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Roadside and Cloud Architecture for C-ITS Services

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Abstract

This paper presents a roadside and cloud architecture for the provision of C-ITS services based on the support provided by the road infrastructure. The proposed architecture was developed in the scope of Portuguese C-Roads project with the main goal of managing the V2X communications units and network message flows of motorway operators. ETSI ITS-G5 RSUs are deployed with a cellular link connection for remote control and configuration. They are connected to a cloud MQTT broker based on a geographical tiling scheme, which allows the selection of the appropriate coverage areas to disseminate C-ITS messages. This infrastructure is being deployed in the field, spread by different motorways in Portugal. Centrally, everything is managed and monitored through a C-ITS platform that also offers traffic visualization and event reporting. Furthermore, the devised architecture is independent of the underlying communications technology, so it can be adapted to support other existing and future technologies.

Keywords:

Roadside infrastructure, Vehicular communications, C-ITS, ITS-G5

Introduction

The deployment of C-ITS infrastructure is taking place all around the world with the main goals of maximizing traffic safety, improving travel experience and minimizing environmental damage. One of the fundamental technologies for the provision of advanced C-ITS services is V2X communications, which guarantees the exchange of information among different road users (vehicles, cyclists and pedestrians) but also between them and the roadside infrastructure and cloud services. There are several competing technologies for the deployment of V2X networks. ETSI ITS-G5 and C-V2X (including both Uu and PC5 interfaces) are the most prominent ones.

On the roadside infrastructure, communications units (RSUs) play a key role in the development of V2X applications providing the link between road users and the infrastructure. Additional sensors and processing devices also play an important role as they can provide increased perception of the overall traffic system. For instance, extra information made available by traffic radars, lidar sensors and cameras (and the associated AI processing) is essential for the support of safety services in the most critical areas of the roads, such as lane merging scenarios, intersections and blackspots.

While RSUs and other roadside systems provide a link for road operators, it’s the C-ITS management platforms that are their main tool to monitor and visualize all traffic events and statistics that happen on the roads under their control. In these motorways, enabled with V2X communications, the central C-ITS management platform, also called the C-ITS station (C-ITS-S), can receive information about the position and dynamics of all connected vehicles inside the coverage areas of the communications units, as well as events reported automatically by future autonomous vehicles or manually by drivers of legacy cars (e.g. through a vehicle HMI). Conversely, the road manager is also able to send specific warnings generated in the C-ITS platform, for example, in case of road works or other operator interventions.

This paper presents the roadside and cloud infrastructure deployment for the provision of C-ITS services in a 1106 km motorway network managed by Brisa in Portugal, in the context of the European C-Roads initiative [1]. After this introductory section, a description of the related work in the area is provided. Then, the roadside infrastructure and cloud architecture is presented, as well as the deployment scenario where the equipment was effectively installed. Lastly, the conclusions and future work are discussed in the final section.

Related Work

Wireless vehicular communications are being used in the development of C-ITS infrastructure and traffic management systems under the scope of several research projects and public-private initiatives. Some examples in Europe are SCOOP@F [2], InterCor [3], CONCORDA [4], NordicWay [5], C-MobILE [6], among many others. These deployments include the installation of roadside units (RSUs) for direct V2X communications with vehicles on the road and the associated backhauling network interconnection, in some cases serving cross-border scenarios spanning multiple countries. For instance, the InterCor project handles the interconnection and interoperability issues of several C-ITS corridors in Europe, linking roads in the Netherlands, France, Belgium and the UK. For that purpose, a communications network architecture is defined, mainly based on ETSI ITS-G5 technology for the interface between vehicle and roadside systems and an additional interface to exchange information between back-office systems [7].

In some pilots, such as the PASMO project [8], a myriad of road sensors is deployed, including e.g. traffic radars, IP cameras, parking sensors, weather stations, etc., whose operation depend on different protocols. In such scenario, a different architecture with a cloud software platform based on the machine-to-machine (M2M) paradigm is necessary, in order to handle all these heterogeneous devices (both sensors and communications units) through various communications protocols (e.g. HTTP, MQTT, CoAP, AMQP). Additionally, these systems have also to deal with a variety of communications technologies for data collection and information exchange (ITS-G5, LTE, LoRa, radio links, fiber optics), posing even more challenges for the integration of all the components.

Scalable cloud solutions are required to manage the enormous and heterogeneous amount of data generated by road traffic systems, including standard ETSI C-ITS messages, such as CAMs, DENMs, IVIMs, SPaTEMs, CPMs, etc., but also other types of information like Local Dynamic Maps (LDMs), HD-Maps, sensor raw data, video streams, among many others. Geocasting facilities, as the ones adopted in C-MobILE project [9], ease the task of interconnecting all road agents, from vehicles to the service providers and traffic management centres (central C-ITS stations).

