

# Defining C-ITS Reference Architecture\*

\*Industrial Experience Report

Priyanka Karkhanis, Mark van den Brand, Saurab Rajkarnikar

Eindhoven University of Technology

Eindhoven, The Netherlands

Email: p.d.karkhanis@tue.nl, M.G.J.v.d.Brand@tue.nl, s.rajkarnikar@tue.nl

**Abstract**—C-ITS (Cooperative Intelligent Transport Systems) is an initiative to facilitate cooperative, connected and automated mobility. It is based on the concept of System of Systems and promotes a new way of thinking for solving grand challenges where the interactions of technology, policy and economics are the primary drivers.

The C-ITS domain comprises widely spread systems like traffic management systems, traffic light controllers, or vehicle on-board units. Such complex and heterogeneous systems have independent uses but demand a strategy to facilitate their convergence.

The main objective of C-ITS is to define an integrated architecture based on a number of existing C-ITS projects. The architecture provides a way to standardize and a unifying modeling approach by means of a common language that can be reused by other organizations to guide their internal development processes. The architecture and its concepts are based on the conceptual model of the ISO/IEC/IEEE 42010 [5] international standard for architecture descriptions of systems, System of Systems and software. It defines architecture viewpoints for C-ITS systems and uses the concept of architecture perspectives for shaping these architecture viewpoints. In this paper we present the methodology used for defining the C-Mobile reference architecture. We demonstrate this by means of the C-Mobile reference architecture, which allows large scale demonstrations of integrations of C-ITS systems across Europe.

**Index Terms**—C-ITS, ITS, architecture framework, transportation

## I. INTRODUCTION

The European Parliament in its directive 2010/40/EU [1] 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 [9] with projects in

- the US (named Intelligent Vehicle Highway System [10])
- various countries in Europe (with the program Prometheus [11])
- Japan (with a research committee Road/Automobile Communication System [12])

Cooperative Intelligent Transport Systems (C-ITS) [8] 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 cooperatives 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.

It aims to make road transport safe and efficient while decreasing casualties and serious injuries on European roads.

The C-Mobile project (Accelerating C-ITS Mobility Innovation and deployment in Europe) is an EU project that spans across eight C-ITS equipped deployment sites and regions with more than 37 participating institutes and companies.



Fig. 1. The C-ITS equipped deployment sites partnering with C-Mobile. 1. Newcastle, UK, 2. Eindhoven and Helmond (North Brabant), The Netherlands, 3. Bordeaux, France, 4. Vigo, Spain, 5. Bilbao, Spain, 6. Barcelona, Spain, 7. Region of Central Macedonia, Greece and 8. Copenhagen, Denmark

The eight C-ITS equipped deployment sites already have C-ITS services through various projects that took place in the past. However, many of these are not compatible with each other. C-Mobile plans to become a common approach

that ensures compatibility and become a basis for large scale deployment in Europe. It is working with various public and private stakeholders while carrying out and developing cost effective business models particularly from the end user's perspective.

To help reach the project goals, an architecture capable of being deployed to the whole of Europe is needed. The architecture definition process in C-MoBiLE has been defined to support the following sub-goals.

- Analyse existing C-ITS architectures to provide common concepts and vocabulary.
- Identify a set of patterns that have been detected (or applied implicitly) during the analysis of existing C-ITS architectures and their implementations.
- Create a C-ITS reference architecture that enables pan-European interoperability of C-ITS (concrete/implementation) architectures based on the generalization of existing C-ITS architectures.
- Define an implementation architecture specifying components and their relationships (interfaces) guided and constrained by the C-ITS reference architecture.
- Identify service-relevant parts of the architecture and define services based on the business analysis.

## II. RELATED WORKS

There are various C-ITS projects under development with several already completed and deployed successfully. Of those projects, the following were similar C-ITS reference architecture projects.

- 1) Dutch C-ITS Reference Architecture (DITCM) [3] [4]: This project focused mostly in developing a reference architecture for large scale C-ITS deployment in the Netherlands. It was build based on current and some finished C-ITS projects.
- 2) CONVERGE<sup>1</sup>: This was a German funded project that developed an open platform for service providers with focus on Car2X (V2X or Vehicle to Vehicle/Infrastructure) Systems Network.
- 3) COMPASS4D<sup>2</sup>: 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) NordicWay<sup>3</sup>: 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. This is one of the first projects that utilizes cellular networks for communication.

## 5) US-ITS (ARC-IT)<sup>4</sup>:

The US-ITS or ARC-IT project is a large scale reference architecture that acts as building blocks for small scale regional C-ITS projects in various regions of the USA.

