group of applications. Below are the main findings and conclusions listed per group of application on specifications:

- V2V applications based on ITS-G5: for these applications one should notice that the first V2V ITS systems based on ITS-G5 are not yet released by car manufacturers and are expected to become available in the coming years, i.e. between 2015 and 2020. Safety-related applications are the first ITS-G5 applications expected to be deployed and are described in the architecture. For V2V the deployment guidelines of the Car2Car Communication Consortium – based on ETSI ITS standards framework – will be leading. Security specifications are today developed in ETSI and Car2Car CC, but are not yet finalized.
- I2V applications based on ITS-G5: for these applications the deployment guidelines of the Amsterdam Group - e.g. via specifications of the pan-EU ITS Corridor projects - should be used. Many technical specifications are still under development in ETSI ITS Release 1, especially for I2V applications (e.g. IVI, MAP, SPAT, TSM message sets). White papers on specific applications will be needed to describe which safety-related information in real-world traffic situations needs to be send between vehicles and infrastructure is missing. Also technical specifications/standards on the deployment of cooperative roadside networks and the interfaces to back-office systems are missing today. In this document the relevant options are described to support access to an I2V system at the network or facilities layer. The underlying security architecture aspects of the options are shortly addressed. However, for a lot of projects the security architecture is not addressed, it should therefore also be described in more detail in white papers.
- I2V applications based on cellular or hybrid communication: non-safety related ITS applications on traffic flow, comfort and environment based on cellular communication are already deployed today on large scale to inform

individual road users, e.g. via connected navigation, pay-how-you-drive and fleet management applications. The focus in projects like Praktijkproef Amsterdam and Shockwave Traffic Jams A58 is to see how information from connected cars (i.e. floating car data from smart phones) and existing traffic monitoring and control systems of Dutch road operator can be fused to improve information and to use this information either to prevent traffic jams by earlier and more accurate detection or to reduce the (collective) impact by improved individual on-trip or pre-trip advices by market parties. The interface specifications and implementation issues, together with the best practices, from these trial projects are very relevant for future projects. The 'open data' interfaces from the road operator networks can in the near-future be reused to inform drivers via cooperative roadside networks.

- I2I applications: to support a scalable and open eco-system, with multiple service providers, data providers and communication providers, a distributed service directory is needed. Additionally, systems for identity management and billing can be used. This concept, together with the system and interfaces specifications, is developed in projects like MOBiNET (MOBiCENTER) and Converge. In Converge also the governance systems and the hybrid communication architecture are addressed. The concepts of MOBiNET and Converge are included in the architecture and are relevant to create an open market with low entry barriers for both service providers and communication providers with ITS-G5 networks.
- VRU safety applications: in the VRUITS project ITS applications to improve safety for vulnerable road users are described. The building blocks are reused in the architecture. This project is still in the research phase, and the first trials will be performed in 2015. Results from this project will be used to enhance the existing ETSI standards in the near future.

6.1 Future Steps

The objective of this work is to provide an integrated architecture in which the solutions of a selected set of projects are described in a consistent way. This is seen as a first step towards a widely accepted reference architecture that facilitates the development, interoperability and deployment of cooperative ITS in the Netherlands. To keep this ambition on the long term, the architecture should be improved and kept up to date with the advances in the field.

To arrive at a well-usable and tested reference specification that can be a solid basis for coherent future C-ITS developments in the Netherlands (and possibly beyond), the reference architecture has to be elaborated in four ways and put into practice.

Firstly, the business model blueprints have to be operationalized to support detailed business model design. The framework presented in this document provides an illustrative catalogue of high-level business models, but does not provide the tools (in terms of design guidelines and templates) for the definition of new C-ITS business models. Also, an approach needs to be developed to step from qualitative, multi-sided business model radars to quantitative business models, making the concrete business case in terms of costs and benefits for individual partners.

Secondly, the integrated architecture has to be simplified to result in a reference architecture. Simplification need to take place by limiting the options currently supported by the integrated architecture. The resulting reference architecture should still support all services from the underlying projects. However, currently, more implementation options are supported for the same functionality, due to the fact that multiple projects have been used as a basis, and because the project contexts have led to implementation options that no not need to be supported in the long run. The aim of the simplification should be improve reusability, reduce implementation costs, and improve maintainability.

Thirdly, the technical system architecture has to be mapped to practical guidelines for C-ITS system design and validation against the reference architecture. Without proper practical guidelines and supporting techniques, an architecture framework may become a specification that is lightly checked a-posteriori in system design to arrive at the observation of ‘a reasonable fit’ by default - and to result in non-interoperable systems in the end. A well-structured C-ITS architecture evaluation checklist will be a valuable tool for this purpose.

Fourthly, the business model design and the system architecture need to be clearly mapped to allow for integrative business and technology engineering. The exemplary mapping provided in Section 4.8 should be interactively built and presented with the use of a toolset supporting not only the integrated development and maintenance of this architecture, but also facilitating the use of it for current and future projects. This means that the identification of required system modules (listed in a catalogue) should be directly deducible from a business model in a clear and traceable, top-down way. The other way around, functionality present in system architectures should allow for bottom-up experimentation with business model ideas. Toolset should be such that integration of business and technology in C-ITS developments is made an attractive front-end activity, rather than an obligatory closing chore.

7 References

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8 Appendix A: ITS application sequence diagrams

8.1 Introduction

The data flow between the sub-systems of the selected C-ITS Applications are described in this section. These applications can be realized using connected (cellular) or cooperative (ITS-G5) communication, and separate sequence diagrams have been devised, if applicable. It should be noted that an actual implementation of some specific ITS applications can in practice be realized with changes in sub-systems and data flows in the sequence diagrams. However, most of the sub-systems and data flows are valid. The data flow

8.2 V2V application descriptions

8.2.1 Hazardous Location Warning (HLW)

The sequence diagram in Figure 8-1 is also valid for the use case Hazardous Location Warning. In this case a vehicle detects a hazardous location (e.g. a slippery spot or a spot with poor visibility) by analysing all available in-car sensors, and sends a warning to other vehicles via V2V communication. Optionally (not shown) the information is received by a RIS and send (via CIS) to either other upstream RIS systems or to TMC to warn other non-ITS vehicles via roadside substations.

8.2.2 Emergency Brake Light Warning (EBLW)

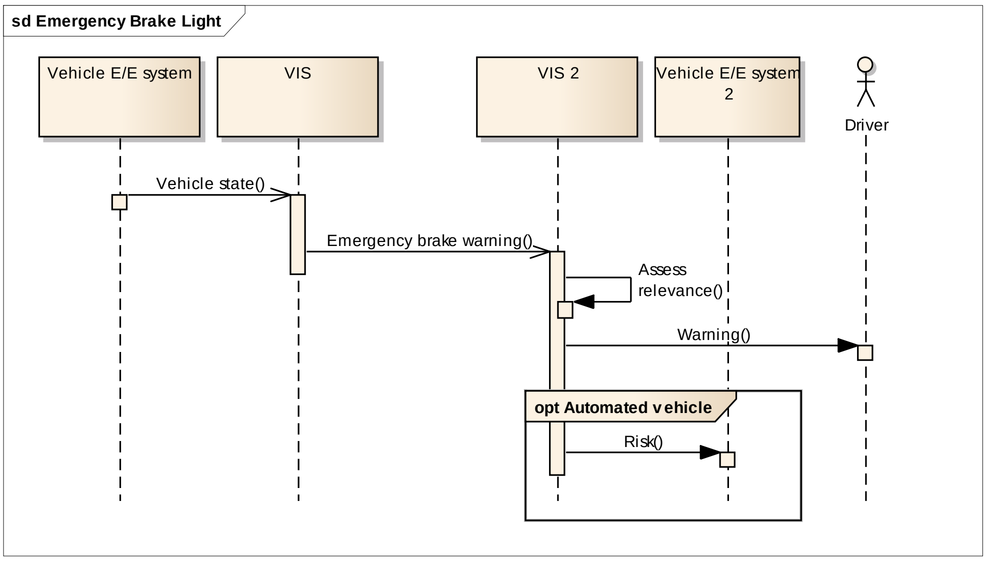

Figure 8-1 Sequence diagram for Emergency Brake Light

8.2.3 Slow Vehicle Warning (SVW)

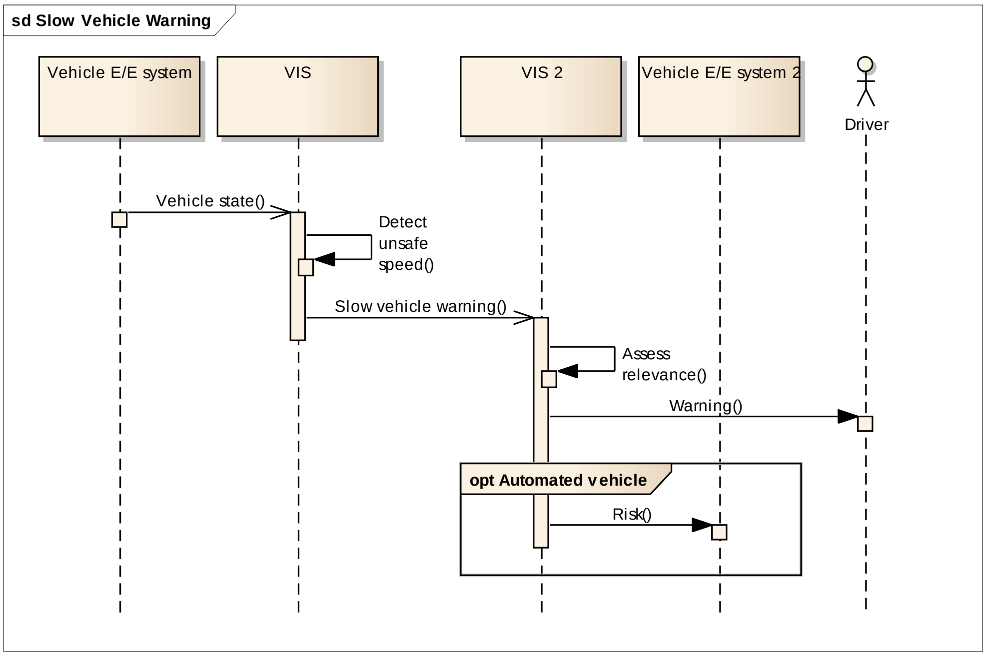

Figure 8-2 Sequence diagram for Slow Vehicle Warning

8.2.4 Cooperative Adaptive Cruise Control (CACC)

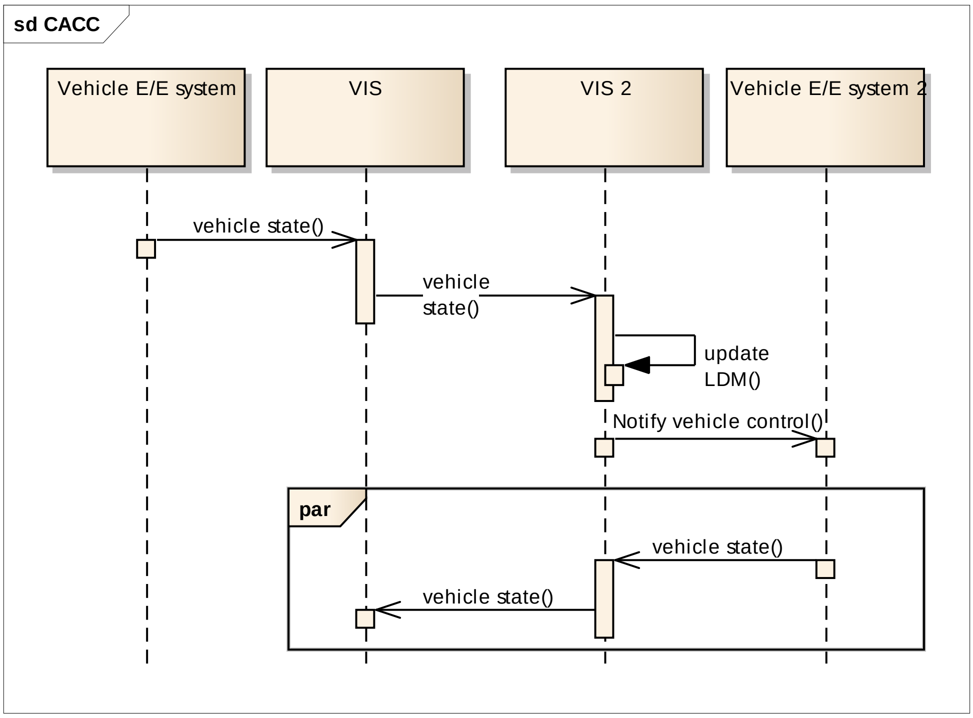

Figure 8-3 Sequence diagram for Cooperative Adaptive Cruise Control

8.3 I2V application descriptions

8.3.1 Incident Warning (IW)

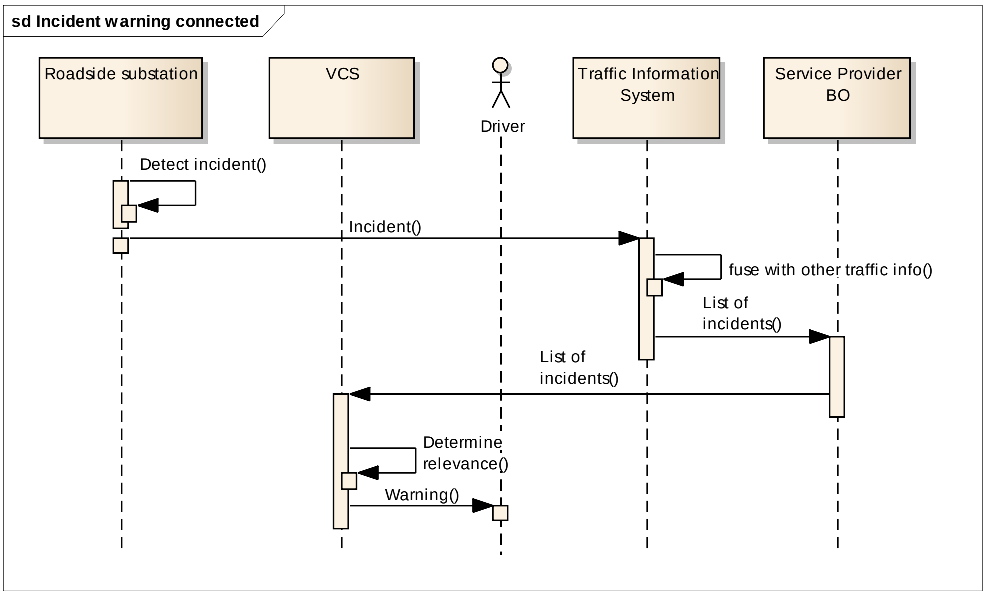

Figure 8-4 Sequence diagram for Incident Warning / Information via connected communication

