# A semantic model of intelligent transportation systems

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**Abstract.** Intelligent transportation systems, representing core components of smart cities, combine sensing, computing, and wireless communication technologies to provide efficient and convenient mobility. Road intelligent transportation systems (ITS) have been studied in recent decades through simulation platforms that integrate computational models for various use cases, such as traffic lights control and management. However, semantic descriptions, illustrating road ITS as a whole and creating a basis for designing simulation platforms, have not been addressed. In this paper, a semantic model of road intelligent transportation systems is proposed, which describes road ITS components and architecture, serving as a formal basis for road ITS simulation platforms. Building upon the semantic model, an extension of the Industry Foundation Classes schema, facilitating ITS simulation platforms based on building information modeling, is discussed. The paper concludes with a summary, a discussion, and an outlook on potential formalization efforts.

## 1. Introduction

Vehicular cyber-physical systems combine physical, computing, and networking processes in vehicular environments. A vehicular cyber-physical system (VCPS) is composed of a physical subsystem, including all physical components and processes, and a computational subsystem that includes the networking processes and computational models (Legatiuk et al., 2017). As an application branch of vehicular cyber-physical systems, an intelligent transportation system (ITS) considers vehicles as intelligent VCPS components with combined on-board sensing/actuating, computing, and communication capabilities. Intelligent transportation systems constitute key elements of smart cities and increase quality of life by providing safer, greener, and more cost-effective mobility.

A road ITS refers to the land-based mode of transport that uses roads as travel routes. Road intelligent transportation systems comprise numerous elements and data-sharing processes with intermittent and temporal connections, resulting in complex and heterogeneous systems. Traffic management and fleet logistics control, road safety and maintenance management, navigation and positioning, and autonomous driving are among the most important applications of road intelligent transportation systems. To evaluate and improve road ITS performance, it is necessary to monitor road intelligent transportation systems. Therefore, simulation platforms are developed to study the performance of road ITS applications. Mitigating monitoring challenges, simulation platforms employ road ITS computational models for different use cases, aiming to investigate road ITS capabilities, potential improvements to application designs, and future mobility demands (Ghariani et al., 2014).

In recent years, simulation platforms have been employed to study different ITS mechanisms, focusing on specific use cases, e.g. traffic simulations, or global assessment of intelligent transportation systems. Boschian et al. (2011) have defined a reference model of intermodal transportation networks, describing an information management system between different modes of transport. The reference model together with a simulation module constructs an integrated structure that founds operational decision-making processes. Fernández-Isabel and Fuentes-Fernández (2015) have proposed a model-driven engineering framework to develop road ITS simulations. The framework consist of an ITS modeling language, focusing on traffic simulation and sensor networks components, and a guideline on how to obtain ITS modeling language for different simulation scenarios, e.g. traffic lights management. Datta et al. (2016) have listed challenges relevant to integrating connected vehicles into Internet of Things ecosystems, and have proposed a framework that comprises building blocks, software elements, and their operational phases and benefits. Also, the authors have discussed the implementation and interoperability of the proposed framework by mapping the semantic-based description of framework elements into standard architectures.

Despite the extensive research on simulation platforms for traffic-related applications and urban traffic management, a formal description of road intelligent transportation systems, providing a basis for simulation platform designs, has received little attention. Building information modeling (BIM), may utilize open standardized data formats, i.e. the Industry Foundation Classes (IFC) standard, to formally describe information and to facilitate information exchange. However, the current IFC schema contains limited entities to be used for defining road ITS components. This paper presents a semantic modeling approach for describing road ITS models. First, background information relevant to road ITS semantic modeling is given. Next, a semantic model of road intelligent transportation systems is presented, followed by an ITS case study, devised to validate the semantic model. The paper concludes with a summary and a discussion on a potential IFC schema extension to be employed for road ITS simulation platforms.

## 2. Knowledge sources for semantic modeling

For defining the semantic model of road intelligent transportation systems, properties of all physical and computational components of vehicular environments are to be formally described. In this section, sources that provide knowledge on the physical and computational components relevant to road ITS are analyzed with respect to semantic modeling. The knowledge sources are categorized into (i) network architectures, (ii) road ITS applications, (iii) intelligent road infrastructure, and (iv) communication networks and are briefly explained in the following subsections.

