

Semantic modeling of road intelligent transportation systems

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Abstract: *Intelligent transportation systems are key elements of smart cities, facilitating traffic management and autonomous driving. Road intelligent transportation systems implemented using wireless networks have been studied in recent decades, mostly for specific use cases, such as traffic lights control and driver assistant applications. Moreover, with the advent of the Internet of Vehicles, the so-called “vehicular cloud” concept has been studied to advance road intelligent transportation system (ITS) applications. However, formal semantics that describe every aspect relevant to road intelligent transportation systems, as a basis for ITS simulation platforms created to assess the performance of road ITS applications, have not been proposed. In this paper, a semantic model for road intelligent transportation systems is presented, which describes intelligent road infrastructure and vehicular cloud infrastructure, both considered as key components of a typical road ITS. The semantic model provides a formal basis for road ITS simulation platforms for modeling and simulating various functionalities of intelligent roads, which can be employed for explaining the nature of data-sharing processes and communication types in road intelligent transportation systems. The applicability of the semantic model is exemplarily demonstrated by semantic modeling of a simple road ITS.*

1. Introduction

Intelligent transportation systems constitute key elements of smart cities, promoting quality of life for citizens by granting efficient commute and mobility. An intelligent transportation system (ITS) is a combined application of sensing/actuating, computing, and communication technologies to evolve safer, more environmental friendly, and more cost-effective transportation systems for all modes of transport [1, 2]. In this context, wireless sensor networks and wireless communication technologies provide tools frequently employed for implementing intelligent transportation systems. An ITS produces a large amount of information that is used to pursue several goals, such as traffic management and autonomous driving, and to offer ITS users many applications, such as packet tracking, navigation, and hazard warning applications.

A road ITS refers to a land-based transportation system that uses roads as the travel route. Traffic management and fleet logistics control, navigation and mobility, maintenance management, and autonomous driving are among the most important applications of road intelligent transportation systems. To improve the performance of road ITS applications, it is vital to monitor and manage road intelligent transportation systems. The large number of data-sharing processes and applications within a road ITS, the potentially numerous road ITS elements, and the frequent changes in connections between these elements, pose challenges to monitoring road ITS performance. Hence, ITS simulation platforms are developed to study, evaluate, and monitor the performance of road intelligent transportation systems [3]. Road ITS simulation platforms integrate several road ITS behavioral models and different use cases to investigate present and future mobility demands and various scenarios [4].

Road ITS simulation platforms have been utilized in the past two decades to study and evaluate different traffic management mechanisms. Krajzewicz et al. modeled a traffic lights control algorithm using an open-source traffic simulation, called “simulation of urban mobility” (SUMO) [5]. Ghariani et al. have proposed a comparative analysis framework for evaluating the performance of existing simulation platforms for public transport control systems [3]. A model-driven framework of road intelligent transportation systems has been proposed by Fernández-Isabel and Fuentes-Fernández [6]. This framework has been obtained to develop simulations of road ITS applications, e.g. traffic lights management.

Despite the extensive research on road ITS simulation platforms, a formal description of road intelligent transportation systems to be used as a basis for designing road ITS simulation platforms has not received adequate attention. Formal descriptions of road intelligent transportation systems can be derived through semantic modeling of the road ITS elements and the communication types between the elements. This paper presents a semantic model of road intelligent transportation systems. First, a typical road ITS architecture is briefly explained. Next, upon assessing road ITS requirements and standards, knowledge sources for semantic modeling are summarized. Then, the semantic model of road ITS is presented, followed by an example of an illustrative ITS topology, developed using the proposed semantic model. The paper concludes with a summary and an outlook on potential further formalization efforts of the proposed semantic model.

2. Description of road intelligent transportation systems

Designing road ITS simulation platforms requires full understanding of road ITS elements, hereinafter termed “system elements”, road ITS characteristics, and communication types between system elements, together forming the road ITS architecture. The following discussion gives an overview of typical ITS architectures, with emphasis placed on the architecture employed in this paper.