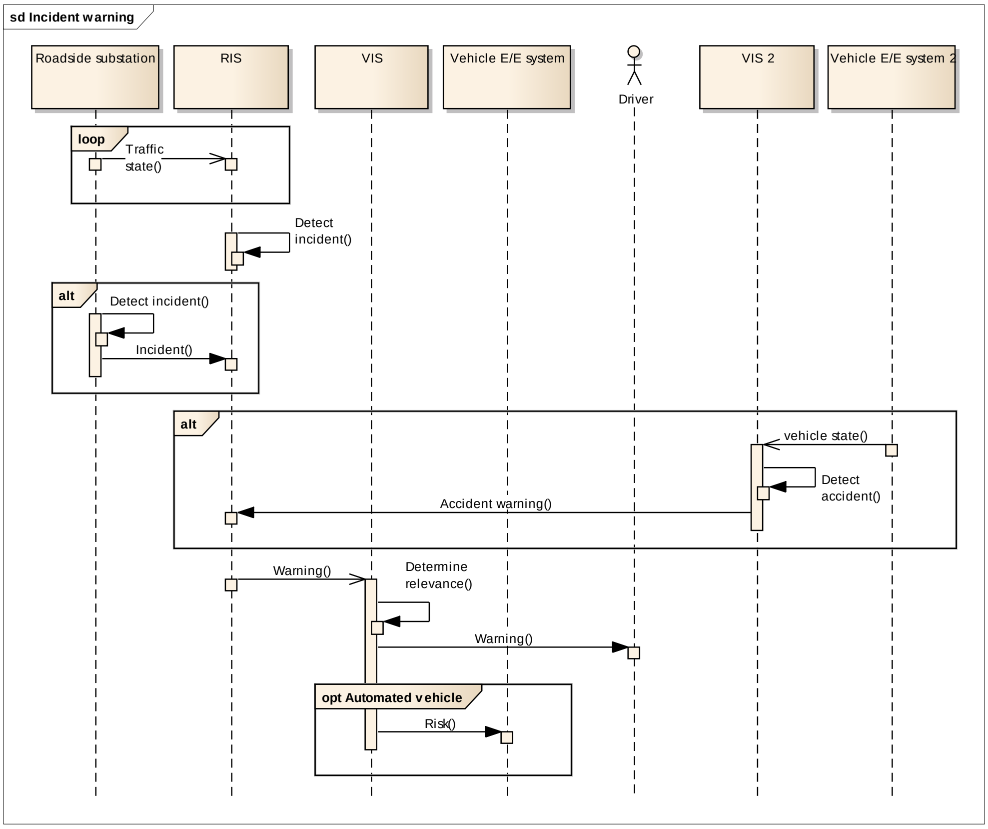

Figure 8-5 Sequence diagram for Incident Warning via cooperative communication

8.3.2 Road Works Warning (RWW)

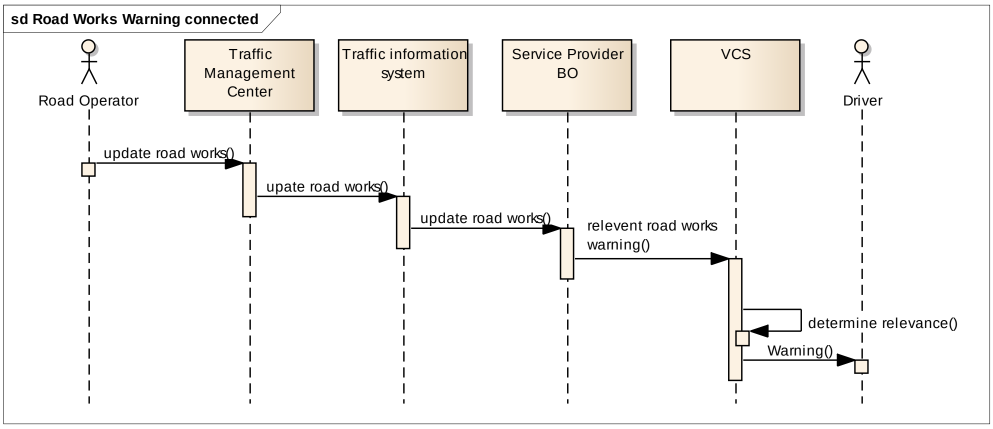

Figure 8-6 Sequence diagram for road works warning / information via connected communication

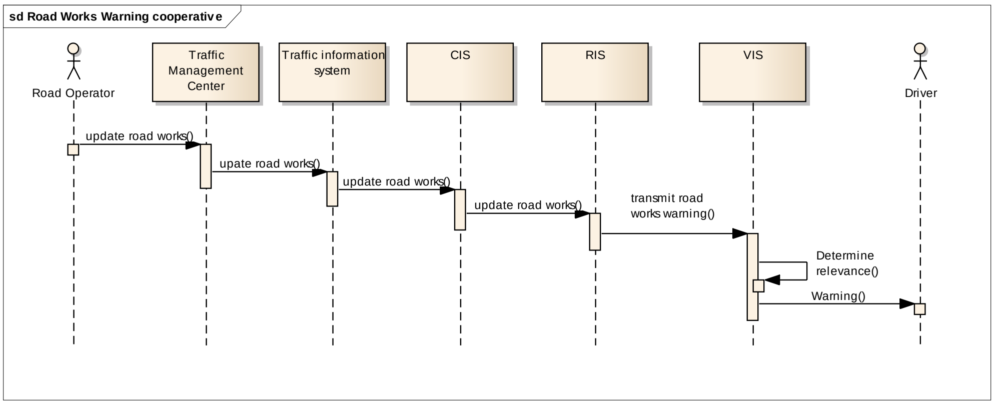

Figure 8-7 Sequence diagram Road works warning via cooperative communication

8.3.3 Traffic Jam Ahead Warning (TJAW)

The sequence diagram of Incident Warning is also applicable to Traffic Jam Ahead warning.

8.3.4 Red Light Violation Warning (RLVW)

The following sequence diagram describes the application that warns a driver about another 7vehicle violating a red light.

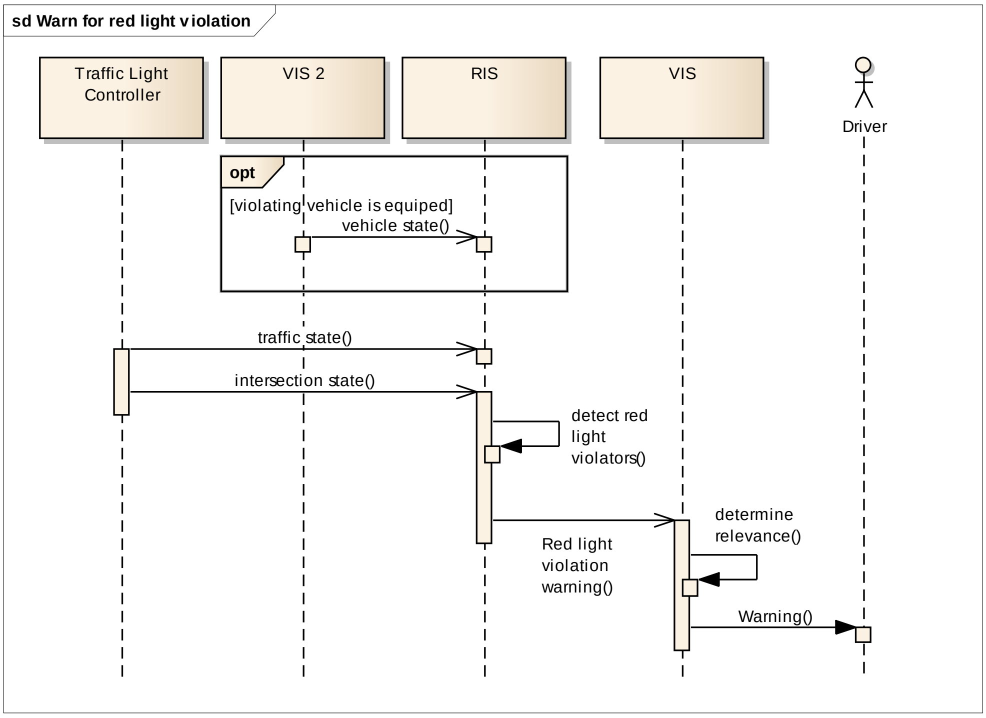

Figure 8-8 Sequence diagram Red light violation warning by remote vehicle

The following sequence diagram describes the application where a driver is warned if he or she is about to violate a red light.