### 2.1 Network architectures

A vehicular ad-hoc network (VANET), representing the fundamental road ITS architecture, is a network paradigm based on peer-to-peer communications, i.e. V2X (vehicle-to-anything) communications. As a type of mobile ad-hoc networks, VANETs are self-forming networks with autonomous and intermittent connections, leading to frequent changes in ITS topology (Dixit et al., 2016). Road ITS elements that are connected through VANETs are referred to as "network nodes". To guarantee the integrity of data packet transmissions and communications between network nodes, different routing protocols and security standards are employed for vehicular ad-hoc networks. However, varying traffic densities and communication technologies pose challenges to the VANET deployment in ITS networks.

Merging VANETs with the Internet of Vehicles – the Internet of Things in vehicular environments – initiated the idea of employing underutilized resources of vehicles, i.e. on-board units, to decentralize computing processes and provide location-based services. Network nodes that were solely data consumers have become data producers as well; therefore, the cloud computing concept together with the VANET paradigm has created the vehicular cloud concept. Eltoweissy et al. (2010) have coined the term "autonomous vehicular clouds" as a group of vehicles that, by means of V2X communication, share on-board units and services with other authorized network nodes. Edge computing, vehicular cloud computing (VCC), and information-centric networking (ICN) are main characteristics of vehicular clouds that facilitate robust data sharing and cloud formation. An example of vehicular cloud formations and characteristics is depicted in Figure 1.

Advances in the automotive industry have led to the design of vehicles with various computational on-board capabilities, such as powerful computing units, several types of sensors, and different communication devices. Therefore, vehicles can absorb information from the environment, perform computational processes, and operate accordingly. As a result, all network nodes, including vehicles, are able to perform decentralized data processing, i.e. edge computing, to handle time-sensitive operations more efficiently, and to record data with local relevance temporarily (Atchison, 2018; Gerla et al., 2014). VCC is the mechanism used to access underutilized on-board units in the vicinity, combining resources to perform computing processes for location-based services and applications. In other words, VCC distributes computing burden between network nodes and lessens road ITS deployment costs by decreasing the number of centralized computing resources (Whaiduzzaman et al., 2014). Unlike VANET applications that mostly focus on traffic safety scenarios, e.g. collision avoidance, edge computing and VCC can be employed for cooperative and autonomous driving, hazard management, and infotainment applications (Eltoweissy et al., 2010; Gerla, 2012). ICN is a communication paradigm that places focus on the content of data packets by decoupling data packets from node IP addresses. Network nodes can send/receive data packets and translate packet contents with respect to several ICN architectures and messaging protocols that specify standard machine-readable naming and beacon exchanges (Ahlgren et al., 2012; Wan et al., 2014).

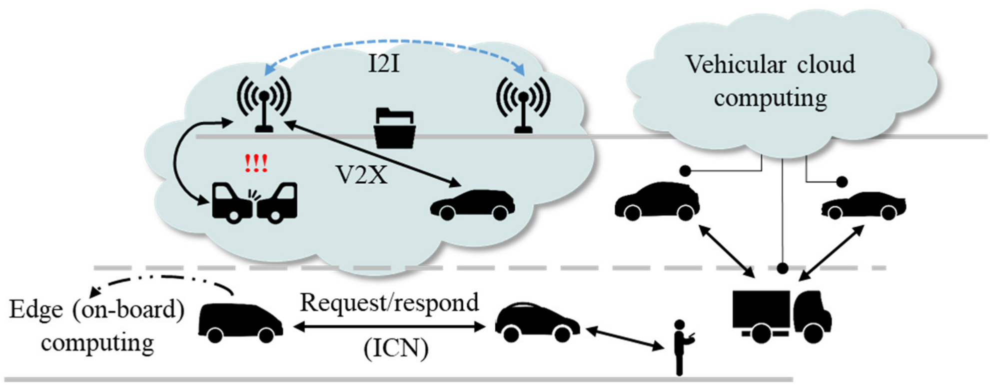


Figure 1: Example of vehicular cloud formations

Drawing from the above review of network architectures serving as a knowledge source for the semantic model proposed in this study, the vehicular cloud is recognized as the network architecture relevant to road intelligent transportation systems. The abovementioned properties of vehicular clouds are reflected in the semantic model as operations in network nodes. Moreover, communication scenarios are derived from the VANET topology and added to the semantic model.