2.1. Vehicular ad-hoc networks

ITS stations are defined as the functional system elements that together build the ITS architecture. One of the most popular road ITS architectures is the vehicular ad-hoc network (VANET). In VANET, mobile network nodes, i.e. connected ITS stations, share data packets among each other via vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. In VANET, the ITS topology changes frequently due to the autonomous and dynamic nature of network node connections [7]. As a result, data routing and secure communication between network nodes are issues worth taking into consideration to ensure high data quality and to secure communications between network nodes against malicious attacks.

2.2. Vehicular cloud

The emergence of the Internet of Things in vehicular environments, the so-called Internet of Vehicles (IoV), has founded the vehicular cloud, an advanced architecture of road intelligent transportation systems [8]. Network nodes can connect to each other through different wireless technologies by accessing on-board resources of ITS stations in their vicinity [9]. Olariu et al. have defined the autonomous vehicular cloud (AVC) as a group of autonomous

vehicles that, by means of peer-to-peer connections, provide their on-board resources and data to authorized users [10]. Vehicular cloud computing (VCC) and information-centric networking (ICN) are two major characteristics of vehicular clouds that facilitate data sharing among network nodes and contribute to cloud formation [8, 11].

Vehicular cloud computing encompasses sharing and using typically under-utilized on-board resources by network nodes, which assume a combined consumer and producer role of network nodes [8, 9, 11]. Vehicles can absorb data from the surrounding environment and also can produce and share data with other network nodes. In the vehicular cloud, vehicles can access resources in their vicinity, through V2V and V2I communications, creating cloud infrastructure. Unlike VANET applications that mostly focus on traffic safety messages and collision avoidance scenarios, VCC can be utilized also for autonomous driving, infotainment and multimedia applications, and disaster management [1, 11].

In the vehicular cloud, data packets exchanged between network nodes are decoupled from publisher node IP addresses, thus placing the focus on the contents of data packets themselves [8]. In this direction, information-centric networking (ICN) serves as a communication paradigm in the vehicular cloud that decouples information from a producer network node by assigning names to contents and by later providing contents to consumer network nodes using a scalable name resolution infrastructure [12]. ICN results in efficient cloud-based services by caching data packets in network nodes. Figure 1 shows an example of vehicular cloud formation in a section of a road: When the vehicle V1 broadcasts data packets to other vehicles and roadside units, or when a pedestrian receives weather condition information from the neighboring roadside unit on his/her smartphone or uses Internet accessed through roadside unit RSU2, two different vehicular clouds form.

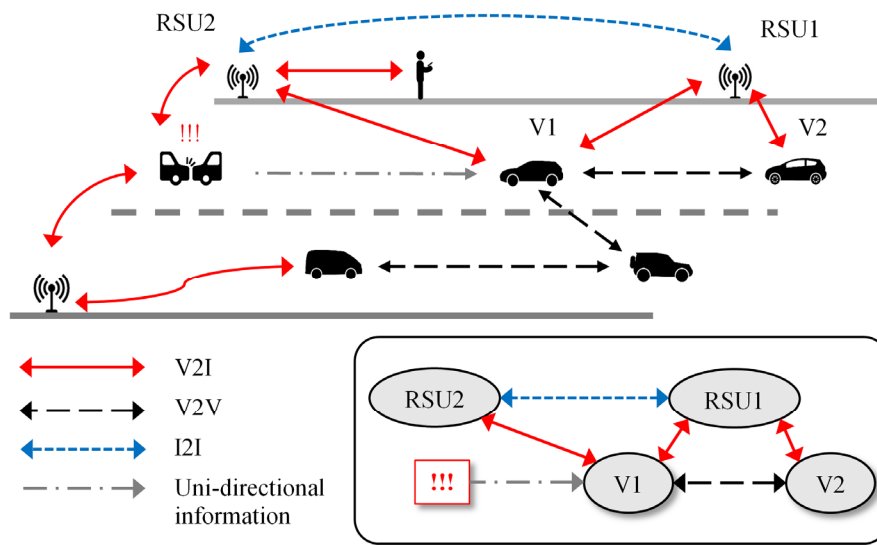


Figure 1. Vehicular cloud formation

3. Knowledge sources

Creating semantic models of complex systems, e.g. intelligent transportation systems, requires assessing information derived from various knowledge sources [13-15]. Broadly speaking, when semantically modeling a system, the system goals and architecture, existing infrastructure and technologies, and related standards and protocols provide substantial information that directly affect topology and content of semantic models. In this direction, for

creating the semantic model proposed in this paper, knowledge sources pertaining to road intelligent transportation systems are categorized into (i) road ITS applications, (ii) intelligent road infrastructure elements, and (iii) communication standards, which are explained briefly in the following subsections.