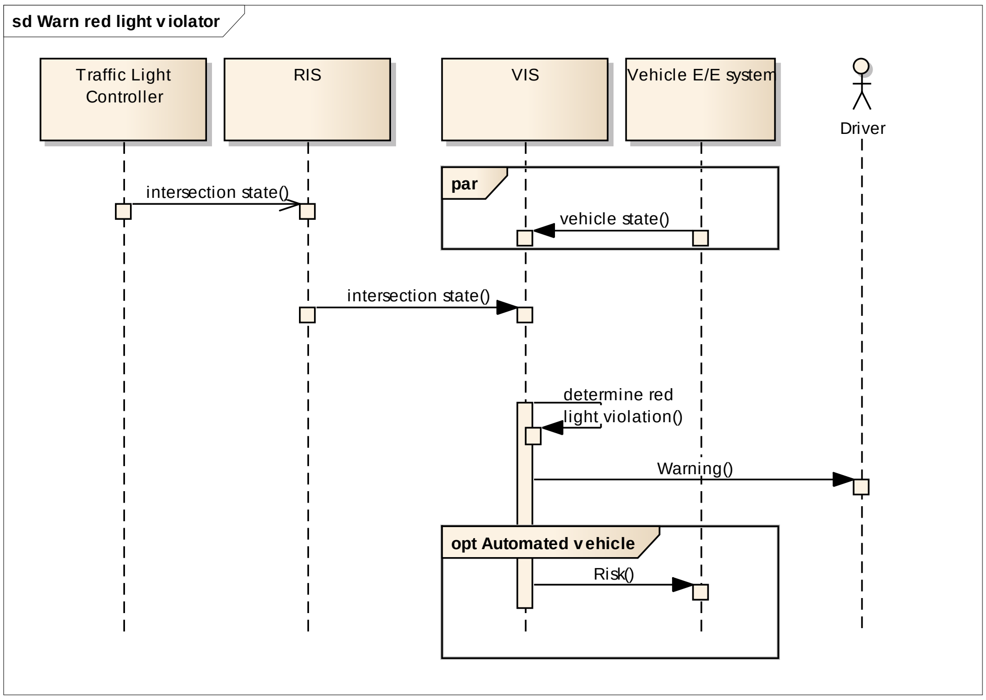

Figure 8-9 Sequence diagram Red light violation warning for host vehicle

8.3.5 In Vehicle Signage (IVS)

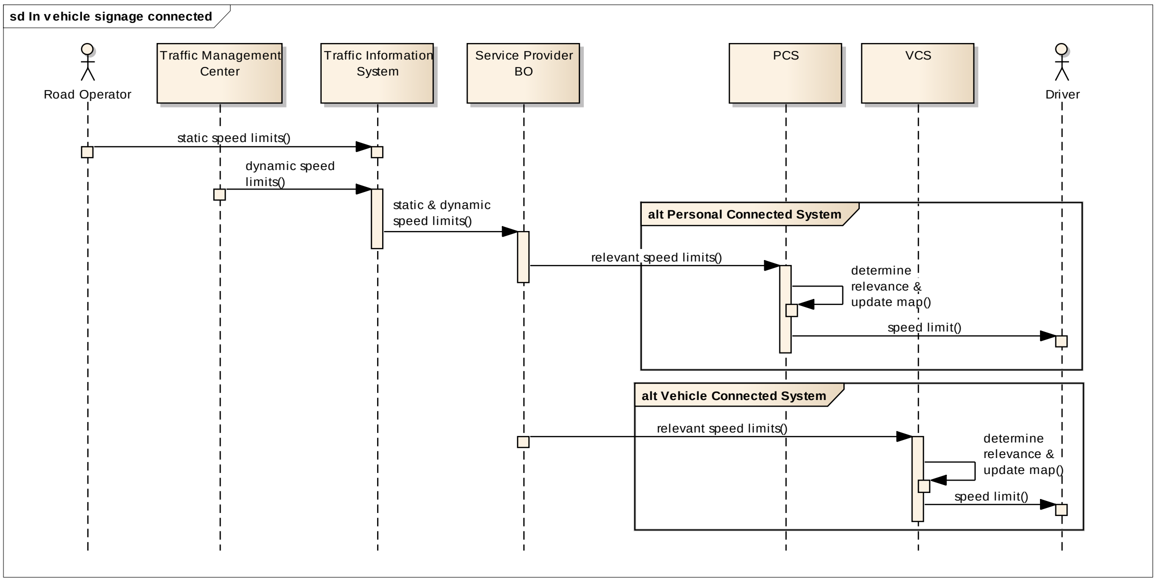

Figure 8-10 Sequence diagram IVS via connected communication

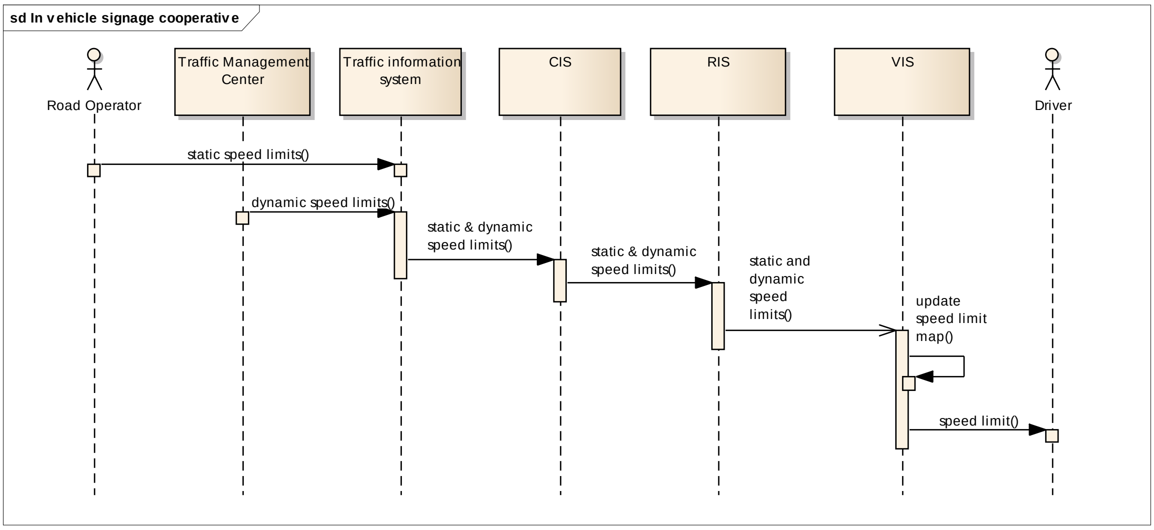

Figure 8-11 Sequence diagram IVS via cooperative communication

8.3.6 Merging Assistant with CACC (MA)

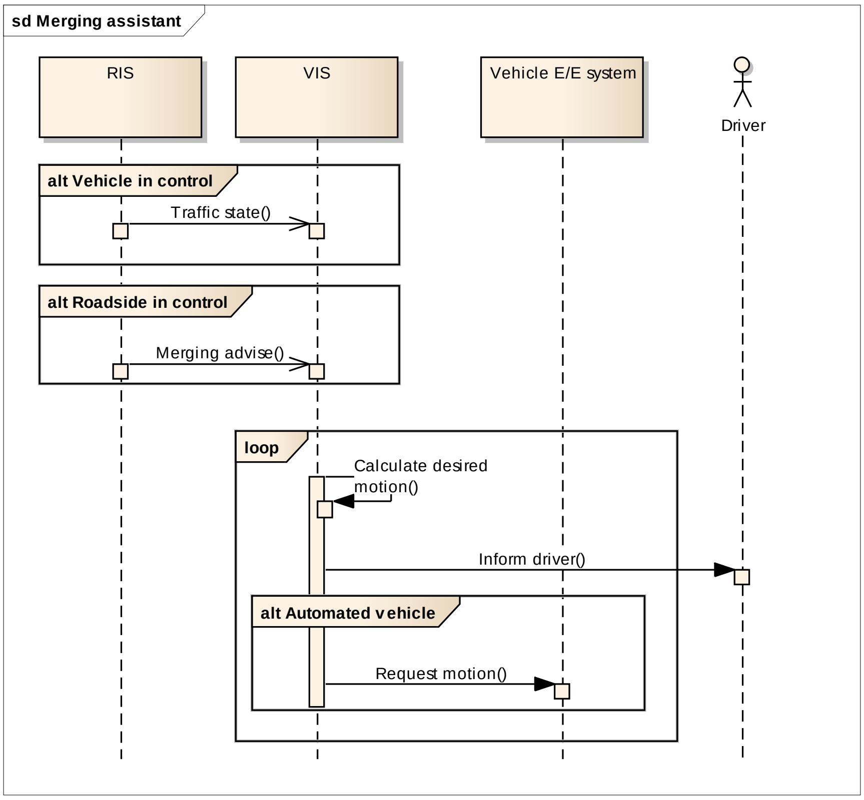

Figure 8-12 Sequence diagram Merging Assistant via cooperative communication

8.3.7 Shockwave Damping via Speed Advice (ShD)

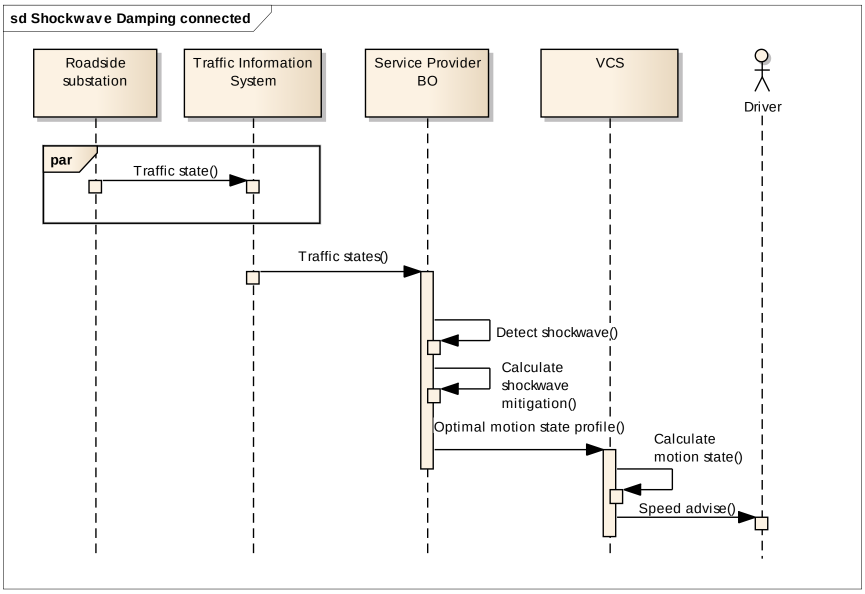

Figure 8-13 Sequence diagram shockwave damping via connected communication

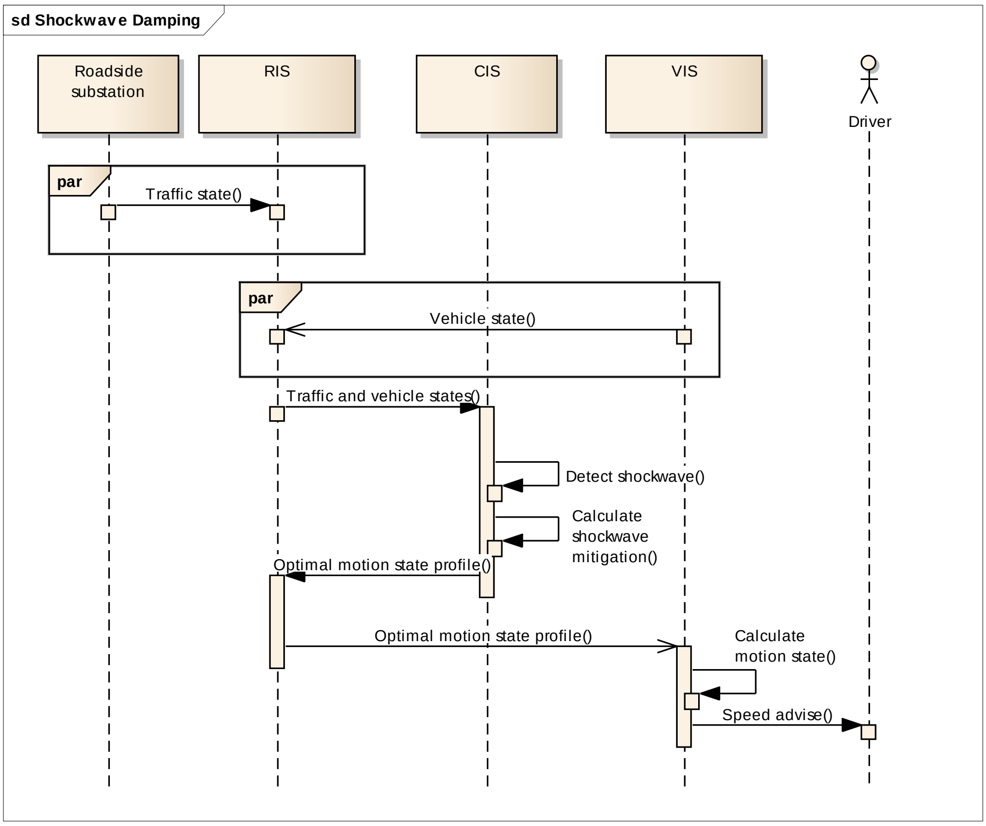

Figure 8-14 Sequence diagram shockwave damping via cooperative communication

8.3.8 Green Light Optimal Speed Advice (GLOSA)

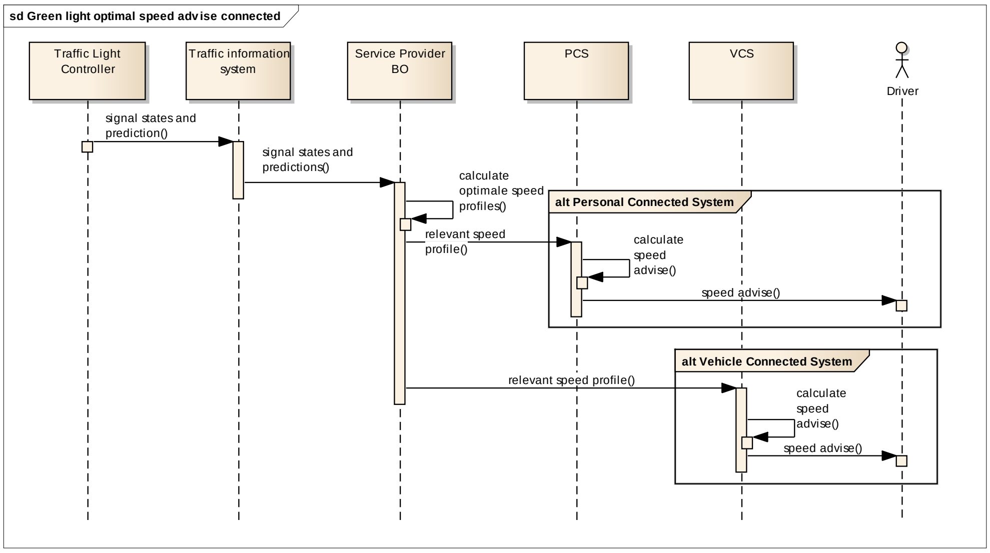

Figure 8-15 Sequence diagram for GLOSA via connected communication

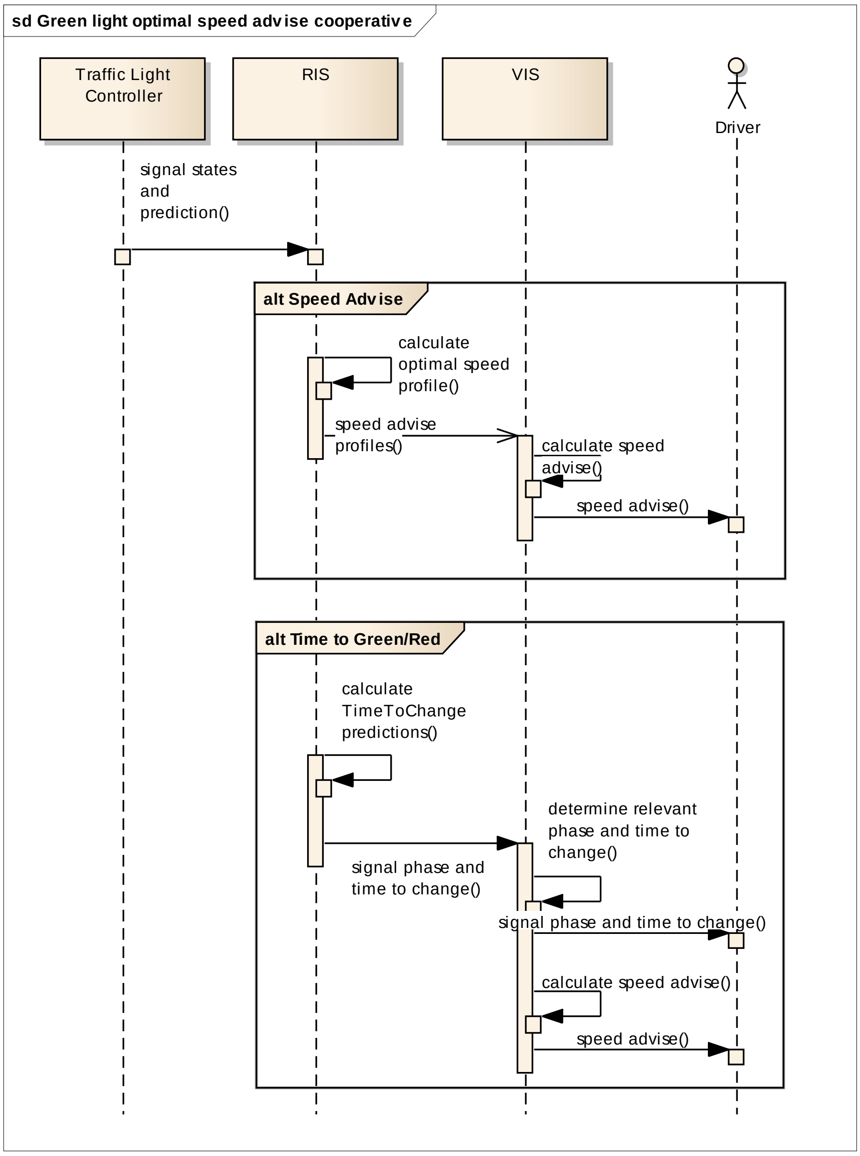

Figure 8-16 Sequence diagram for GLOSA via cooperative communication

8.3.9 Green Wave via Speed Advise

See GLOSA, section 8.3.8.

