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Citation for published version (APA):

DOI:
10.1109/ICSA-C.2018.00044

Document status and date:
Published: 13/08/2018

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher’s website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

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Download date: 05. Jul. 2024
Defining the C-ITS Reference Architecture*

*Industrial Experience Report

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Abstract—Cooperative-Intelligent Transport Systems (C-ITS) aims to facilitate cooperative, connected and automated mobility. The C-ITS domain comprises widely spread systems like traffic management systems, traffic light controllers, and vehicle on-board units. Such complex and heterogeneous systems have independent uses but demand a strategy to facilitate their convergence. C-ITS is currently demonstrated by projects such as C-MobILE, which is a large scale demonstration project spanning from 2017-2020.

One of the main objectives of C-MobILE is to define a reference architecture for large scale C-ITS deployment and demonstration at the partner deployment sites across Europe. The C-MobILE C-ITS reference architecture is defined using the C-ITS architecture framework that is compatible with the ISO/IEC/IEEE 42010 international standard for architecture descriptions of systems. C-MobILE C-ITS reference architecture captures the needs of deployment sites and provides a guidance for future projects. In this paper, we present the context and the functional view of the C-MobILE C-ITS reference architecture and share the lessons learned.

Keywords—C-ITS; ITS; Reference Architecture; Cooperative-Intelligent Transport System;

I. INTRODUCTION

The European Parliament in its directive 2010/40/EU defines Intelligent Transport Systems (ITS) as “systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport.” ITS can be further described as systems which aim to make transportation safe and economical by combining data from the vehicles and other sensors on the roadway together with weather information. It began during the 1990s [1] with projects in:

- the US named Intelligent Vehicle Highway System [2]
- various countries in Europe with the program Prometheus [3]
- Japan with a research committee Road/Automobile Communication System [4].

Cooperative-Intelligent Transport Systems (C-ITS) [5] adds upon ITS by providing ways for connected vehicles to interact with other connected vehicles or any infrastructure such as the traffic light controller, roadway signals or roadside units. This interaction is where the term cooperative comes from. In this scenario the vehicles can act as sensors as well. The C-ITS domain covers not only the field of software- and systems engineering, but also traffic engineering, civil engineering, and information technology, which require a unified architecture for the C-ITS domain.

C-MobILE (Accelerating C-ITS Mobility Innovation and deployment in Europe)\(^1\) is one of the projects that is currently advancing C-ITS by aiming for a fully safe and efficient road transport without casualties and serious injuries on European roads. The C-MobILE project is a large scale C-ITS deployment project running from 2017-2020. It involves eight C-ITS equipped deployment sites with more than 37 project partners. The C-ITS equipped deployment sites partnering with C-MobILE are:

- Newcastle, UK
- Bordeaux, France
- North Brabant, the Netherlands
- Vigo, Spain
- Bilbao, Spain
- Barcelona, Spain
- Thessaloniki, Greece
- Copenhagen, Denmark

There are 20 C-ITS services, such as Road Hazard Warning, Road Works Warning and Green Light Optimal Speed Advisory, that are considered for the C-MobILE project.

The architecture definition process in C-MobILE has been defined to support the following sub-goals:

- Analyze existing C-ITS architectures to provide common concepts and vocabulary.
- Create a reference architecture that enables pan-European deployment of C-ITS architecture based on the generalization of existing C-ITS architectures.

In this paper, we share the C-MobILE C-ITS reference architecture, which is part of the main results of the first six months of the project [6]. We focus on the descriptions for context and functional views as well as the lessons learned.

II. RELATED WORKS

Several projects have already been undertaken in the field of C-ITS. Among them, the following are C-ITS reference references:

\(^1\)C-MobILE: http://c-mobile-project.eu/
architecture projects that sought to develop a base for future C-ITS deployments.

1) Dutch C-ITS Reference Architecture (DITCM) [7]: This project focused mostly on developing a reference architecture for large scale C-ITS deployment in the Netherlands. It was built based on current and several finished C-ITS projects.

2) CONVERGE²: This was a German funded project that developed an open platform for service providers with focus on Vehicle to Vehicle or Infrastructure (V2X) systems network.

3) COMPASS4D³: This was an EU funded project that worked with three C-ITS services such as Road Hazard Warning, Red Light Violation Warning and Energy Efficiency Intersection Service.