3.1. Road ITS applications

The goals of road ITS simulation platforms are manifold; however, the main goal of an intelligent transportation system is to induce safer, greener, and more convenient mobility. The need for providing safety to ITS passengers and goods, for decreasing environmental impacts of transportation, and for increasing traveling efficiency with respect to time, energy, and facilities has led to the design of several road ITS applications. The standard ETSI EN 302 665 [9] categorizes road ITS applications into “road safety”, “traffic efficiency”, and “other applications”. Moreover, road ITS applications can be further categorized according to following topics:

- Traffic and fleet logistics management, involving commuting with optimized routes, less fuel consumption and faster arrival to destinations. Traffic lights control, road information, and packet tracking systems are examples of applications in this category.
- Maintenance management, which includes assessing and continuous monitoring of infrastructure to ensure convenient mobility and secure transport. Winter road services, damage detection of pavements, and detouring alerts in navigation systems are applications in this category.
- Telematics, which combines telecommunications and informatics for applications in vehicles, such as driver-assistant systems, autopilots, and fully autonomous driving. Some applications are designed to monitor vehicle performance and to send reports to authorities in case of accidents or vehicle malfunctions. Telematics and traffic management applications have overlaps when considering navigation and vehicles tracking, since both offer information to vehicles individually or as a group.
- Infotainment, which combines information and entertainment for applications in vehicles, such as media libraries, online gaming, news platforms, and traffic data reports. Infotainment applications can help, for example, passengers enjoy their time on-board, receive footage from traffic congestions *en route*, or have video conferences while driving.

3.2. Intelligent road infrastructure

Road ITS applications are dependent on infrastructure and on data derived from this infrastructure. Intelligent roads comprise ITS stations equipped with sophisticated infrastructure including devices with sensing/actuating, computing and communication capabilities. ITS stations, essentially, represent core elements of road intelligent transportation systems and can be either mobile or fixed stations [16]. ITS stations, according to [9], are further categorized into:

- Personal ITS stations, including portable smart devices, e.g. smart phones, tablets (mobile)
- Central ITS stations, which are ITS central systems, also called “control centers” (fixed)

- Vehicle ITS stations, which are essentially vehicles themselves, e.g. cars, trucks, motorbikes (mobile)
- Roadside ITS stations, which include traffic shields, cameras, gantries, poles, with embedded wireless sensor technologies (fixed)

Depending on the ITS station category, ITS stations may comprise different on-board resources and functional components. It is worth noting that road ITS users are connected to the road ITS via one of the aforementioned ITS station categories; for example, a biker without a personal ITS station, is not recognized by the system as a “user”, but can be recognized as an “obstacle” by a vehicle ITS station. Figure 2 shows a reference architecture of road ITS stations, as defined in [9], consisting of six layers that define different functionalities within road ITS stations, and of interfaces between the layers.

The application layer includes safety and traffic efficiency applications as well as other road ITS applications. Application, information, communication, and session support functionalities as well as a layer management entity are parts of the facilities layer. The networking and transport layer comprises one or several networking protocols, one or several transport protocols, and a layer management entity. The access layer contains station-internal and station-external interfaces and a layer management entity. The management layer consists of application, station, cross-layer, and regulatory management functionalities as well as of a common management information base. Finally, the security layer contains security functionalities, such as firewall and intrusion management, authentication, authorization and profile management, hardware security modules, and a security information base.