8.3.10 Stopping Behaviour Optimization (SBO)

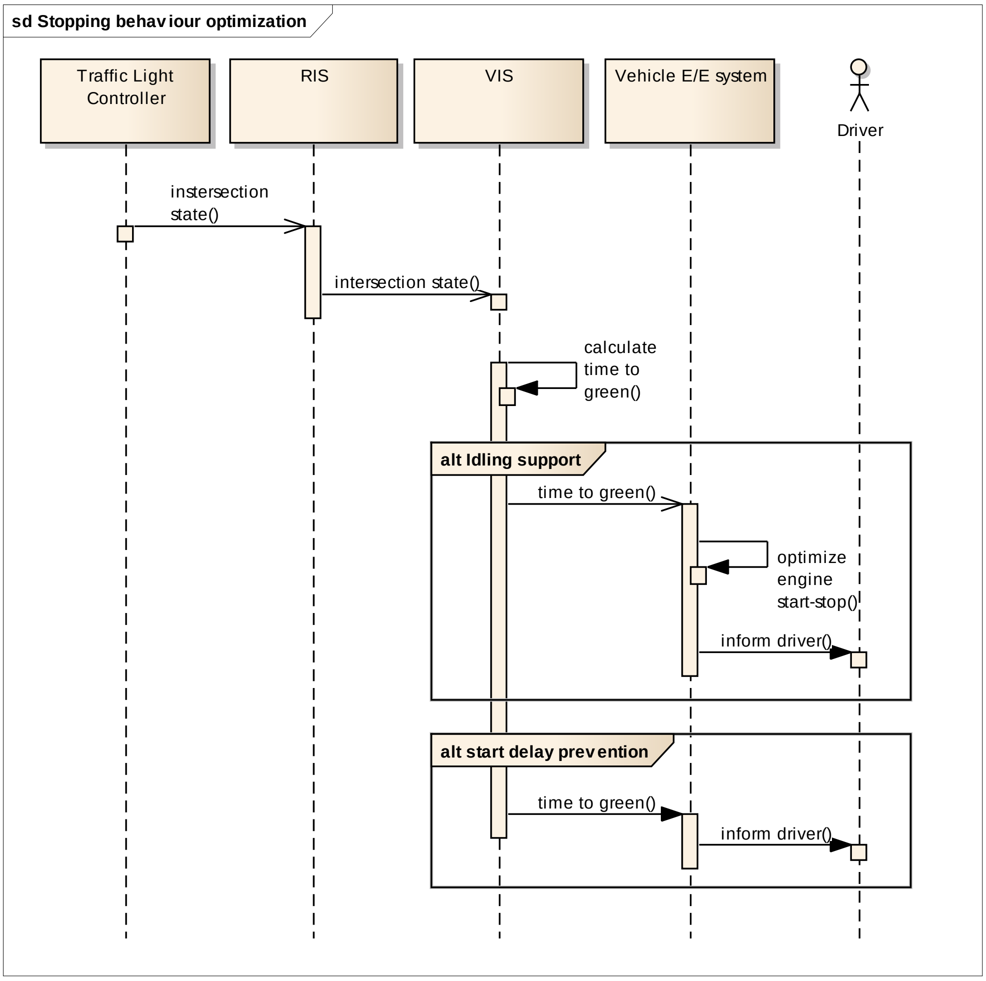

Figure 8-17 Sequence diagram for Stopping Behaviour Optimization via cooperative communication

8.3.11 Priority Request (PR)

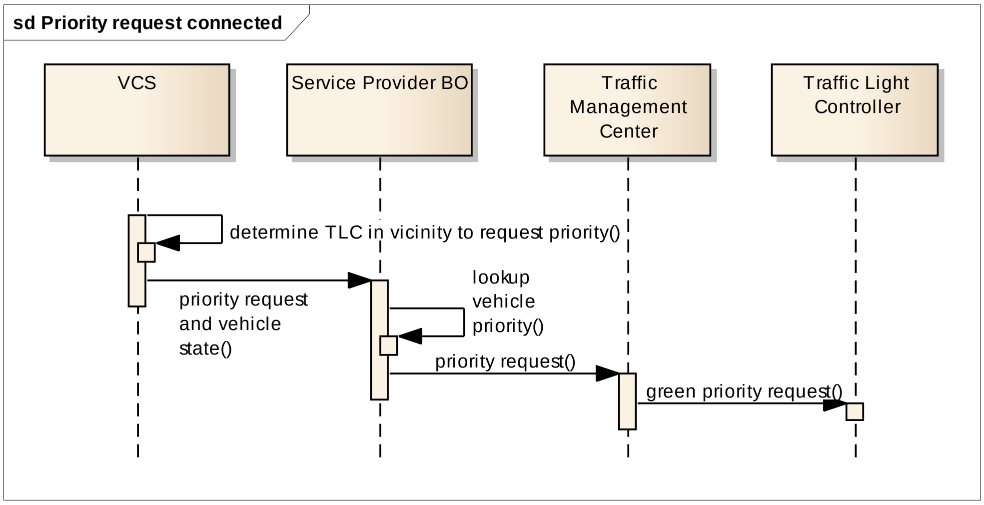

Figure 8-18 Sequence diagram for Priority Request via connected communication

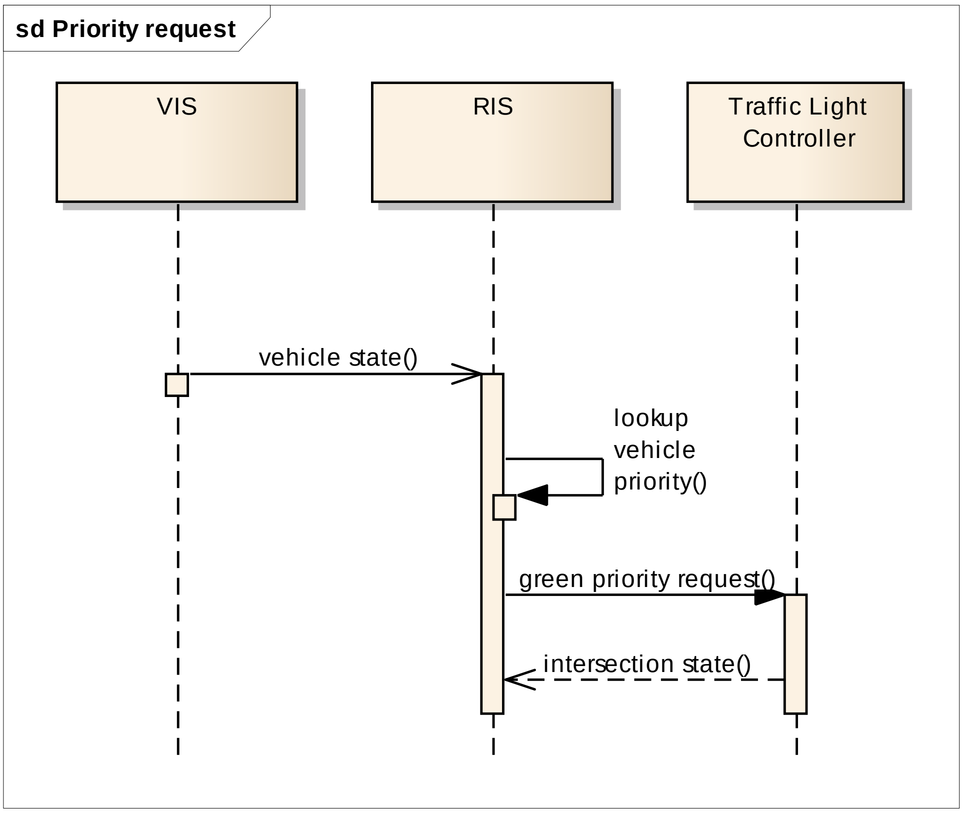

Figure 8-19 Sequence diagram for Priority Request via cooperative communication

8.3.12 Navigation related applications (NAV)

Traffic Information Service (TIS)

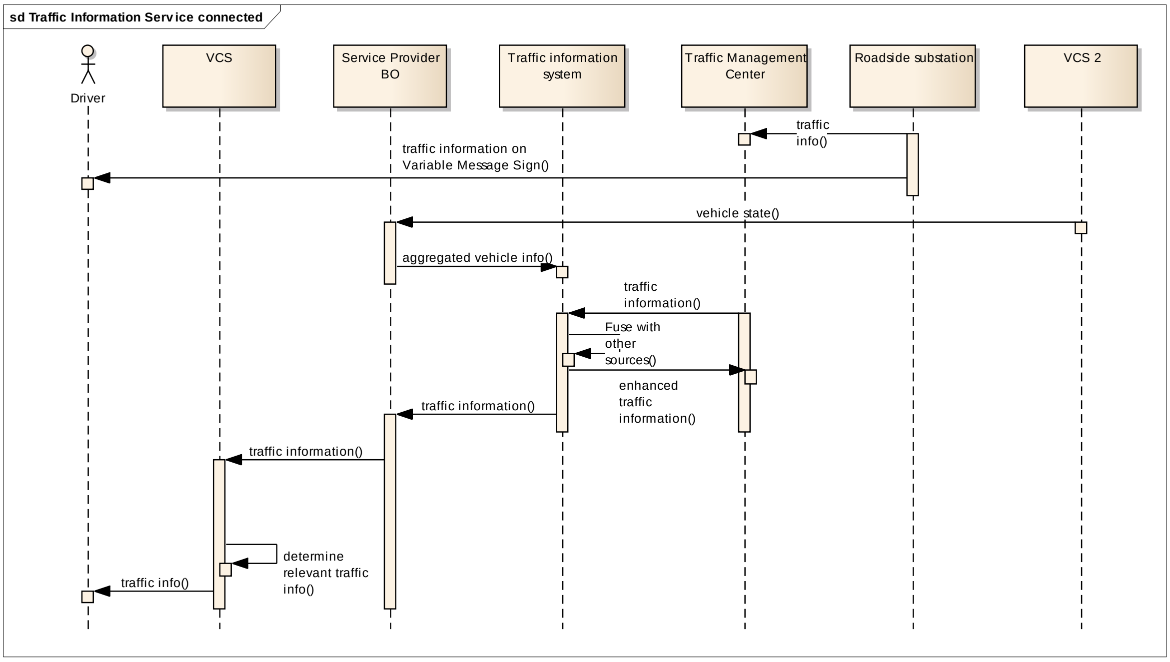

Figure 8-20 Sequence diagram for Traffic information Service via connected communication

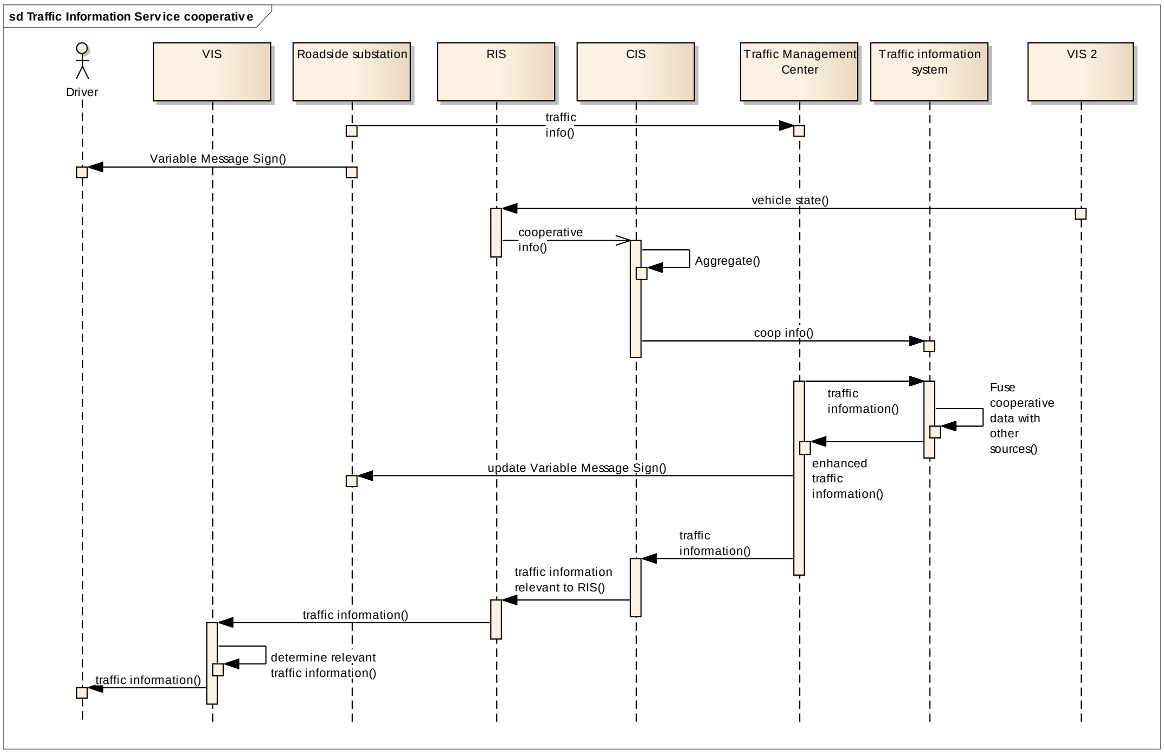

Figure 8-21 Sequence diagram for Traffic information Service via cooperative communication

Rerouting (RR)

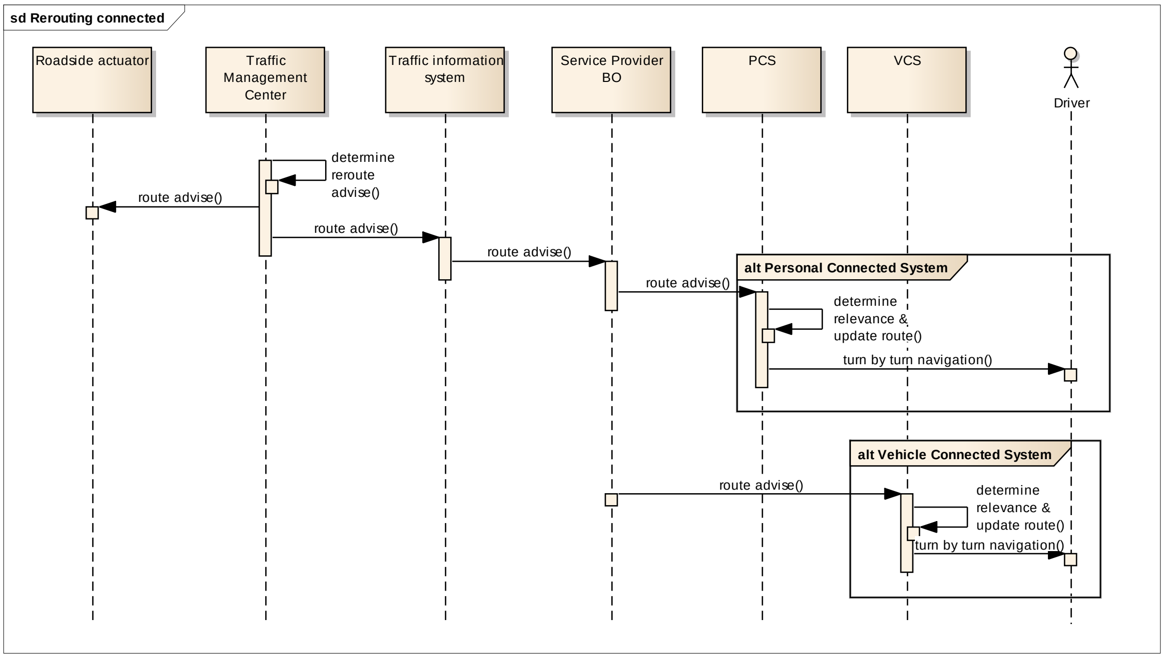

Figure 8-22 Sequence diagram for Rerouting via connected communication

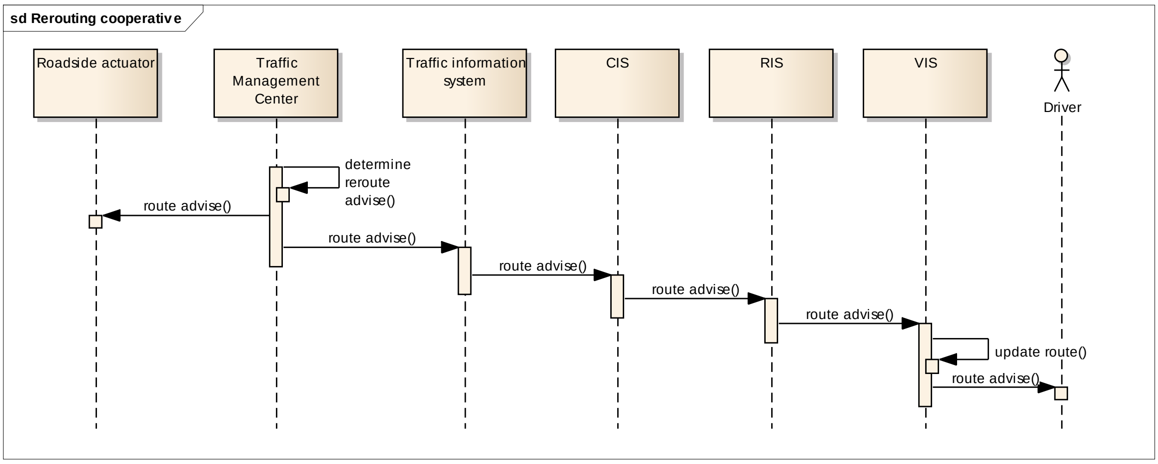

Figure 8-23 Sequence diagram for Rerouting via cooperative communication

Intermodal Route Planner (IRP)