## 2.2 Road ITS applications

Road ITS applications are designed to advance safe and convenient mobility scenarios, i.e. providing safety to ITS users and goods, decreasing adverse environmental impacts, and increasing efficient commutes with respect to energy consumption and travel time (Mirboland and Smarsly, 2018). As recommended by the European Telecommunications Standards Institute standard (ETSI EN 302 665), road ITS applications, with respect to the application categories, can be classified into "traffic efficiency", "road safety", and "other applications". Furthermore, with respect to application topics, road ITS applications can be grouped into "traffic and fleet logistics management", "telematics", "maintenance management", and "infotainment". Traffic and fleet logistics management applications comprise optimized commutes and traffic infrastructure control to avoid congestions and grant efficient travels. Telematics combine telecommunications and informatics for applications in vehicles and are developed to monitor the performance of vehicles ("intra-vehicle monitoring") as well as to report malfunctions to drivers or authorities. It should be noted that traffic and fleet logistics management and telematics applications overlap when a group of vehicles is considered for positioning and tracking scenarios. Maintenance management applications are based on continuous assessing and monitoring infrastructure and road conditions to provide road status information, detect structural damages, and notify drivers with detouring alerts in case of disasters or accidents. Finally, infotainment combines information and entertainment for applications in vehicles and grants passengers enjoyable time en route, providing access to Internet-based applications. Examples of different road ITS applications are listed in Table 1.

Table 1: Road ITS application groups and some examples

| **Application categories (ETSI EN 302 665)** | **Application topics** | **Examples** |
|---|---|---|
| Traffic efficiency | Traffic and fleet logistics management | Optimized traffic signals, road traffic information, packet tracking systems, navigation, hazard warnings |
| Traffic efficiency, road safety | Telematics | Driver-assistant systems, autonomous driving, intra-vehicle monitoring, navigation and positioning |
| Road safety, other applications | Maintenance management | Damage detection of pavements, winter road services, disaster management |
| Other applications | Infotainment | Internet-based applications, multimedia libraries, gaming and news platforms |

The semantic model proposed in this paper offers a generic view to map any application of road intelligent transportation systems. However, the focus is set on traffic and fleet logistics management applications, to provide a formal description of road ITS for traffic simulation platforms.

### 2.3 Intelligent road infrastructure

Road ITS applications use the data recorded and processed by network nodes. Therefore, road ITS applications are highly dependent on functional elements and on-board resources, i.e. ITS stations that together build the ITS architecture. Intelligent roads comprise ITS stations equipped with various types of devices that have sensing/actuating, computing and communication capabilities. ITS stations are of mobile or fixed type and, according to ETSI EN 302 665, can be further categorized into:

- Central ITS stations, also referred to as "control centers" or "base stations" (fixed).
- Personal ITS stations, i.e. smart devices, e.g. laptops, tablets, and smart phones (mobile).
- Roadside ITS stations, which comprise, e.g., traffic shields, cameras, and poles (fixed).
- Vehicle ITS stations, including all vehicle types, e.g. trucks, cars, and motorbikes (mobile).

Depending on the category, an ITS station may include different functional components and devices. It is assumed that all ITS stations comprise four main on-board units: Sensing unit, computing unit, communication unit, and power unit. The sensing unit contains sensing technologies relevant to traffic detection systems, e.g. micro-electro-mechanical systems (MEMS), inductive loops, radio-frequency identification (RFID), light detection and ranging (LIDAR) sensors, and automatic license plate recognition (ALPR) cameras, or sensor systems to detect environmental changes, such as pollution and temperature sensors. The computing unit comprises main processing and storage devices, while communication devices, e.g. radio transceivers, beacons, and Wi-Fi routers are parts of the communication unit. The power unit includes different power supply means, such as photovoltaic (solar) panels and piezoelectric transducers that may co-exist with electrical grids to deliver energy to ITS stations.

In addition, it is worth noting that roadside ITS stations may comprise actuators and control devices to change traffic signals and to control traffic flow on specific routes and road structures (e.g. bridges). Also, most roadside ITS stations provide gateways to the Internet and are therefore considered access points for vehicular clouds. In this paper, regardless of the underlying technology, intelligent road infrastructure is mapped into the semantic model primarily in terms of the abovementioned categories with sensing, computing, communication, and power units.