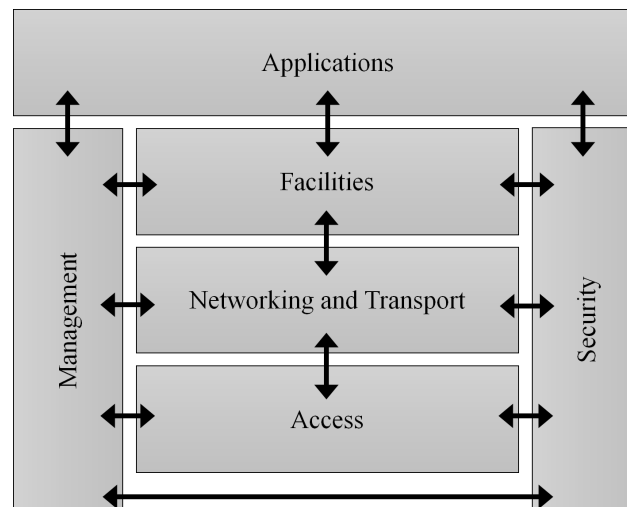


Figure 2. Road ITS station reference architecture

3.2. Communication standards

Advances in wireless network technologies have enabled integrating on-board wireless communication capabilities into vehicles. Therefore, vehicles can cooperatively connect to ITS stations via V2X (X: Vehicles, Infrastructure) communication, thus resulting in the so-called cooperative ITS (C-ITS) stations [10, 11]. Wireless and cellular networks are leveraged for V2X communication fulfilling requirements for several applications and use cases.

C-ITS standards adopt the ETSI EN 302 665 architecture [9], an ITS communication (ITSC) architecture, based on the ITS-S reference architecture. The ITSC architecture comprises two domains, the ITS domain including all ITSC components, and a generic domain, referring to

external networks and non-ITSC components (Figure 3) [17]. ITS ad-hoc network refers to communication between mobile and fixed ITS stations, interconnected by ITS-G5, which represents access layer specifications for ITS transceivers operating on 5.9 GHz frequency band [18]. The ITS-G5 specifications comply with the wireless access in vehicular environment (WAVE) or IEEE802.11p standard and are adapted to meet regional requirements in Europe.

The ITS access network grants access to specific services and applications, providing connections between roadside ITS stations as well as between mobile and fixed stations. Public access networks provide general access to data services and applications for public users, whereas private access networks give secure access to authorized groups of users [17].

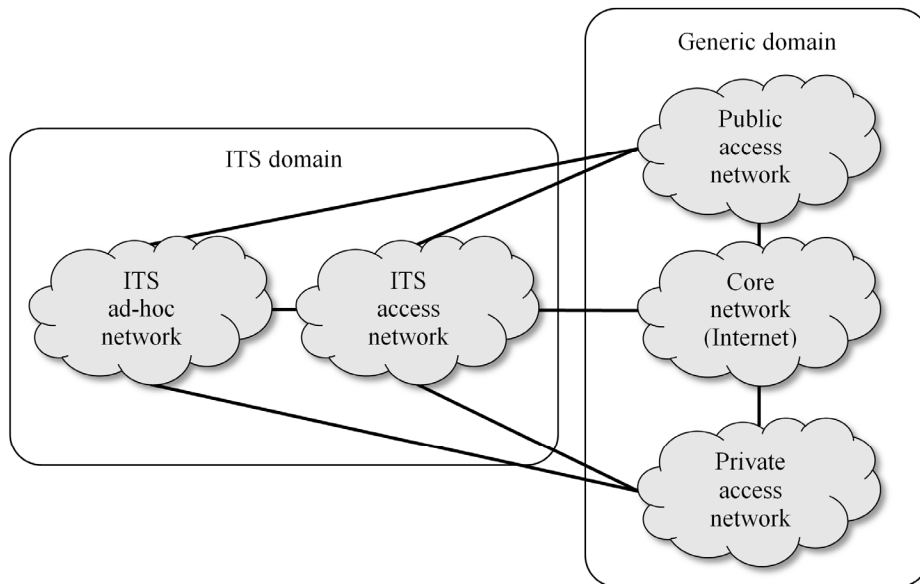


Figure 3. ITS network architecture

ETSI TR 101 607 [18] lists standards and protocols required for the deployment of C-ITS stations. Figure 4 indicates a few base standards and protocol stacks applied to different layers of ITS-S reference architecture, i.e. ITS communication standards [17-20].