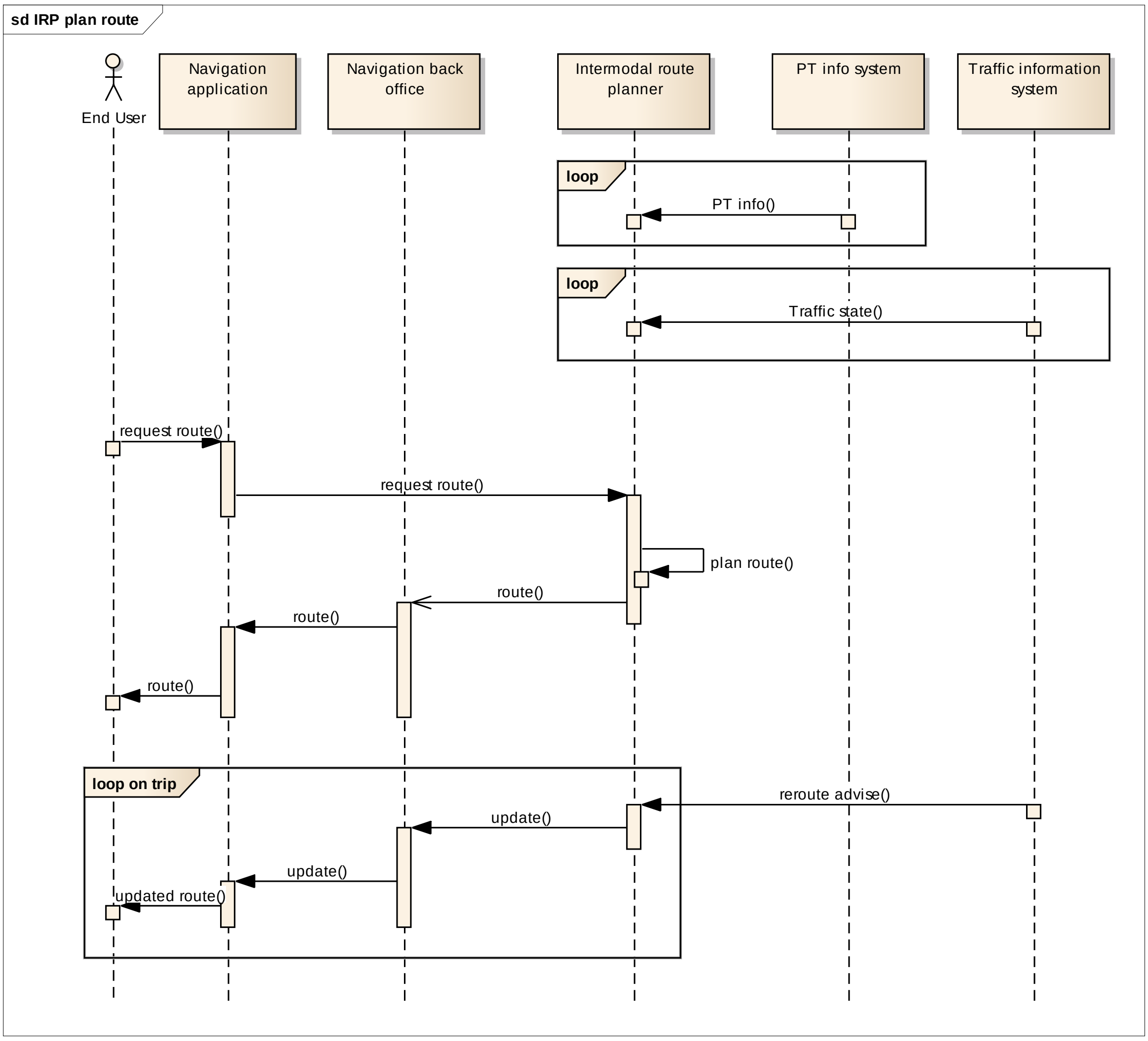

Figure 8-24 Sequence diagram for IRP via connected communication

Electrical Vehicle Charging Point Planner (EVCP)

This application can be realized with sequence diagram of rerouting, see Figure 8-22.

Smart Parking Assistant (SPA)
This application can be realized with sequence diagram of rerouting, see Figure 8-22.

8.3.13 Pay How You Drive (PHYD)

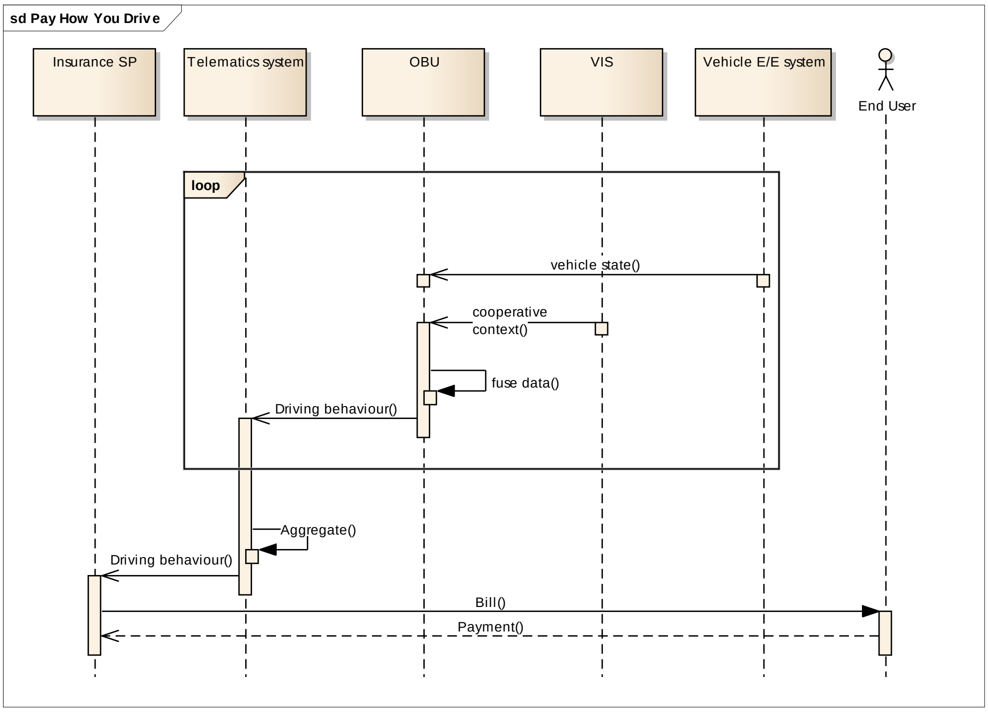

Figure 8-25 Sequence diagram for Pay How You Drive via connected communication

8.4 V2I applications

8.4.1 Probe Vehicle Data (PVD)

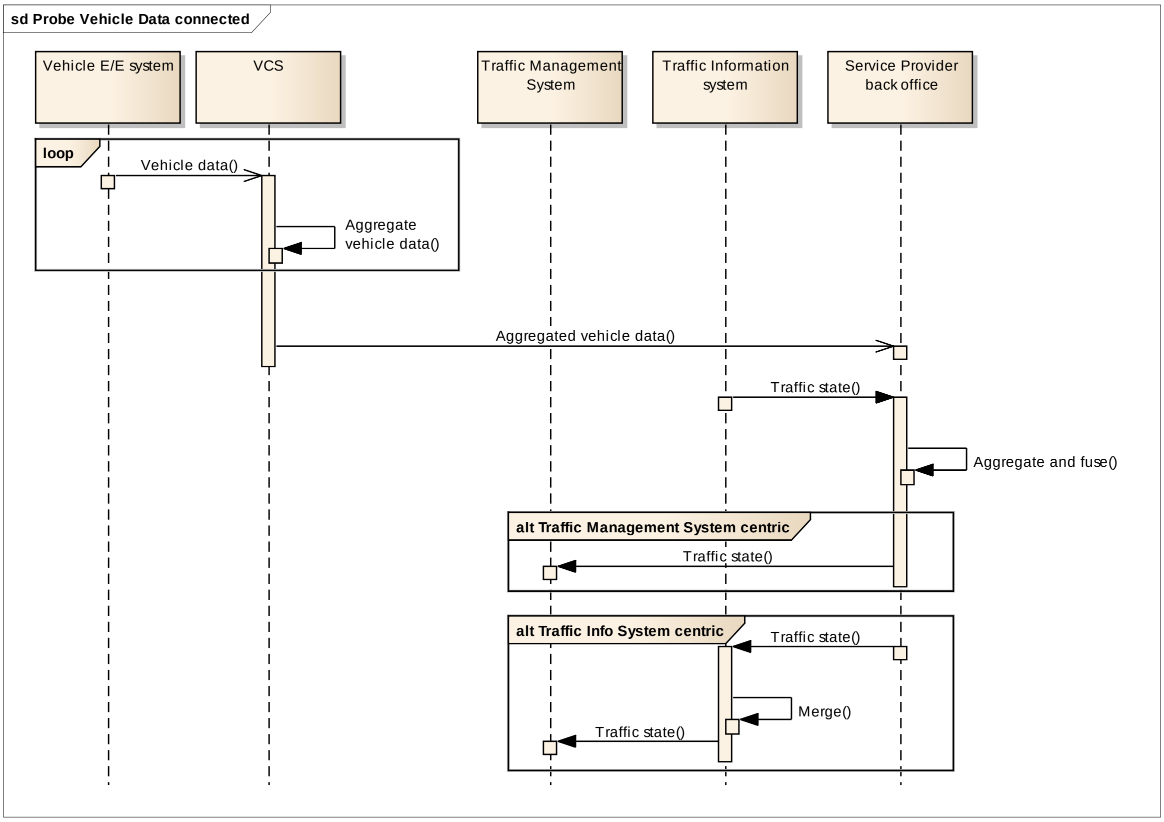

Figure 8-26 Sequence diagram for Probe Vehicle Data from connected cars

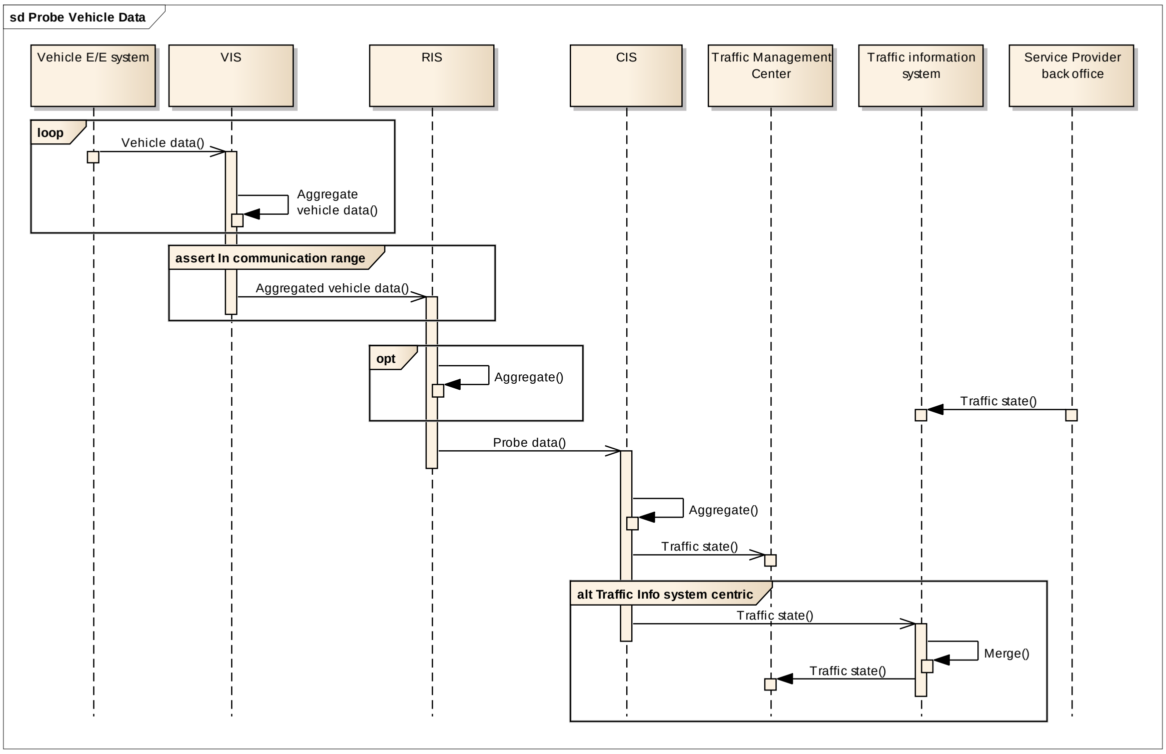

Figure 8-27 Sequence diagram for Probe Vehicle Data from cooperative cars (A58, PPA)

8.5 I2I applications

8.5.1 Local Traffic State Data (LTSD)

See Figure 8-13.

8.5.2 Local Traffic Control Data (LTCD)

See Figure 8-10. The traffic control measures from a road operator (dynamic speed limits) are sent to service providers.

8.5.3 e-Market place for service providers

No sequence diagram. More details can be found in section 4.5.5.

8.5.4 Cooperative Message Distribution

No sequence diagram. More details can be found in section 4.5.6.

