Validating Connected Vehicles Architecture

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***Abstract*—Connected vehicles, smart cars, smart roads, and autonomous cars are bringing a new era of road transportation systems. In addition, several promising applications are looming based on these new concepts. This imposes unprecedented scenarios for cars and roads in modern transportation systems. Therefore, connected vehicles architectures must be developed and implemented carefully in order to accommodate these changes. On the other hand, several challenges appear when dealing connected vehicles due to the complex and dynamic characteristics of such system. Hence, it is essential to identify and validate possible challenges in connected vehicles architectures at early stages of development.**

***Index Terms*—Connected Vehicules, Architecture, Validation**

I. Introduction and Motivation

Intelligent transportation systems are based on providing smart and connected vehicles. Despite that vehicular communications is an emerging issue, it is clear that current IP-based networking technology cannot meet the demands of such application, in particular when the evolving applications of vehicular communications are considered, such as autonomous driving, smart vehicles, and smart road. Therefore, new networking paradigms and architectures are necessary. In addition, vehicular communications have several characteristic that make it unique, first it is requires mobiliary and must support dynamically partitioned topologies. Second, it is several network interfaces, including Wireless, dedicated short-range communications, cellular, and even satellite links. Finally, it must be prone to disruption, interfaces, and partitioning [1].

Connected vehicles play important role in modern intelligent transportation systems to provide method to collect data, communication between vehicles, and traffic monitoring and control. Vehicular networks have different characteristics from normal wired and wireless networks. In fact, they can be viewed as a network that is built on top of these, while having their own protocols, performance requirements, physical characteristics, and event traffic dynamics and shapes. For instance, in a connected vehicle solution, various types of connections must be handled in addition to vehicle-to-vehicle, such as vehicle-to-sensor, vehicle-to-Internet, and vehicle-to-road infrastructure. Despite these challenges, there are several possible chances to make use of these features for better performance in vehicular networks by, for instance, changing the role of conventional passive "host" into an active node, reducing unnecessary transmissions, networks reforms by resiliency to topology changes.

In this paper, we identify challenges that arise from design, implementation and applications of connected vehicle architecture, then we propose a formal verification [3] based approach to validate various aspects in their design and operation. Our approach is based on formalizing different levels of the connected vehicle reference implementation [2], and then providing a set of requirements as safety properties, and then using an underlying formal verification framework to validate these requirements.

II. Connected Vehicle Architecture

The connected vehicle reference implementation architecture is illustrated in Figure 1 [2]. The architecture provides the underlaying basis for identifying the key interfaces across the connected vehicle environment and the core system implementation. It is comprised of four layers: enterprise, functional, physical, and communications layer. The *enterprise* layer describes the relationships between organizations and the roles they play within the connected vehicle environment. This layer is depicted as a set of objects that interact to exchange information, and manage and operate system components. It also identifies the interactions between these objects and resources. In addition, roles determine the relationships between different objects and also between objects and resources.

The *functional* layer describes the abstract functional elements as processes along with their logical interactions as data flows in order to satisfy the system requirements. The functional layer also provides methods to control and manage system behaviors, such as monitoring operations, and the collection, transformation, generation, and processing of data. The *physical* layer describes systems and devices and their application objects as well as the interfaces between

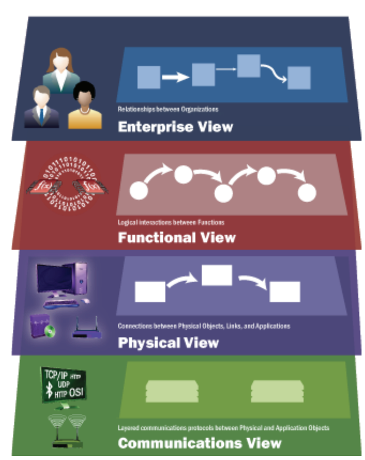

Fig. 1. Connected Vehicle Reference Implementation [2]