## 2.4 Communication networks

Advances in wireless network technologies have enabled integrating on-board wireless communication capabilities into vehicles. Therefore, vehicles can cooperatively connect to network nodes via V2X communications, i.e. cooperative-ITS (C-ITS) communications (Gerla, 2012). Wireless and cellular networks are leveraged for C-ITS communications, due to easy deployment and scalability needed for intelligent transportation systems and the ability to fulfil networking requirements in vehicular environments. According to the ETSI EN 302 636-3 standard, ITS communication (ITSC) networks are composed of external networks between ITS stations and internal networks in each ITS station. The architectures of both ITS external and internal networks are depicted in Figure 2 and are briefly described in the following paragraphs with respect to the knowledge relevant to the semantic model.

### *ITS external network architecture*

The external network architecture includes an ITS domain and a generic domain, as shown in Figure 2. In the ITS domain, the ITS ad-hoc network represents wireless C-ITS communications between vehicle, personal, and roadside ITS stations. The ITS access network interlinks roadside and central ITS stations and provides communication between vehicle ITS stations through roadside ITS stations. In the generic domain, public access networks grant general data services and applications to public users, whereas private access networks provide secure access only to authorized groups of users.

### *ITS internal network architecture*

The internal network in an ITS station interlocks functional networking components of the ITS station. A reference architecture for ITS station internal networks based on layered communication protocols is shown in Figure 3 (ETSI EN 302 665, ETSI TR 101 607). The reference architecture comprises six layers, which characterize different functionalities within ITS stations, and interfaces between layers.

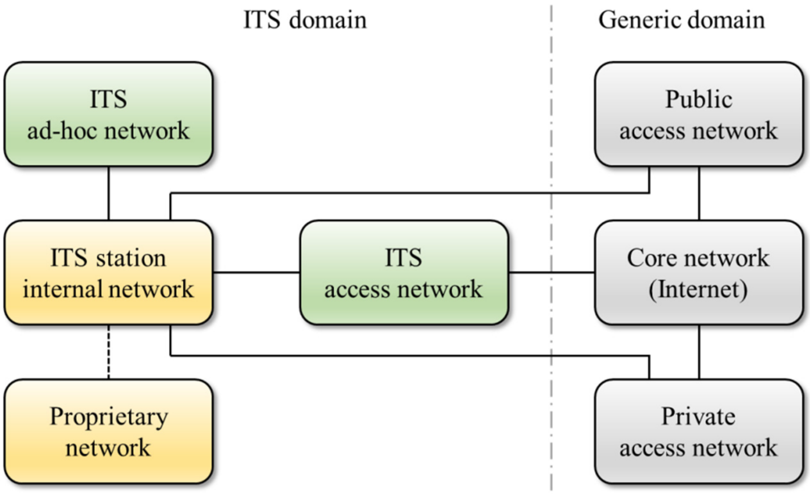


Figure 2: Road ITSC architecture – external (green and grey) and internal (orange) networks

The application layer contains standards for road safety, traffic efficiency, e.g. road hazard signaling and collision risk warning, and other applications. The facilities layer includes maintenance of applications, the decentralized environmental notification-based service, communication channels selection, and session supports. The networking and transport layer comprises one or more networking protocols (e.g. GeoNetworking), one or more transport protocols (i.e. dedicated ITSC transport protocols), and a layer management entity. The access layer contains station-internal and station-external interfaces, and specifications for V2X communications in 5.9 GHz frequency band (ITS-G5). Finally, having interfaces with all other layers, the management layer and the security layer contain functionalities that grant ITS station cross-layer and regulatory management as well as intrusion and authorization management, respectively.

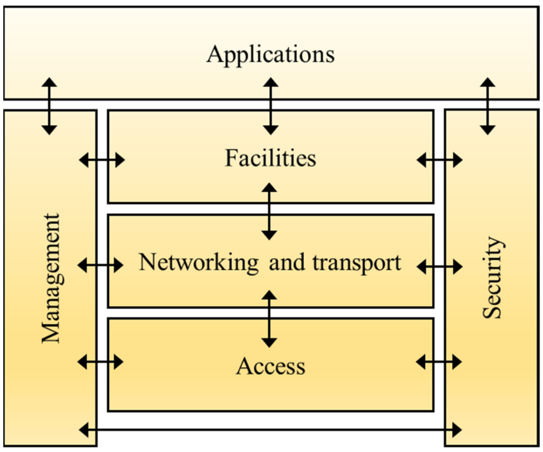


Figure 3: The layered reference architecture for ITS station internal networks

## 3. A semantic model of road intelligent transportation system

Upon analyzing the knowledge sources of road intelligent transportation systems elucidated in the previous section, Figure 4 presents an extract of the proposed semantic model developed from the aforementioned knowledge sources. The semantic model is shown in terms of a class diagram, in which, for the sake of clarity, attributes, methods, and multiplicities of associations are omitted. In the following paragraphs, main elements of the semantic model are described.