8.5.5 Coordinated Traffic Management

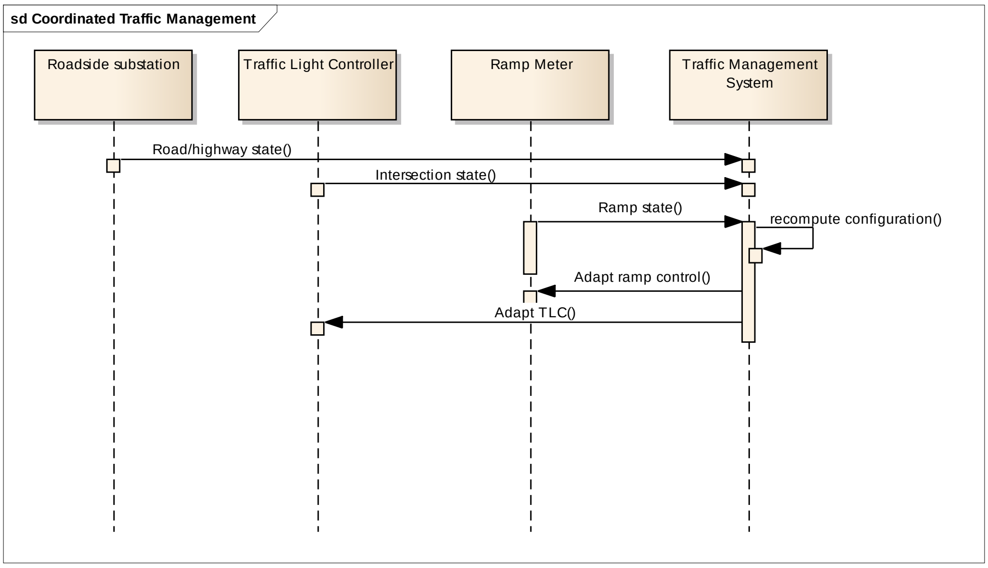

Figure 8-28 Sequence diagram for Coordinated Traffic Management

8.6 VRU applications

The sequence diagrams from VRUITS are described in [21]. In this section the sequence diagrams of the selected applications are based on the VRUITS D4.2 document. Please note that some abbreviations differ from the previous definitions used in this document: VRU-CS = VRU-Connected System (=PID), IIS = Internet Information System (=SP BO), VRU-IS = VRU-ITS Station (=VRU-OBU) and VSS = Vehicle Sensor System (type of V-VLS).

8.6.1 Intelligent Pedestrians Traffic Signal (IPTS)

a) IPTS with I2VRU communication (IPTS + I2VRU): a pedestrian is informed by either the traffic light controller or a central system on waiting time, crossing time, green line on/off etc.

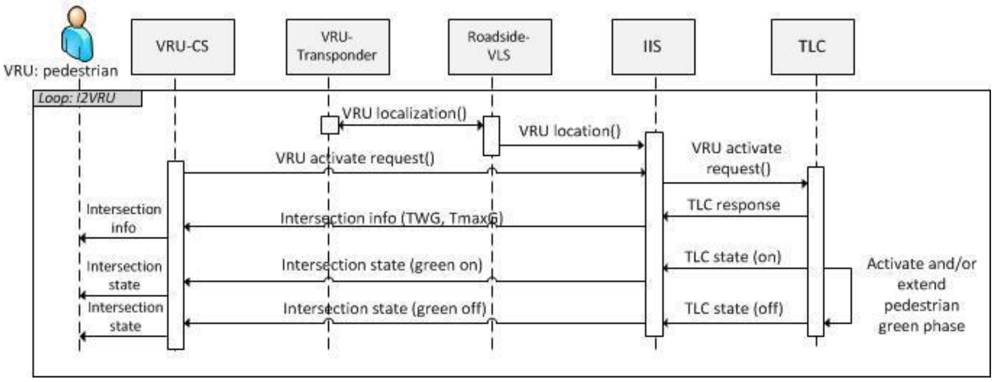

Figure 8-29 Sequence diagram for IPTS with I2VRU communication

b) IPTS with I2V communication (IPTS + I2V): a car driver is warned about pedestrians crossing a road; see section 8.6.2.

8.6.2 *Intersection Safety for VRU's (INS)*

Three sequence diagrams are given to describe INS:

a) Intersection Safety with roadside-centric detection of VRU and roadside-centric situation assessment of the collision risk;

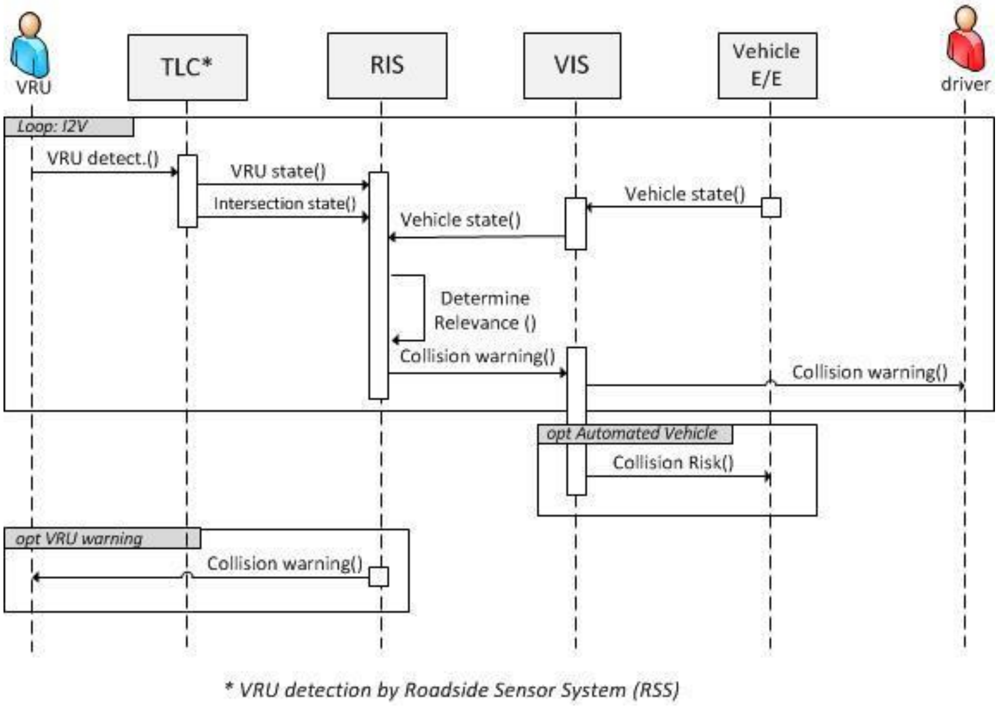

Figure 8-30 Sequence diagram for INS with roadside-centric detection of VRU and roadside-centric situation assessment of the collision risk

b) Intersection Safety with car-centric detection of VRU and car-centric situation assessment of the collision risk;

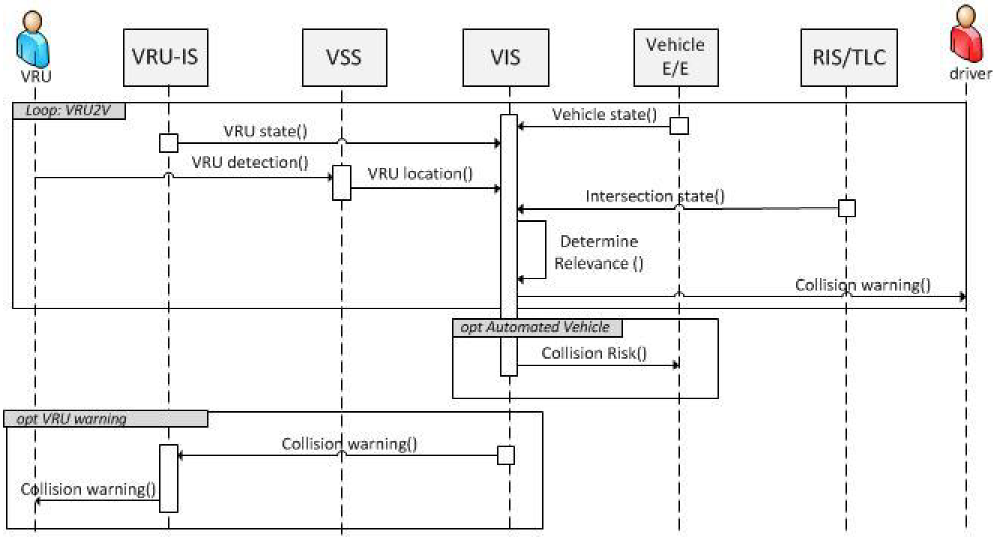

Figure 8-31 Sequence diagram for INS with vehicle-centric detection of VRU and roadside-centric situation assessment of the collision risk

c) Intersection Safety with roadside-centric detection of VRU and car-centric situation assessment.

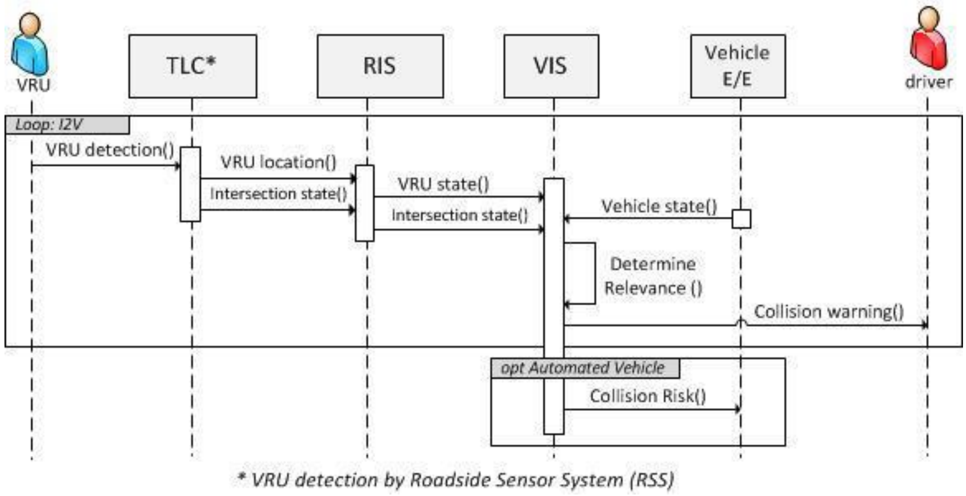

Figure 8-32 Sequence diagram for INS with car-centric detection of VRU and car-centric situation assessment of the collision risk

8.6.3 VRU presence warning via VRU Beacon System (VBS)

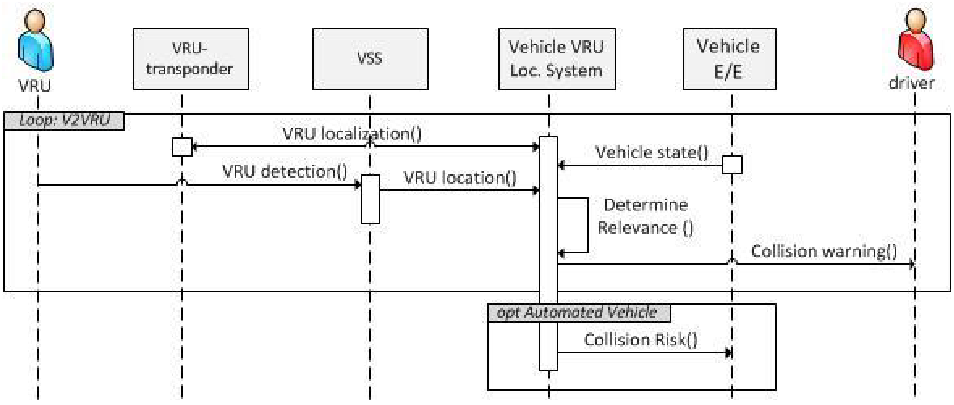

Figure 8-33 Sequence diagram for VRU Beacon System

8.6.4 VRU presence warning via Cooperative VRU Detection (CVD)

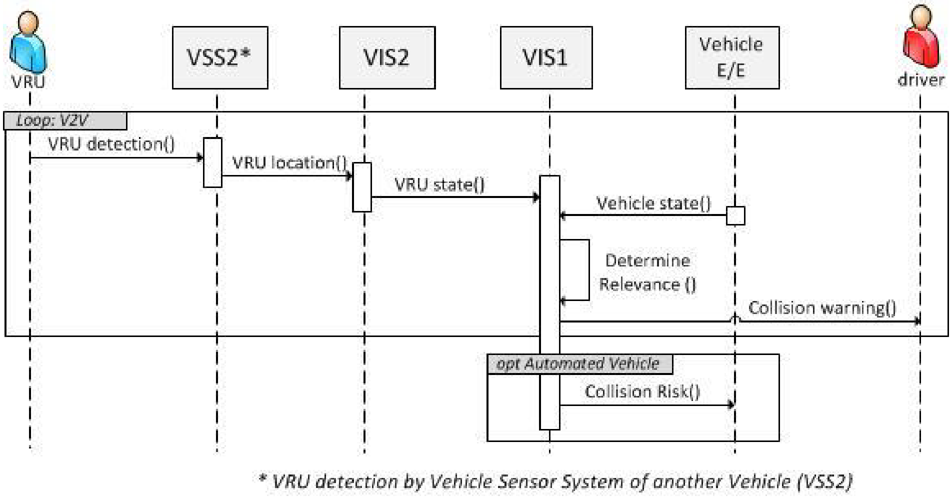

Figure 8-34 Sequence diagram for Cooperative VRU Detection

8.7 Types of information exchange

This section describes the type of information that is exchanged between components in the sequence diagrams in Figure 8-1 to Figure 8-34.

<u>Vehicle / VRU related information</u>

Vehicle state
Vehicle state data is dynamic data that originates from the vehicle on-board sensors and control systems, e.g. current position, velocity and accelerations. Based on this data applications can determine whether for instance heavy braking is occurring and consequently an emergency brake warning can be issued.

Vehicle state data can be both event and time based, and can only originate from the VEE or OBU.

VRU state / VRU location
VRU state data is dynamic data that originates from the VRU-vehicle on-board sensors and control systems, e.g. current position, velocity and accelerations. VRU state data can be both event and time based, and can only originate from the VRU-OBU or external detection systems

VRU location is information on location of VRU determined by external roadside or vehicle localization systems for VRUs.

Vehicle data
Vehicle data covers both aggregated (or probe) data on dynamic vehicle state and static vehicle data. Static data contains the following type of information:

- Type of vehicle: car, truck
- Type of traffic: private, public transport

- Type of load of truck: hazardous
- Number of occupants
- Unique identification
- Etc.

Vehicle data originates from the VEE or OBU, but can be aggregated on the OBU or in the infrastructure (RSU / BO). Aggregated vehicle data can be shared with other components.

Risk
Risk is a metric that is determined in applications in the OBU, and risk is transmitted to VEE systems for advanced driver assistance. These subsystems are responsible for acting upon these risks, but the internal decision logic is outside the scope of this project.

Notify vehicle control / request vehicle motion
The VEE system is responsible for automated vehicle control. The OBU determines for instance the risk or desired vehicle motion and informs the vehicle control systems with the desired action. The VEE system then handles the interaction with the vehicle.