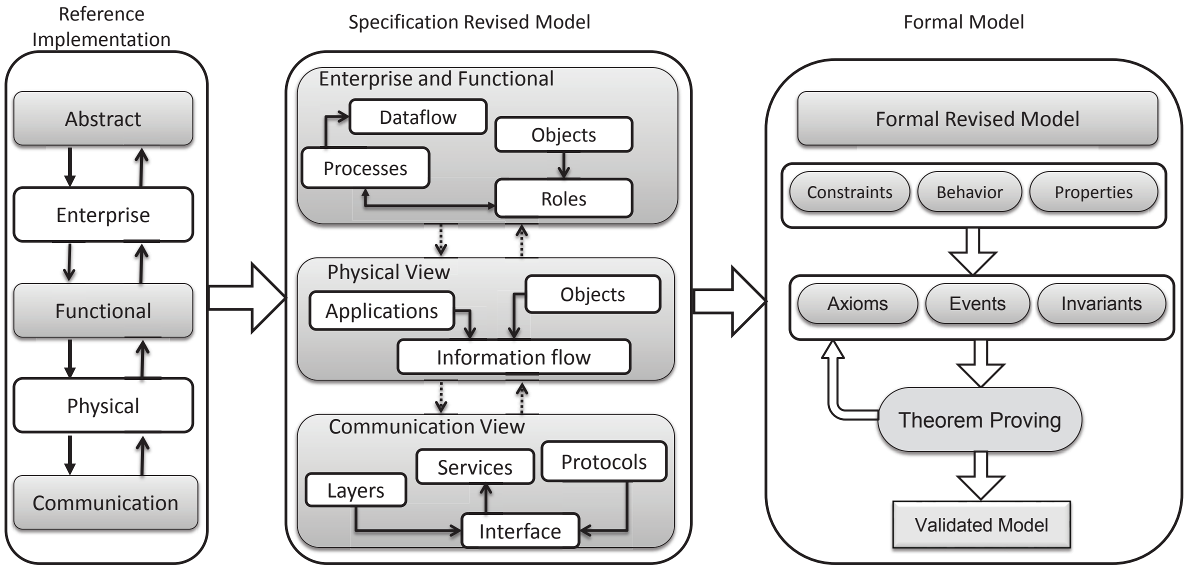

Fig. 2. Proposed Validation Methodology

those physical objects. In this layer, connected vehicles form, interact, and exchange information to provide services for applications. Finally, the *communications* layer describes the layered sets of communications protocols that are required to support communications among the physical objects that participate in the connected vehicle environment. The connected vehicles architecture communications model is specified using a seven layers model similar to the OSI reference model.

III. Challenges and Validation Method

The architecture model described above is currently being considered for implementation [4], therefore, it is essential to identify and validate several requirement about it. For this purpose, challenges in connected and smart vehicles need to be highlighted properly. First, cars need to be equipped with methods to connect to various available technologies, this may require partnerships between automotive and mobile industries. Second, connected vehicles must be prone to network partitioning, where network and traffic dynamics can change suddenly. Third, safety services must be considered with high priority, in particular, with self-driving cars are arriving soon. In addition, cars in near future will be equipped with automatic calling and localizing systems that automatically contacts emergency services and directs them to the vehicle location in emergency events. Finally, the new era of smart vehicles applications will have great impact on connected vehicles architectures, since there are several useful applications that can emerge from inter-vehicle communication, for instance, information sharing, collision detection, resolving lane changing problems, and cooperative road merging methods [5].

Given these challenges, it is essential to validate any proposed architecture for connected vehicles at early states of planning and development. Figure 2 illustrates the proposed methodology for modeling and validating such architecture including its four organization layers. First, the relation ships between layers, and also between different components and process within each layer must be clearly identified. Second, a formal model is developed for these layers, where constants and variables are used to define objects and their attributes, invariants are used to define roles and requirements to be validated, and finally events are used to define dataflow, processes, and applications, then a theorem proving framework, such as Event-B Rodin platform, can be used to validate the given invariants. Event-B [6] method can be used for this purpose.

IV. Conclusion

In this paper we defined challenges in the analysis of connected vehicles architecture. Then we proposed a method to model and validate the architecture based on formal verification, where several requirements need to be modeled and validated using the underlaying formal verification framework. We believe that validating new connected vehicles designs is necessary at early stages of development due to its heterogeneous and complex architecture in order to avoid problems in the proposed architecture, which will influence several applications that will be developed and put into practice based on the architecture. Next, we intend to provide an implementing for the proposed approach using formal methods.

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