TS 102 723 / TS 102 890-1	Management	Applications	TS 101 539	Security	TR 102 893 / TS 102 940
		Facilities	TS 102 890-3 / EN 302 637		
		Networking and Transport	EN 302 636		
		Access	EN 302 663		

Figure 4. Base standards for ITS communications

The base standards listed in Figure 4 are:

- Applications layer standards for message sets and applications, e.g. road hazard signaling and collision risk warning (ETSI TS 101 539)
- Facilities layer standards for message sets and applications for V2X communications, e.g. facilities layer function (ETSI TS 102 890-3) and decentralized environmental notification-based service (ETSI EN 302 637)
- Network and transport layer standards using basic transport protocols, e.g. GeoNetworking (ETSI EN 302 636), and Internet protocol version 6 (IPv6)
- Access layer standards for the 5.9 GHz frequency band (ETSI EN 302 663), multichannel operation, and decentralized congestion control
- Management layer and cross-layer standards, e.g. ITS domain, communication management specifications (ETSI TS 102 890-1), and OSI cross-layer topics (ETSI TS 102 723)
- Security layer standards, e.g. thread, vulnerability and risk analysis (TVRA- ETSI TR 102 893), and ITS communications security architecture and security management (ETSI TS 102 940)

4. A semantic model of road intelligent transportation systems

Upon analyzing the existing knowledge sources of road intelligent transportation systems, information for road ITS semantic modeling is extracted. Figure 5 is a conceptual illustration of the proposed semantic model for road intelligent transportation systems. It is worth noting that depending on the level of abstraction, semantic models can include a user-defined degree of detail, and class diagrams can be further expanded with classes, class attributes, operations, and associations between classes.

The abstract class ITSSStation represents the core elements of intelligent road infrastructure. ITS stations, as mentioned in section 3.2, can be of two types, which are depicted by abstract subclasses FixedITSSStation and MobileITSSStation. Subclasses CentralITSSStation, RoadsideITSSStation, and VehicleITSSStation and the abstract subclass PersonalITSSStation represent the categories of road ITS stations, which can be further detailed by introducing specialized forms of system elements into the semantic model. Here, as an example, PersonalITSSStation is the abstract superclass for Smartphone and Tablet subclasses, meaning that here personal ITS stations can be one of these two subclasses.

The ITSCommunication class represents all communication types between system elements and is linked to the ITSSStation abstract class with a uni-directional association, which indicates that road ITS stations make use of ITS communication methods and can own various types of ITS communications for connections between system elements. However, the ITSCommunication class cannot access the ITSSStation abstract class methods and attributes. The ITSCommunication abstract class implements different communication types as, for example, represented by the Wired, WLAN, and Cellular classes. Furthermore, road ITS stations that are communicating with one another through ITSCommunication class are recognized here by the NetworkNode class.

The Roadstructure class represents the physical structure of the road including, e.g. pavement and resting areas. DigitalRoad class is composed of ITSSStation and Roadstructure classes and is defined as one type of Road class, which generally includes all types of roads, whether equipped with intelligent road infrastructure or not.