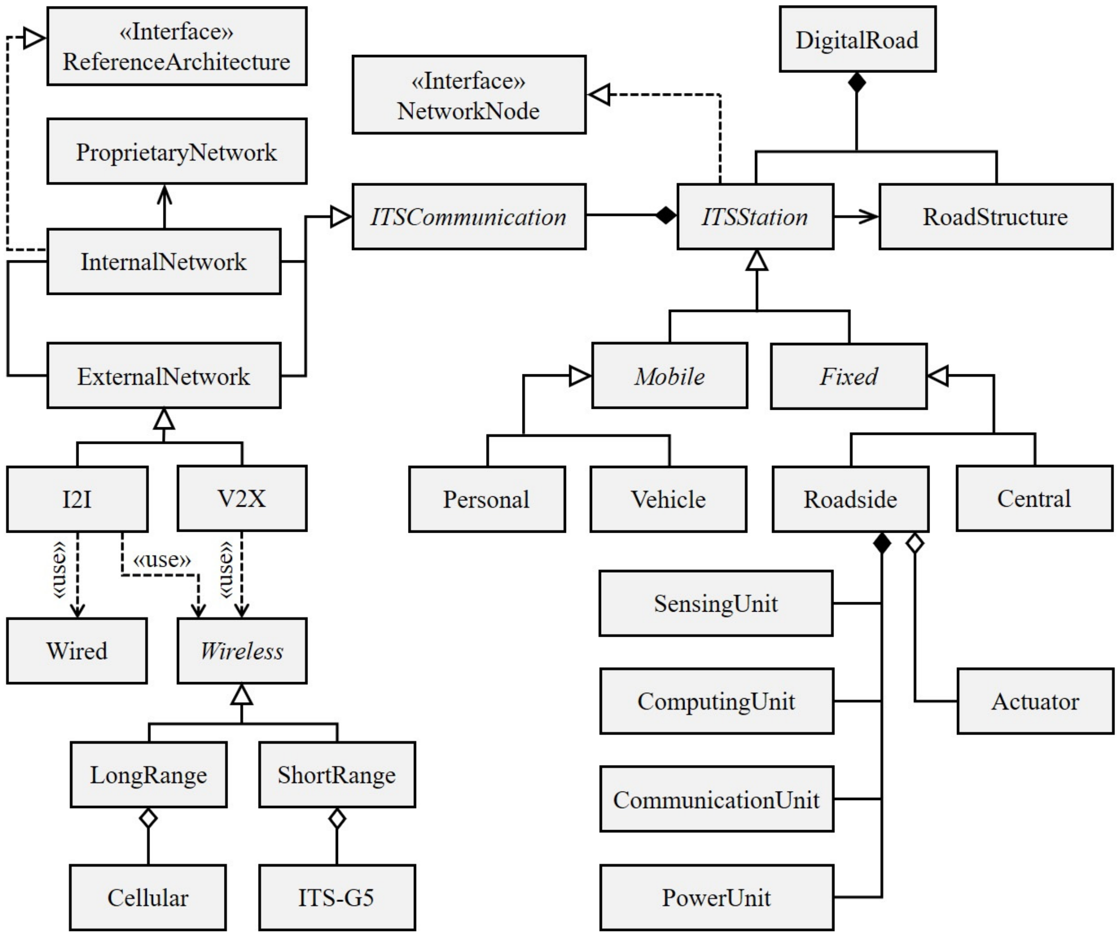


Figure 4: Semantic model of road intelligent transportation systems

The *DigitalRoad* class is composed of *RoadStructure* and *ITSStation* classes. The *RoadStructure* class represents the physical road structure including, e.g. pavement and resting areas. The abstract class *ITSStation* represents the core elements of intelligent road infrastructure. ITS stations, as mentioned previously, are categorized into two groups, depicted by the abstract subclasses *Fixed* and *Mobile*. Fixed ITS stations are of two types, *Central* and *Roadside*, and mobile ITS stations are categorized into *Vehicle* and *Personal* classes. The *SensingUnit*, *ComputingUnit*, *CommunicationUnit*, and *PowerUnit* depict ITS station on-board units and are shown in Figure 4 exemplarily for the *Roadside* class. ITS stations may have one or more control devices, such as *Actuator* devices.