4) NordicWay⁴: This project, as the name suggests, focused mostly on the Nordic countries (Finland, Sweden, Norway and Denmark) and is a pre-deployment pilot project for C-ITS deployment.

5) US-ITS (ARC-IT)⁵: The US-ITS (ARC-IT) project defined a reference architecture that act as building blocks for small scale regional C-ITS projects in various regions of the USA.

These reference architecture projects defined their own multidisciplinary approach towards their deployed strategy. The DITCM project used standard notations which considered for the Netherlands while the US-ITS project used their own notations. Projects such as NordicWay and Compass4D did not focus on many services, rendering these projects unsuitable for large scale deployment across Europe.

III. PROBLEM STATEMENT

As described in the related project section, the existing C-ITS projects had their own ad-hoc notations that create inconsistencies towards achieving the goal of developing a base for large scale C-ITS deployments. In addition, the partner deployment sites have their own C-ITS implementations with their own C-ITS architecture, ad-hoc notations and differing categorizations. Thus, there is no standard notation for use in a large scale deployment, to the best of our knowledge. This demands a standardized approach to consolidate and integrate existing architectures, addressing concerns such as security and maintainability. This is where the C-MobILE project comes in. It aims for a large scale demonstration across various deployment sites with an architecture that harmonizes existing architectures and technologies. It also plans to be a building block or the base for future C-ITS implementations in other cities or regions.

IV. METHODOLOGY

The term “Reference Architecture” has various meanings, multiple purposes and uses, varying levels of detail and abstraction, and very little common guidance. According to Cloutier et al. [8], “A Reference Architecture captures the essence of existing architectures, and the vision of future needs and evolution to provide guidance to assist in developing new system architectures.” For C-ITS reference architecture, our methodology is based upon this definition.

To develop a common and compatible C-MobILE C-ITS reference architecture, we analyzed existing C-ITS reference architectures and projects that included DITCM, CONVERGE, COMPASS4D, MOBiNET⁶, NordicWay, US-ITS (ARC-IT) and SCOOP@F [9]. Besides these C-ITS architectures, we considered ITS implementations of the deployment sites involved with C-MobILE.

For the definition of the C-MobILE C-ITS reference architecture, we used the C-ITS architecture framework which is defined in the scope of the C-MobILE project [6]. We extracted the systems, components, protocols, networks, and technology details from these architectures manually, as illustrated in Fig. 1. The C-ITS architecture framework is based on the ISO/IEC/IEEE 42010 [10] international standard for architecture descriptions of systems and software [11] and uses architecture viewpoints of the architecture framework for automotive systems [12]. To describe the C-MobILE C-ITS reference architecture, Systems Modeling Language (SysML) was used [13]. SysML is a general purpose modeling language for systems engineering, and consists of structure and behavior diagrams. Having a common architecture framework and modeling language enables the C-ITS organizations to guide their internal process as it reflects a common understanding of C-ITS. We used

²Converge. https://converge-online.de/
⁵Arc-it version 8.1. https://local.iteris.com/arc-it/
⁶MOBiNET. http://www.mobinet.eu/
Enterprise Architect as the tool for developing the structure diagrams.

V. C-MoBI LE C-ITS REFERENCE ARCHITECTURE

The C-MoBiLE C-ITS Reference Architecture describes various systems at a high level in the form of models using SysML structural diagrams, providing high level information to architects and other stakeholders. As a result of the architecture analysis, we have extracted the C-MoBiLE C-ITS reference architecture from various existing architectures, which is consistent with the DITCM reference architecture [7]. As an illustration of the C-MoBiLE C-ITS reference architecture, we discuss here the context and functional views by displaying the context model in Fig. 2 and the functional model in Fig. 3. The system structure is captured by categorizing into systems such as Central, Roadside, Vehicle and Traveler/VRU System with a Support System that supports all the other systems (Fig. 2). Here, VRU means Vulnerable Road Users, such as pedestrians and cyclists. These systems are further decomposed into subsystems such as Traffic Management System (TMS) for the Central System (Fig. 3).

The context viewpoint describes the relationships, dependencies, and interactions between the system and its environment [11]. The context view (Fig. 2) conforms to the context viewpoint and helps systems stakeholders understand the system context [6].