(Green light) priority request
Green light priority can be requested by specific types of vehicles, e.g. public transport and emergency vehicles. Each vehicle transmits vehicle data, containing the vehicle type and authentication for security purposes. The RSU receives this data from approaching vehicles, and when a vehicle with priority approaches, a green priority request is issued to the Traffic Light Controller. Whether the traffic light obeys to the request is decided in the Traffic Light Controller software.

<u>**Driver interaction**</u>
Interaction with the driver can be of the following types:

- Warning: for instance a red light violation warning
- Advise: for instance on start delay prevention, speed advice and on non-critical events

Warning
A warning is a message presented to a driver on a hazardous location or situation. The hazardous location can be automatically detected by either a vehicle (sensor) or a roadside sensor or can be generated by a road operator. Examples of warnings are:

- Accident / Incident warning
- Emergency brake warning
- Slow vehicle warning
- Red light violation warning

A warning on a hazardous location can be send to drivers of vehicles with non-ITS systems via central systems like TMC and roadside actuators.

Advises
Advises can be of the following types:

- Merging advise: advise for a merging manoeuvre

- Speed advise profiles: list of speed advises vs locations
- Optimal motion state profile: list of optimal motions vs locations
- Speed advise: advisory speed
- Navigation / route advise
    - Request route: an end user places a request for a route
    - Route: directions to travel from one place to another
    - Turn by turn navigation: continuous presentation of travel directions
    - Updated route: notification with updated information on previously computed routes

Advises are communicated to end-users.

Driving behaviour
Driving behaviour can be monitored via logging of vehicle state information.

Cooperative info / context
Cooperative info or context is the information obtained by and from cooperative systems. An example of cooperative context in a vehicle is the current speed advise, a driver behaviour monitor can use this information to determine whether the driver obeys advises or not.
Other cooperative information can include floating car data that can be fused with legacy (non-cooperative) information in for instance the TMC or TIS.

Infrastructure related information

Traffic state
For traffic state two types of data can be distinguished:
- Real-time traffic data: data on traffic flow, average traffic speed and realized and estimated travel time
- Road status data: event-based data on road works, road messages (i.e. messages on queues, incidents and warnings) and status of bridges (open/closed), etc.

The real-time traffic data are determined via aggregated data. On a single point the following parameters are collected: (i) flow, (ii) speed, (iii) density. Additionally more detailed information can be collected e.g.
- Partial flow: flow per lane, destination or type of vehicle.
- Per vehicle: Intended destination / intended route; Type of vehicle: person car, truck; Type of traffic: private, Public Transport; Type of load of truck: hazardous; Number of occupants, etc.

The road status data is event-based and changes can be initiated from vehicle / OBU, RSU or TMS.

Intersection state / Intersection information
Intersection state data is dynamic data on current and predicted signal state of traffic lights at an intersection. Intersection information is info on configuration settings or properties of e.g. TLCs. The information is used in applications to determine optimal speed, automatic stop-start of engine or in violation warnings. The intersection state is always originated from an intersection controller like a TLC.

Time-to-green defines the time until the traffic light controller transitions from red to green and is part of intersections status. Time-to-green is computed by the OBU, based on the received intersection status.

Road works
Dynamic information on road works, i.e. location, type of work and start / stop time.

Traffic signs
Dynamic information on speed limits and traffic signs, e.g. from Variable Message Signs (crosses, advice speed, speed limit, route advice, (extra) travel times, etc.).

9 Appendix B: Selected Projects

In this section the selected projects are described.

9.1 PPA

In the PPA roadside project, the application *coordinated traffic management* is implemented [40] for data collection and scenario management between road operators. For this application the main functionalities are monitoring (*Monitoren*) and controlling (*Regelen*), as depicted in Figure 9-1. There are four monitor blocks defined: potential congestion estimator (*Kiemenspeurder HWN*) and traffic jam estimator (*Fileschatter HWN*) at the high-way A10, and queue length estimator (*Wachtrijschatter SWN*) and buffer capacity (*Bufferruimte SWN*) on urban roads (*SWN*). In addition there is control on the high-way ramp meters (*TDI=Toerit Dosseer Installatie*) and traffic light controllers (*VRIs*) based on the control info from the supervisor algorithms (*Supervisor HWN/SWN*) of the high-way A10 and urban roads S10x connected to the A10.

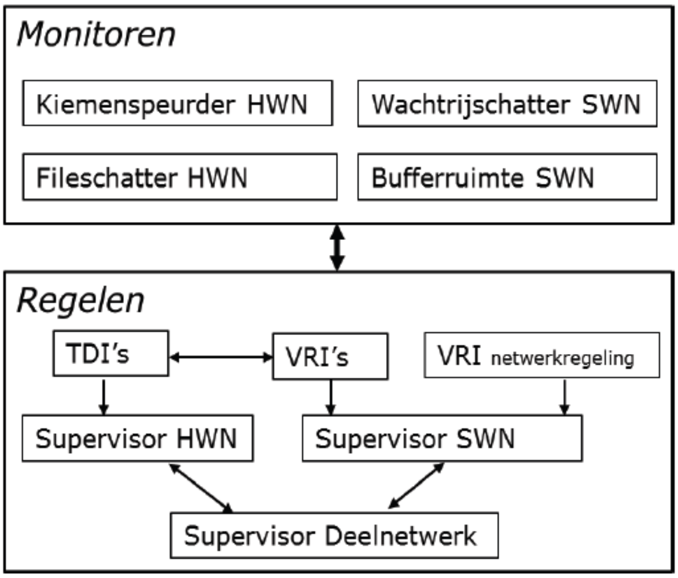

Figure 9-1: Control concept of PPA

9.2 Beter Benutten Shockwave Traffic Jams A58

The main application supported in the project *Shockwave Traffic Jams A58* is shockwave damping [39]. This project aims at applying an open horizontal architecture rather than a vertical stovepipe architecture. In this approach functions are split, i.e. end-user services from **service providers**, data information services from **data providers** and road-side communication services from **communication providers** (via ITS-G5 roadside network(s)) and well-defined interfaces between these functions are used. In this horizontal architecture a provider can focus on a certain layer of the system, e.g. a roadside communication network, rather than focusing on end-user applications, which would require implementations of all parts of the system. This corresponds to the philosophy of the project to formalize the interfaces between the different functional components, to allow different implementations of the components by different providers, so the market-oriented data and service providers can compete on the quality of the provided information.

Figure 9-2 illustrates the functional and organisational decomposition used by the A58 project. In this figure the colours of the physical objects (VIS, RIS, CIS, TMC etc) correspond to the roles of service provider (blue), data provider (red), communication provider (green) and road operator (grey) the. In this project the services are not described in detail, however the interfaces (orange lines) are specified in detail.

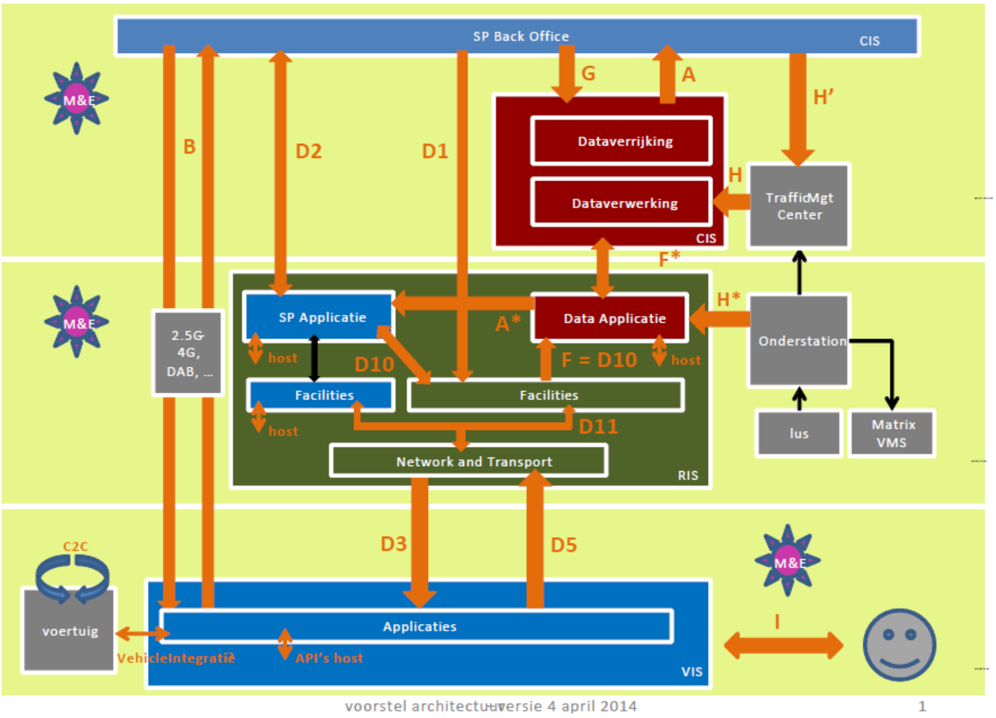

Figure 9-2: Architecture for the BB A58, illustrating the interfaces between the functional components of the difference roles (Blue = Service Provider, Green = Cooperative Roadside and Red = Data Collection)

In Figure 9-3 the specific role of the communication provider is shown. The Roadside ITS station (RIS) includes a 'hosting' function for other service providers, who can install software for their specific C-ITS applications.

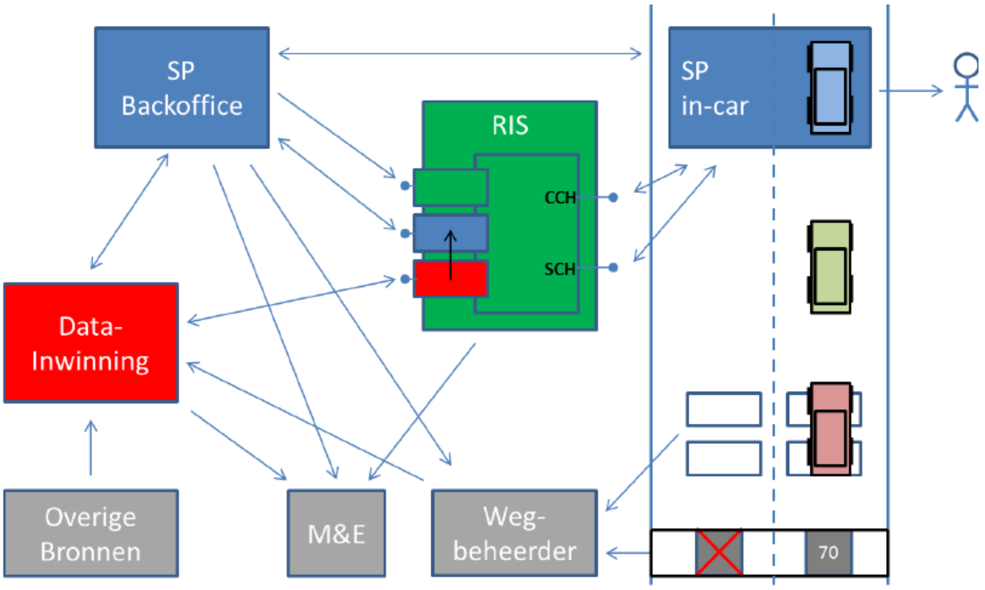

Figure 9-3: Functional decomposition of BB A58 project

9.3 ITS Corridor

The NL-DE-AT ITS Corridor was started on 10 June 2013 when the ministers representing Germany, Austria and the Netherlands signed the Memorandum of Understanding. The goal of the project is the implementation of future-oriented cooperative ITS services via

- A joint road map for the introduction of the initial cooperative ITS services
- Common functional descriptions of the initial cooperative ITS services and technical specifications
- Start of the actual implementation of the initial cooperative ITS services

The two initial services within ITS corridor are Road Works Warning and Probe Vehicle Data. In Figure 9-4 an overview is given of the two applications.

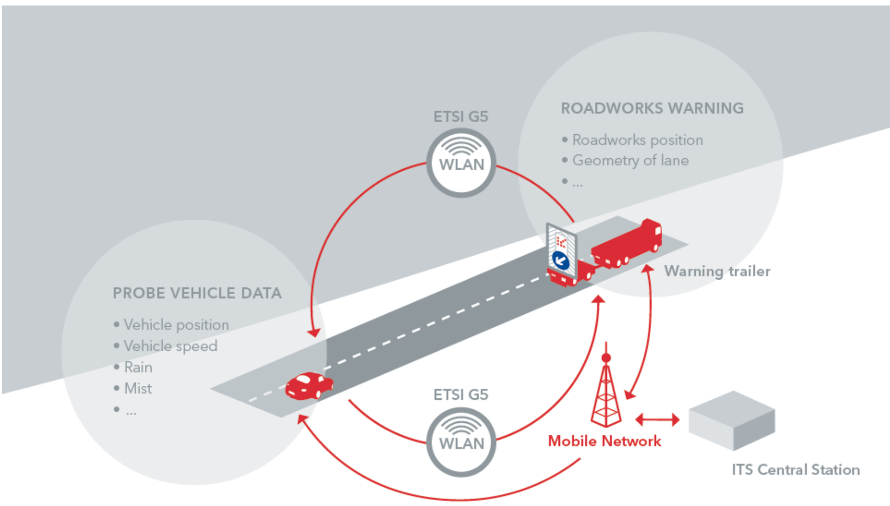

Figure 9-4 ITS applications in NL-DE-AT ITS Corridor project

Both applications were described in DITCM 1.0.
From this project the next documents were available:

- Common functional specification on RWW [41]; this document describes the categories of road works, i.e. long-term/short-term, mobile/stationary and stand-alone/basic;
- Technical specification on RWW for NL [42]: this document describes in detail how traffic signs (speed limit, lane change, closed lane) on a safety trailer and pre-warner in two typical road works scenarios can be communicated via DENM messages. The scenarios are:
    - Short term **mobile** road works (KIII/2.4 – first inner lane closed/ pre-warning vehicle) with a stand-alone and basic service from a safety trailer and pre-warner equipped with ITS-G5: 3 DENM messages are used to send information on 5 (!) static traffic signs
    - Short term **stationary** road works (KIII/2.4 – first inner lane closed/ use of hard shoulder/ pre-warning vehicle) with a stand-alone and basic service from a safety trailer and pre-warner equipped with ITS-G5: 3 DENM messages are used to send information on 6 (!) static traffic signs

No functional or technical specification on Probe Vehicle Data was available. Also no architecture was defined in this project. The architecture for a stand-alone service is straight forward with a RIS and VIS, both supporting the DENM message set. The VIS should translate the DENM messages to warnings to the driver on an in-car display.