The abstract class *ITSCommunication* represents communication networks in the ITS domain and is connected to the abstract class *ITSStation* with a composition relationship, since communication in the ITS domain is fully dependent on ITS stations. The abstract class *ITSCommunication* is a superclass of *InternalNetwork* and *ExternalNetwork*, which indicate communication within ITS stations and communication between ITS stations, respectively. The *InternalNetwork* class is defined based on the ITS station reference architecture introduced earlier. Therefore, the *InternalNetwork* class implements the *Reference Architecture* interface. Moreover, in internal networks of ITS stations, linked on-board units are recognized by the *ProprietaryNetwork* class. It is worth to note that proprietary networks comprise all on-board resources, e.g. sensors, beacons and transceivers, mechanical and/or electrical actuators, and several other devices, which are connected to the ITS station. The *ExternalNetwork* class comprises C-ITS and infrastructure-to-infrastructure (I2I) communications, shown by the *V2X* and *I2I* classes, respectively. I2I communication can be either wired or wireless, while V2X communication is solely wireless. The abstract class *Wireless* is a superclass of *LongRange* and *ShortRange* subclasses, which represent different wireless communication standards. An illustrative example of standards in each subclass is given by the *Cellular* and *ITS-G5* classes, respectively.

***Case study***

For validating the semantic model and, specifically, for better understanding the relationship between *ITSCommunication* and *ITSStation* classes, a scenario of vehicular cloud formation is considered as a case study. In the case study, communications in the ITS domain are employed for road safety and traffic management applications. As shown in Figure 5, it is assumed that an accident, rear-end collision, occurs in a section of a road, and ITS station external networks form a vehicular cloud to broadcast safety-related messages to other nodes.

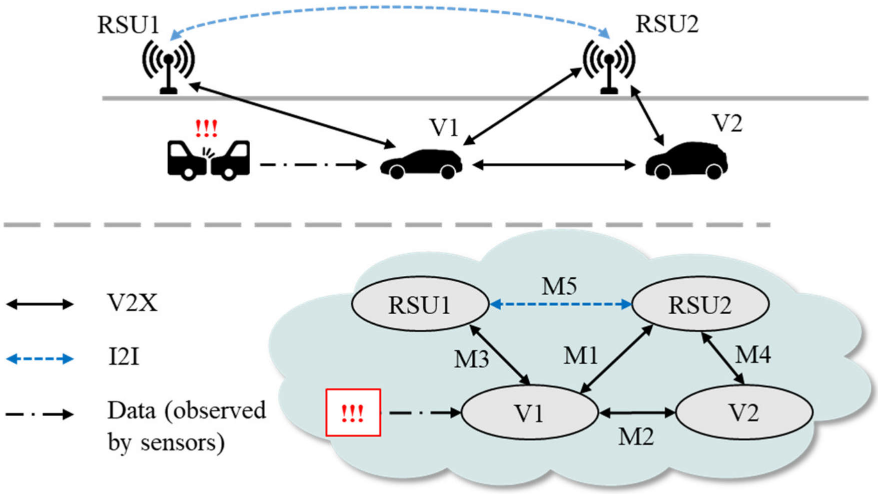


Figure 5: Vehicular cloud formation for road safety in the ITS domain

As can be seen from the scenario in Figure 5, vehicle ITS station *V1* broadcasts collision risk signals to ITS stations with potential interests, e.g. vehicles approaching and roadside units in the vicinity. *V1* sends a warning message (*M1*) to the roadside ITS station *RSU2* using ITS-G5 channels allocated for road safety messaging services. Meanwhile, *V1* utilizes Bluetooth wireless communication to inform vehicle ITS station *V2* with a collision risk message (*M2*). Using traffic management applications, *V1* sends a message (*M3*) to roadside ITS station *RSU1*, requesting the traffic status of an alternative route. *RSU2*, using 4G cellular communications, broadcasts congestion warnings to inform vehicles in farther distances. In response, *V2* asks for media footage of the accident via ITS-G5 (*M4*). In addition, the roadside ITS stations *RSU1* and *RSU2* communicate through 4G cellular communications to perform traffic safety-related actions, such as changing traffic lights (*M5*).