The systems in terms of the context model is as below:
- Support System: Comprises of sub-systems performing various tasks, such as governance, test and certification management, security and credentials management.
- Central System: Comprises of sub-systems to support connected vehicles, field and mobile devices.
- Roadside System: Comprises of sub-systems which covers the ITS infrastructure on or along physical road infrastructure such as roadside units, signal/lane control.
- Vehicle System: Comprises of sub-systems which are integrated within a vehicle such as an on-board systems.
- Traveler/VRU System: Comprises of both personal devices such as smart phones and navigations devices.

A functional viewpoint in the abstract level describes the system’s runtime functional elements and primary interactions [11]. The functional view (Fig. 3) conforms to the functional viewpoint, helps the system’s stakeholders understand the system structure, and has an impact on the system’s quality properties. As discussed previously, the systems were further decomposed into subsystems. The subsystems are depicted in the Functional model in Fig. 3 as functional elements with primary interaction with other subsystems.

The subsystems for the Central System are:
- Traffic Management System (TMS): A functional back-office system of the responsible road operator to enforce legal actions on road sections or intersections.
- SP/DP/TIS BO: Generic Back-Office systems for Service and Data Providers that collects and fuses data from service providers, vehicles and infrastructure.
- Service Provider Exchange System (SPES): An e-Market system for discovery of C-ITS services and C-ITS communication services.
- Communication Data Provider: A generic back-office system of a communication provider used for communication from between other BO systems and road users.

The subsystems for the Roadside System are:
- Roadside: Different types of existing systems such as a Traffic Light controller or substations.
- Roadside Unit: A cooperative roadside communication system responsible for two-way communication functionality at a part of a road network.

Figure 2. Context Model Representation of the C-MoBiLE C-ITS Reference Architecture [6].

Figure 3. Functional Model Representation of the C-MoBiLE C-ITS Reference Architecture.
The subsystems for the Vehicle System are:
- On Board Unit (OBU): A sub-system attached to a car needed for informing/advising the driver.
- Remote Vehicle On Board Unit: An OBU of the other vehicle that is communicating with the host vehicle.
- Vehicle Electrical & Electronic System: The parts of the vehicle such as in-car light sensors, speed sensors and actuators.

The subsystems for the Traveler/VRU System are:
- Personal Information Devices (PID): Typically a smart phone or navigation devices used by an end-user.
- Vulnerable Road Users On Board Unit: An OBU attached to a VRU vehicle like bicycle or moped needed for advising the cyclists or the moped drivers.

VI. LESSONS LEARNED

As described previously, there are various existing projects being deployed at the C-MobILE partner deployment sites. To consolidate these and come up with a C-MobILE C-ITS reference architecture in a inter-disciplinary team was a challenge. During the process of defining the C-MobILE C-ITS reference architecture, we learned the following lessons:

- We analyzed the existing projects and abstracted the commonalities. We defined and discussed the common vocabulary for the project and agreed upon the terms and definitions used for the architecture description.
- Since there was no standardized architecture framework in any of the existing projects, we defined the architecture framework conforming to the ISO/IEC/IEEE 42010 [10] standard. This helped us in defining the views and viewpoints that satisfies the concerns of stakeholders participating in the C-MobILE project.
- We reused existing standards for the definition of the C-MobILE C-ITS reference architecture.
- We used SysML to describe the architecture as it is a mature language that is known to majority of system architects. It is supported by many mature tools such as Enterprise Architect, which was beneficial in designing the architecture diagrams.
- We had weekly architecture team meetings comprising of architecture expertise from the C-MobILE partner deployment sites and other C-ITS projects that helped us in aligning the knowledge and concepts required to structure the C-MobILE C-ITS reference architecture.

VII. CONCLUSION

In this paper, we present the C-MobILE C-ITS reference architecture that was defined after analyzing the existing C-ITS reference architectures and the partner deployment site architectures. The different architectures from the partner deployment sites are used as an input for defining a single homogeneous reference architecture in line with current standards. This reference architecture covers and satisfies each of the selected C-ITS services and can be used at the partner deployment sites. This reference architecture can also form a base for future C-ITS deployments and implementations at other cities or regions. We also share the lessons learned during the architecture definition process.

ACKNOWLEDGMENT

The C-MobILE project is funded by the European Union’s “Horizon 2020 research and innovation programme” under grant agreement No 723311.

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