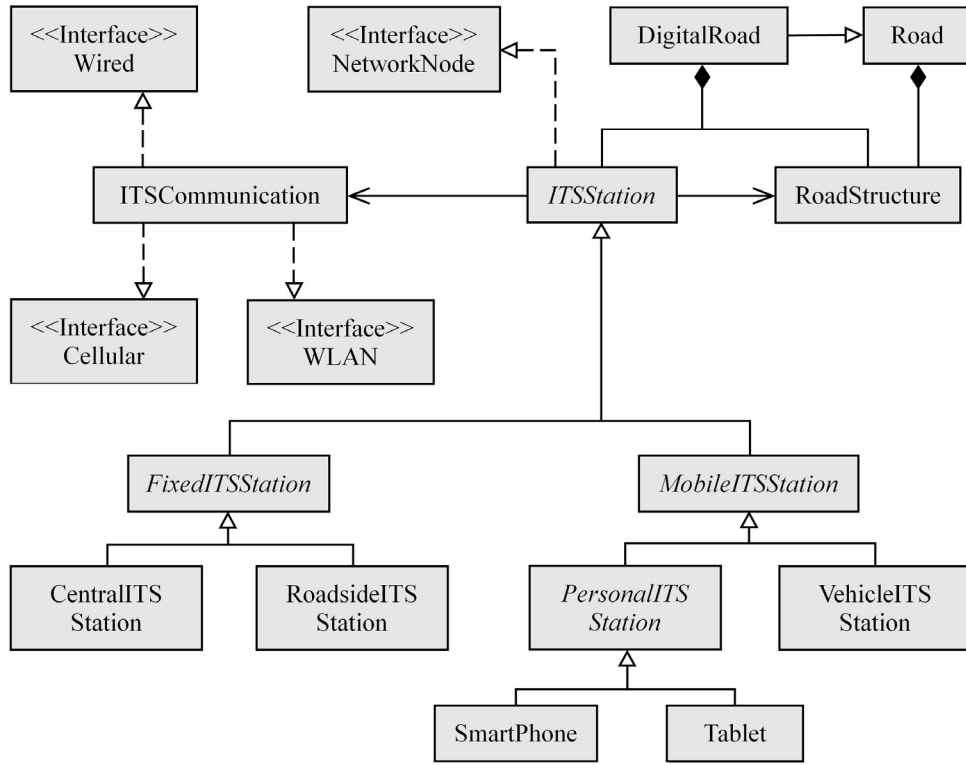


Figure 5. Semantic model of road intelligent transportation systems

For better understanding the proposed semantic model, the vehicular cloud depiction in Figure 1 is taken as an example instance of the DigitalRoad class. Assuming that an incident happens on the road, e.g. a rear-end collision, to which vehicle ITS stations (network nodes) V1 and V2 are approaching, V1 broadcasts a warning message to neighboring network nodes through V2V communication to V2, and through V2I communication to roadside ITS stations RSU1 and RSU2. Furthermore, network node V2 can receive some information, e.g. speed limit and safety messages, from RSU2 through V2I communication. The object diagram of this scenario, an instance of the proposed road ITS semantic model is illustrated in Figure 6.

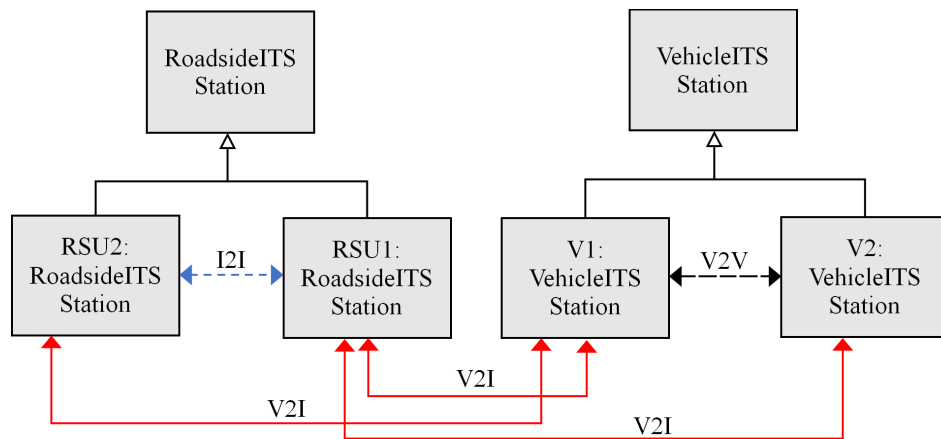


Figure 6: Illustration of data sharing and communication types among ITS stations in an example road ITS using the proposed semantic model

5. Summary and conclusions

A formal description of intelligent transportation systems that facilitates the understanding of road intelligent transportation systems has been proposed in this paper as a basis for designing ITS simulation platforms. Specifically, a road ITS with vehicular cloud architecture has been presented and semantically modeled with respect to road ITS knowledge sources, i.e. road ITS applications, intelligent road infrastructure elements, and communication standards. Object-oriented modeling has been employed to depict associations between classes and interfaces representing elements of intelligent road infrastructure and of vehicular cloud infrastructure on a meta level, and an example of data-sharing processes and communication types in a section of a road has been illustrated using the proposed semantic model. The present semantic model can be further formalized and mapped into existing standards, e.g. the Industry Foundation Classes, and can be used as a basis to model ITS simulation platforms for different use cases.

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