Figure 6 describes the semantic illustration of the scenario depicted in Figure 5 in terms of an object diagram as an instance of the proposed semantic model. The object diagram comprises four ITS station objects, messages shared among ITS stations (*M1*…*M5*), and the wireless communication standards employed for each communication.

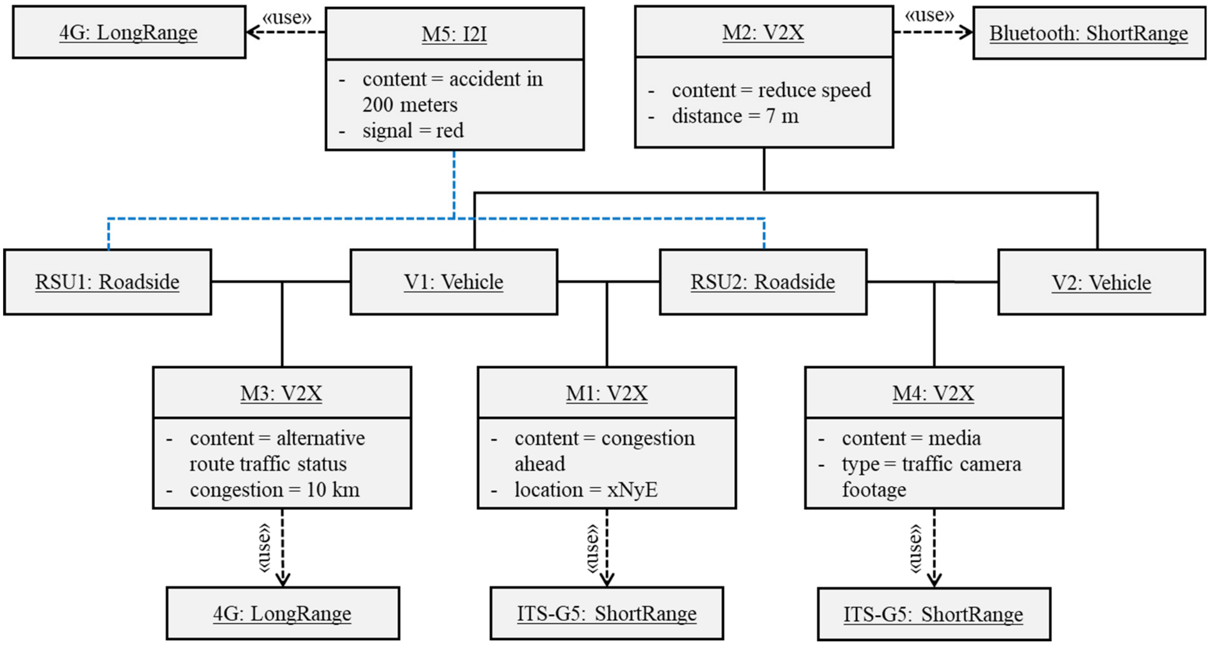


Figure 6: Object diagram of the scenario shown in Figure 5

***Discussion of the results***

As has been demonstrated in this section, the proposed semantic model is able to describe cloud formation scenarios with different numbers of ITS stations connected, various communication types involved, and different on-board units engaged. Moreover, data processing and computational models for various applications may be described using the semantic model, representing a means supporting formal descriptions of road intelligent transportation systems. In future work, the semantic model may be mapped into a standardized metamodel to describe road intelligent transportation systems on a standardized basis, preferably employing building information modeling as an increasingly used method in infrastructure modeling. When using the IFC standard as a formal basis, some entities defined in the IFC schema, such as *IfcCommunicationsApplicance*, may be used to describe road ITS components. However, due to a lack of entities to describe ITS-related infrastructure and components, the current IFC schema cannot be employed for fully mapping the proposed semantic model. Instead, an IFC extension is to be developed to consider all aspects covered by the semantic model of road intelligent transportation systems.

## 4. Summary and conclusions

To achieve a formal description of road intelligent transportation systems, a semantic model of road intelligent transportation systems has been developed. Knowledge sources for semantic modeling of road intelligent transportation systems have been analyzed. Associations and relationships between elements of intelligent road infrastructure and vehicular cloud infrastructure have been defined on a meta level using object-oriented modeling, and a scenario of vehicular cloud formation and data-sharing processes has been depicted for validating the proposed semantic model. The model is applicable for various road ITS use cases, and it can be used as a basis for designing ITS simulation platforms. In future work, extending the IFC schema is envisaged to facilitate standardized description of road intelligent transportation systems in terms of building information models.