## III. PROBLEM STATEMENT

The reference architecture projects sought to develop a base for future C-ITS deployments. However, these approaches eventually led to various architectures that defined their own multidisciplinary approach toward their deployed strategy. They provided standard notations to help in merging these architectures which turned out to be regional. For example, the Dutch C-ITS Reference Architecture used standard protocols but only relating to the Netherlands and CONVERGE only related to Germany while the US-ITS used their own protocols. NordicWay and Compass4D used a standard protocol, however, they did not focus on many services thus rendering those project unsuitable for rest of Europe.

In addition, the partner deployment sites (1) have their own C-ITS implementations with their own C-ITS architecture, ad-hoc notations and differing categorizations.

Thus, there doesn't seem to be a standard notation for use in a large scale deployment. 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 technologies without changing the existing architectures. It also plans to be a building block or the base for future C-ITS implementations in other cities or regions.

## IV. METHODOLOGY

To develop a common and compatible reference architecture, the following C-ITS projects were taken into consideration: (i) The Dutch C-ITS Reference Architecture (DITCM) [3] [4], (ii) CONVERGE<sup>1</sup>, (iii) COMPASS4D<sup>2</sup>, (iv) MOBiNET<sup>5</sup>, (v) NordicWay<sup>3</sup>, (vi) SCOOP@F<sup>6</sup> and (vii) US-ITS (ARC-IT)<sup>4</sup>.

Besides these C-ITS architectures, we considered ITS implementations of the deployed sites involved with C-MoBiLE. We applied a reverse architect approach by extracting the systems, protocols, networks, and technology details from these architectures manually (Fig.: 2).

To define the reference architecture Systems Modeling Language or SysML was proposed. SysML is a general purpose modeling language for engineering systems, and consist of structure diagrams, requirement diagrams and behavior diagrams. The architecture framework and a unified modelling approach can enable common language and will be reused for the next deployment projects. Furthermore, organizations can use the architecture to guide their internal development

<sup>1</sup>Converge. <https://converge-online.de/>

<sup>2</sup>Compass4d. <http://ertico.com/projects/compass4d/>.

<sup>3</sup>Nordicway.<http://vejdirektoratet.dk/EN/roadsector/Nordicway/Pages/Default.aspx>.

<sup>4</sup>Arc-it version 8.1. <https://local.iteris.com/arc-it/>

<sup>5</sup>MOBiNET. <http://www.mobinet.eu/>

<sup>6</sup>SCOOP@F. <https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport/projects-by-country/multi-country/2014-eu-ta-0669-s>

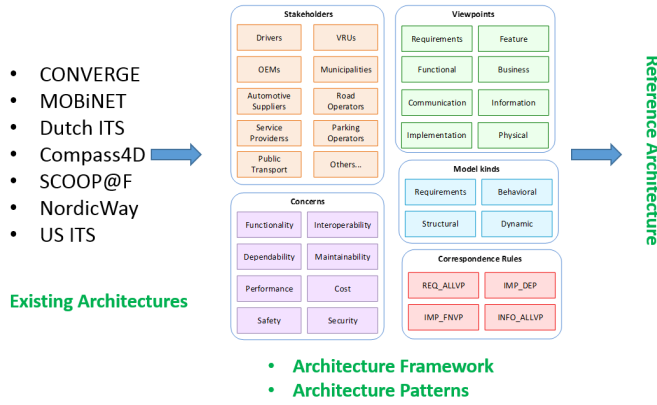


Fig. 2. Developing a reference architecture for C-ITS by extracting and reverse engineering of existing architectures

process as it reflects a common understanding of how the ITS landscape will evolve.

More info on methodology in *Todo: give name of paper*.

## V. C-MOBILE REFERENCE ARCHITECTURE

The C-Mobile Reference Architecture focuses on an abstract level and uses a black box approach wherever possible. It describes various systems at a high level in the form of models using SysML Block Definition Diagrams (BDD) and Internal Block Diagrams (IBD), providing base level information to architects. These block diagrams capture architecture viewpoints defined for C-Mobile. The C-Mobile project neither has the resources nor the intention to redefine all those standards. Instead, at high level we highlight the common systems, their interfaces and protocols by considering various existing projects to ensure interoperability.

As a result of the architecture analysis and reverse architecting process, we have extracted the reference architecture from various existing architectures, which was consistent with the DITCM reference architecture [3] [4]. The structure of a system is captured in functional structure models using BDDs by categorizing into systems and decomposing a system into subsystems. A system defines the functionality and functional data flow interfaces between systems that are required to support a particular ITS application. A functional model digram is shown in Figure ?? for the capturing functional viewpoint.