9.4 DITCM 1.0 architecture project

In the project ‘DITCM 1.0 architecture’ an overall architecture for cooperative-ITS (C-ITS) systems in The Netherlands has been developed. The DITCM 1.0 architecture can be used to develop sub-systems and elements for cooperative, intelligent traffic management services. Cooperative in-car, roadside, and central systems have been considered, with a focus on ETSI ITS-G5 based communication systems and their interfaces to existing vehicle, roadside and central systems.
The architecture view is shown in Figure 9-5.

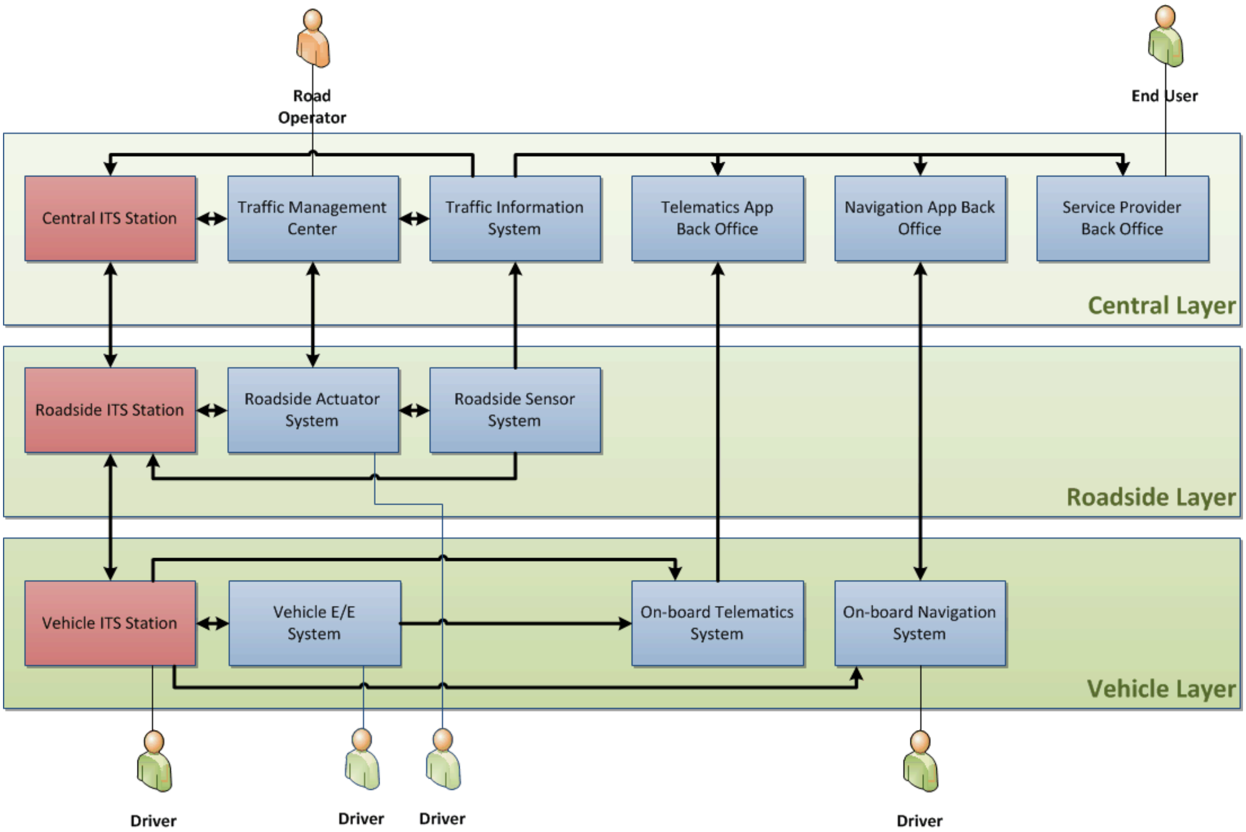

Figure 9-5 Architecture from DITCM 1.0 project with physical building blocks and interfaces

9.5 Converge

Converge is a 3-year German project that started in Aug. 2012 and will finish with a closing event with technical demonstration in the 2nd quarter of 2015. The approach is three-fold:

1) Breakup of „fixed“ relations between access networks and service providers
    a. Specification of uniform interfaces
    b. Secure interaction between participants
    c. „Provider-less“ architecture
2) Exchange of central-side processed data (b2b) over
    a. Virtual market place (i.e. MDM) or
    b. Directly over the Car2X Systems Network
3) Exchange of data between providers and users (b2c) over the Car2X Systems Network

Within Converge an “Architecture for the Car2X Systems Network” is defined in deliverable 4.2 of the project. This document is expected to be released on short term.

9.6 MOBiNET

In the EU FP7 project MOBiNET a B2B e-Market place for B2B and B2C service exchange addressing both end user and business services is developed. On the MOBiNET platform service providers can publish their (ITS) services and subscribe to other services. These services are registered in a central service directory which

provides a search interface to lookup relevant services. The MOBiNET backend platform (called MOBiCENTER) provides services and an SDK to allow the easy creation of new services by service providers e.g. billing, privacy & security, service directory API, etc.
To ease implementation of connected ITS applications a SDK for the end-user market is available (MOBiAgent) which will reduce the time to market for implementation of new ITS use cases.

Within the MOBiNET project the following use cases are implemented:

- Multi Modal Travel Agent
- Green Light Optimal Speed Advise
- Parking Assistant
- Usage Based Insurance

Within MOBiNET the main focus is on the development of the service platform. The use cases mentioned above are used to validate the concept and the implementation of the service platform. The platform provides the functionality necessary to implement ITS services within the ITS ecosystem; a portal for service providers (called Dashboard) is developed to register services. In Figure 9-6 the MOBiNET architecture (at level 1) with the identified building blocks is shown. The system consists of 5 building blocks and has 5 interfaces to external systems. In MOBiNET deliverable 3.2 the sub-systems are described in more detail with functional modules and interfaces. Also a service information model based on Linked USDL [http://linked-usdl.org] and Linked Data principles [http://linkeddata.org] was selected for service descriptions. In Figure 9-7 the technical vision on the architecture is shown, with the web-based interfaces and technologies.

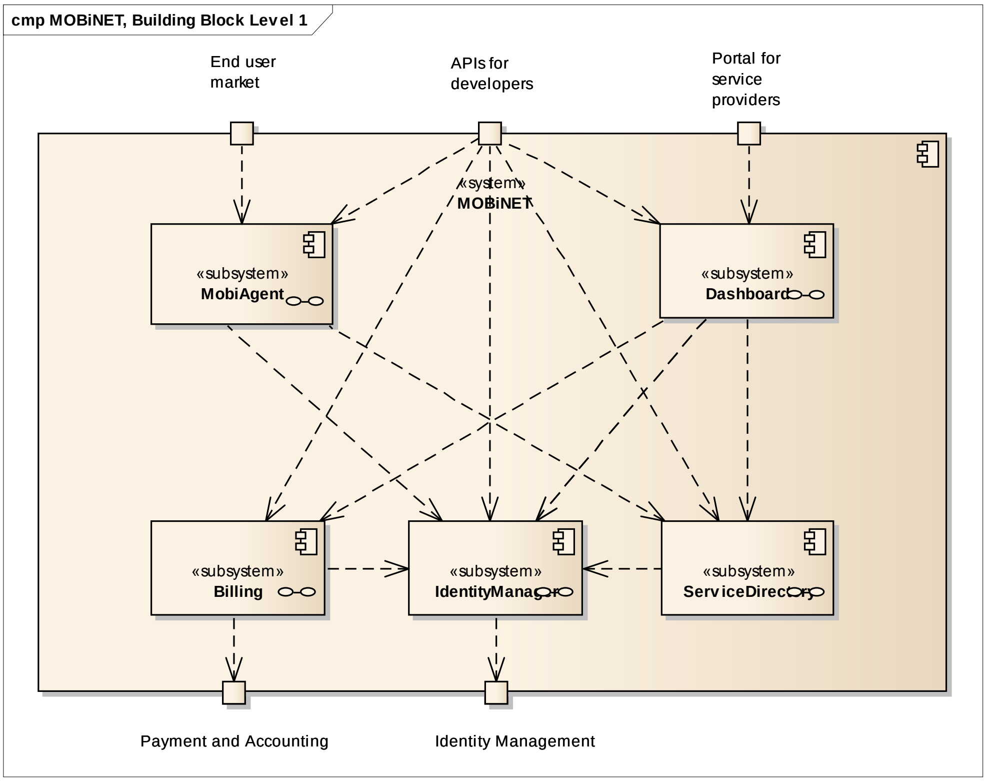

Figure 9-6 MOBiNET architecture overview [MOBiNET D3.2]

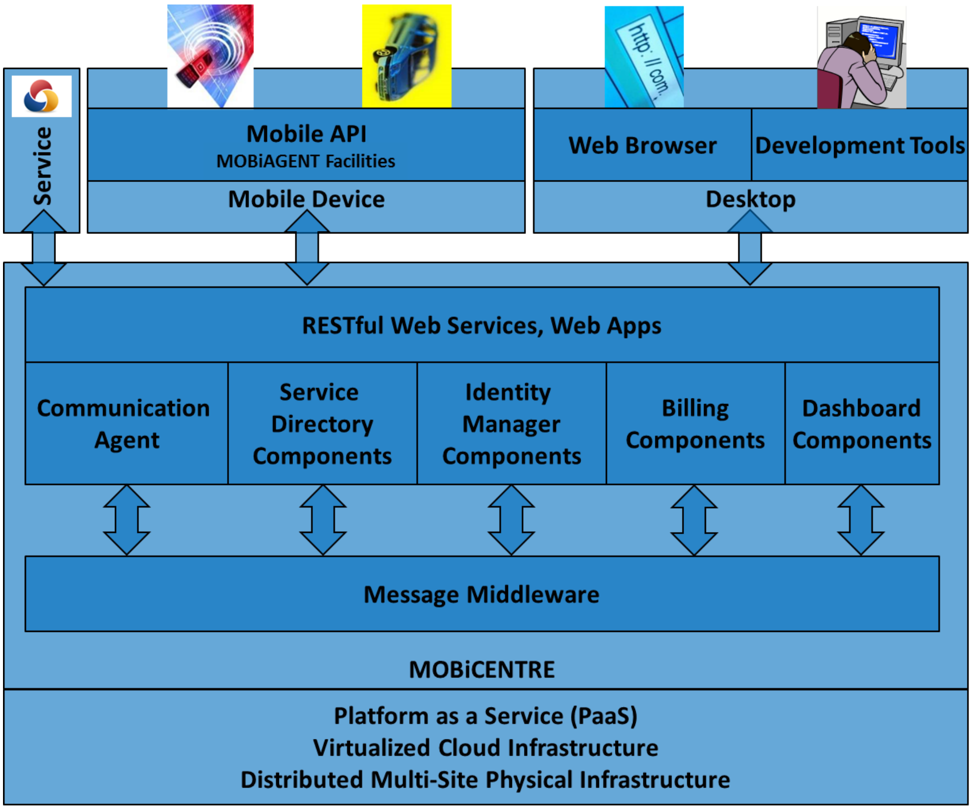

Figure 9-7 Technical vision of MOBiNET [MOBiNET D3.2]

9.7 VRUITS

The VRUITS project takes a VRU-centric approach to come to recommendations for ITS applications aimed at improving the safety, mobility and comfort of VRUs, leading to a full integration of the VRUs in the traffic system. Within the project an architecture for integration of VRUs is described in [21].

The VRUITS architecture – aggregated for the selected VRU ITS applications - is shown in the figure below. The figure shows the different objects e.g. cooperative ITS systems (marked red), tag-based systems (orange), connected systems (green) and existing vehicle and roadside infrastructure (grey) with their interfaces.

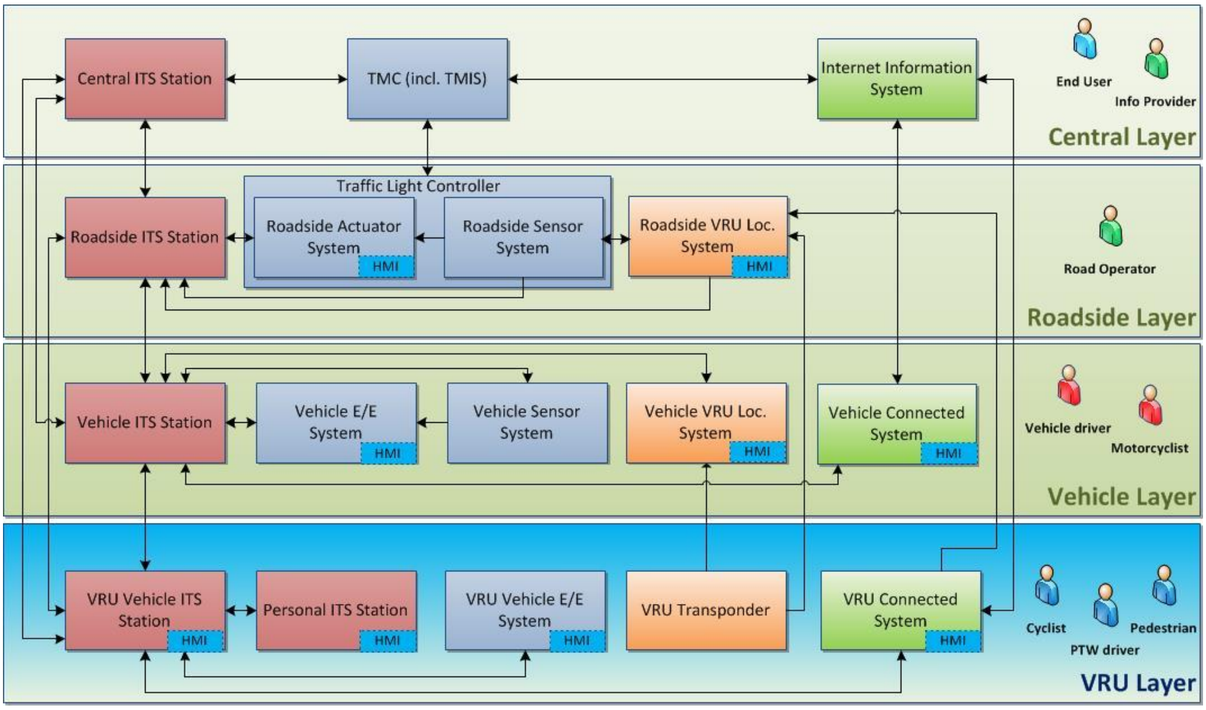

Figure 9-8 Architecture from VRUITS project [21].