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## References

Ahlgren, B., Dannewitz, C., Imbrenda, C., Kutscher, D. and Ohlman, B. (2012). A survey of information-centric networking. *IEEE Communications Magazine*, 50(7), pp. 26-36.

Atchison, L. (2018). *Edge Computing vs. Cloud Computing: Which One Is Right for Your Application?*. [online] New Relic Blog. Available at: https://blog.newrelic.com/technology/edge-computing-vs-cloud-computing-comparison/ [Accessed: February 2, 2019].

Boschian, V., Dotoli, M., Fanti, M. P., Iacobellis, G. and Ukovich, W. (2011). A Metamodeling Approach to the Management of Intermodal Transportation Networks. *IEEE Transactions on Automation Science and Engineering*, 8(3), pp. 457-469.

Datta, S.K., Costa, R.P., Haerri, J. and Bonnet, C. (2016). Integrating connected vehicles in Internet of Things ecosystems: Challenges and solutions. In: *Proc. of the 2016 IEEE 17th International Symposium on A World of Wireless, Mobile and Multimedia Networks*, Coimbra, Portugal, June 21, 2016.

Dixit, M., Kumar, R. and Sagar, A. K. (2016). VANET: Architectures, research issues, routing protocols, and its applications. In: *Proc. of the 2016 International Conference on Computing, Communication and Automation*. Noida, India, April 29, 2016.

Eltoweissy, M., Olariu, S. and Younis, M.F. (2010). Towards Autonomous Vehicular Clouds - A Position Paper (Invited Paper). In: *Proc. of the Second International Conference on Ad Hoc Networks*. Victoria, BC, Canada, August 18, 2010.

European Telecommunications Standards Institute (2010). Intelligent Transport Systems (ITS); Communications Architecture. ETSI EN 302 665 Standard (V1.1.1). ETSI, Sophia Antipolis, France.

European Telecommunications Standards Institute (2013). Intelligent Transport Systems (ITS); Cooperative ITS (C-ITS); Release 1. ETSI TR 101 607 Standard (V1.1.1). ETSI, Sophia Antipolis, France.

European Telecommunications Standards Institute (2014). Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 3: Network Architecture. ETSI EN 302 636-3 Standard. ETSI, Sophia Antipolis, France.

Fernández-Isabel, A. and Fuentes-Fernández, R. (2015). Analysis of Intelligent Transportation Systems Using Model-Driven Simulations. *Sensors*, 15(6), pp.14116-14141.

Gerla, M. (2012). Vehicular Cloud Computing. In: *Proc. of the 11th Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net)*, Ayia Napa, Cyprus, June 19, 2012.

Gerla, M., Lee, E., Pau, G. and Lee, U. (2014). Internet of vehicles: From intelligent grid to autonomous cars and vehicular clouds. In: *Proc. of the 2014 IEEE World Forum on Internet of Things (WF-IoT)*, Seoul, South Korea, March 6, 2014.

Ghariani, N., Elkosantini, S., Darmoul, S. and Ben Said, L. (2014). A survey of simulation platforms for the assessment of public transport control systems. In: *Proc. of the 2014 International Conference on Advanced Logistics and Transport (ICALT)*, Hammamet, Tunisia, May 1, 2014.

Legatiuk, D., Theiler, M., Dragos, K. and Smarsly, K. (2017). A categorical approach towards metamodeling cyber-physical systems. In: *Proc. of the 11th International Workshop on Structural Health Monitoring*. Stanford, CA, USA, September 12, 2017.

Mirboland, M. and Smarsly, K. (2018). Semantic modeling of road intelligent transportation systems. In: *Proc. of the Positioning and Navigation for intelligent transportation systems*, Berlin, Germany, November 15, 2018.

Wan, J., Zhang, D., Zhao. S., Yang, L.T. and Lloret, J. (2014). Context-aware vehicular cyber-physical systems with cloud support: architecture, challenges, and solutions. *IEEE Communications Magazine*, 52(8), pp. 106-113.

Whaiduzzaman, M., Sookhak, M., Gani, A. and Buyya, R. (2014). A survey on vehicular cloud computing. *Journal of Network and Computer Applications*, 40(2014), pp. 325-344.