A functional viewpoint describes the system's runtime functional elements, their responsibilities, interfaces, and primary interactions. The functional view conforms to the functional viewpoint, helps the system's stakeholders understand the system structure, and has an impact on the system's quality properties. The system structure is captured in functional models using BDDs and by categorizing into systems and decomposing a system into subsystems. *Todo: This is the same sentence as in the last paragraph* A system defines the functionality and functional data flow interfaces between systems that are required to support a particular ITS application.

Information flows depict the exchange of information between subsystems.

## VI. CONCLUSIONS AND FURTHER WORK

In this paper we present the methodology used for defining the C-Mobile reference architecture. In the C-Mobile project we have analysed existing C-ITS architectures, especially CONVERGE, MOBINET, and Dutch C-ITS Reference Architecture, to define common concepts and vocabulary for the C-Mobile reference, concrete, and implementation architectures. We used the different architectures from the pilot sites as an input for defining a single homogeneous reference architecture, which will be further refined. We employed a reverse architect approach for manually extracting components, systems, and technological details. The next step is to automate this approach, with the intention to provide benefits for system architects and stakeholders.

## ACKNOWLEDGMENTS

The C-Mobile project is funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 723311.

## REFERENCES

- [1] European Commission. Directive 2010/40/eu of the european parliament and of the council.
- [2] European Commission. Intelligent transport systems. [https://ec.europa.eu/transport/themes/its/c-its\\_en](https://ec.europa.eu/transport/themes/its/c-its_en).
- [3] Marcel van Sambeek, Frank Ophelders, Tjerk Bijlsmaand Borgert van der Kluit, Oktay Turetken, Rik Eshuis, Kostas Traganos, and Paul Grefen. Towards an architecture for cooperative-intelligent transport system (c-its) applications in the netherlands. Available at [https://www.researchgate.net/publication/313580768\\_Towards\\_an\\_Architecture\\_for\\_Cooperative-Intelligent\\_Transport\\_System\\_C-ITS\\_Applications\\_in\\_the\\_Netherlands](https://www.researchgate.net/publication/313580768_Towards_an_Architecture_for_Cooperative-Intelligent_Transport_System_C-ITS_Applications_in_the_Netherlands).
- [4] Dr Igor Passchier, Dr Ir Marcel van sambeek, Ir Joelle van den Broek and Drs Ir Paul Potters. The Dutch C-ITS Reference architecture. Paper number EU-TP0105. 11th ITS European Congress, Glasgow, Scotland, 6-9 June 2016.
- [5] ISO/IEC/IEEE Systems and software engineering – Architecture description,” in ISO/IEC/IEEE 42010:2011(E) (Revision of ISO/IEC 42010:2007 and IEEE Std 1471-2000) , vol., no., pp.1-46, Dec. 1 2011 doi: 10.1109/IEEESTD.2011.6129467
- [6] Emery, D., and Rich H. Every architecture description needs a framework: Expressing architecture frameworks using ISO/IEC 42010. Software Architecture, 2009 & European Conference on Software Architecture. WICSA/ECSA 2009. Joint Working IEEE/IFIP Conference on. IEEE, 2009.
- [7] Raul Ferrandez, Yanja Dajsuren, Priyanka Karkhanis, Manuel Fn-frocken, Marcos Pillado. C-Mobile C-ITS Reference Architecture. ITS World Congress 2018 (unpublished).
- [8] A. Festag, "Cooperative intelligent transport systems standards in europe," in IEEE Communications Magazine, vol. 52, no. 12, pp. 166-172, December 2014. doi: 10.1109/MCOM.2014.6979970
- [9] A. Luis Osrio, Hamideh Afsarmanesh, and Luis M. Camarinha-Matos. Towards a reference architecture for a collaborative intelligent transport system infrastructure. In Luis M. Camarinha-Matos, Xavier Boucher, and Hamideh Afsarmanesh, editors, Collaborative Networks for a Sustainable World, pages 469477, Berlin, Heidelberg, 2010. Springer Berlin Heidelberg.
- [10] P.D. Heermann and D.L. Caskey. Intelligent vehicle highway system: Advanced public transportation systems. Mathematical and Computer Modelling, 22(4):445–453, 1995.
- [11] M. Williams. Prometheus-the european research programme for optimising the road transport system in europe. In IEE Colloquium on Driver Information, pages 1/11/9, Dec 1988.

- [12] K. Takada, Y. Tanaka, A. Igarashi, and D. Fujita. Road/automobile communication system (racs) and its economic effect. In Vehicle Navigation and Information Systems Conference, 1989. Conference Record, pages A15A21, Sept 1989.