This infrastructure, ranging from the roadside sensors and communications units to the cloud C-ITS components, enables the development of connected and automated vehicles (CAVs), which can rely on additional sources of data for extending their fields of view and having more detailed information about their surrounding environment. As a result, more informed decisions can be taken by the CAVs, or even shift some of those decisions to the roadside or cloud infrastructure, therefore optimizing traffic speed and safety features. An example of such deployment is the AUTOPILOT project, where the IoT ecosystem is exploited to integrate connected cars and transform them in automated moving objects, making use of interoperable M2M platforms to interconnect all traffic system components [10].

More recently, other communications technologies have been tested to provide C-ITS services, even under challenging conditions such as cross-border areas [11]. The next generation of mobile networks (5G) promises to leverage these CCAM applications, by offering large bandwidths, low end-to-end latencies and high levels of reliability and availability. For this reason, it is important to design and develop a roadside and cloud architecture that is independent of the underlying communications technologies used to exchange information among the different traffic agents.

Roadside and Cloud Architecture

In the context of C-Roads project in Portugal [12], a roadside and cloud architecture (figure 1) was devised for the deployment of C-ITS services along some of the motorways in the country. The main goal of this architecture is to support road safety use cases in infrastructure-assisted vehicular networks.

The roadside infrastructure includes ITS-G5 roadside units (RSUs) connected to the backhauling network, either through fiber optics or via cellular networks (3G/4G). In the future, this infrastructure can be expanded with additional road sensors attached to the RSUs, such as traffic radars and IP cameras, in order to provide extra information to the C-ITS framework, e.g. regarding the presence and dynamics of legacy (i.e. non-connected) vehicles or vulnerable road users (VRUs) on the road.

All RSUs exchange information through a MQTT Broker located in the cloud, which allows the interconnection with the central C-ITS Platform (MOBICS - Mobility Intelligent Cooperative Systems) [13]. This platform enables the management of all data exchanged between C-ITS devices, existing road infrastructure and traffic management solutions of the road operator. For instance, it allows the constant monitoring of all road activity and enables a human operator to signal a traffic event (e.g. road works) in a specific map location, triggering an action from the platform, which will automatically generate the corresponding C-ITS message (DENM). Subsequently, this message will be forwarded to the relevant geographical area under the coverage of the nearby RSUs.

Moreover, the C-ITS Platform is continuously connected to both the National Access Point, for the exchange of high-level data in DATEX-II format, and the Portuguese Public Key Infrastructure (PKI), for the implementation of the security mechanisms specified in ETSI standards. This PKI interconnection allows certificate and credentials handling, between the Root Certificate Authority, Enrolment Authority and Authorization Authority in the PKI and the RSUs and the OBUs on the road.

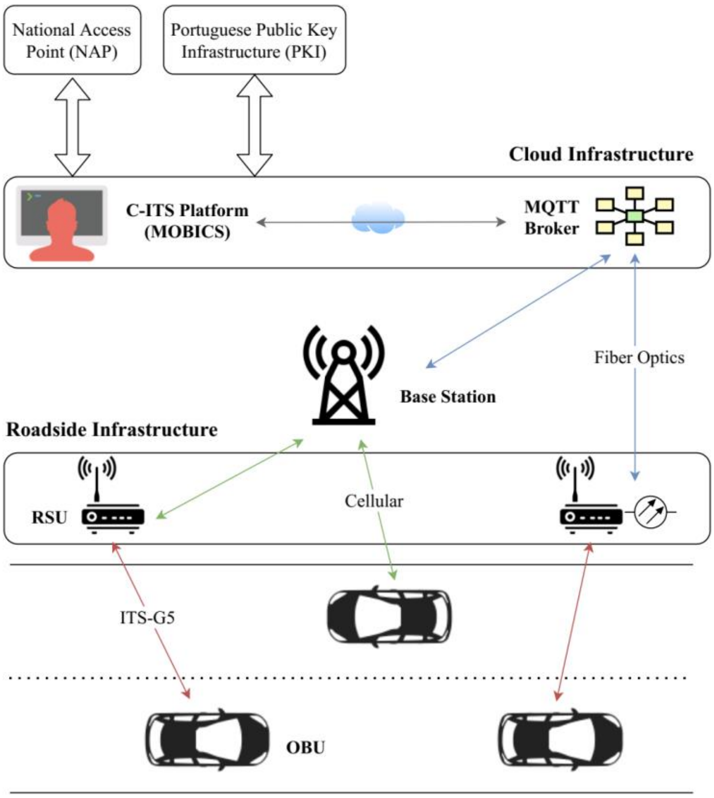

Figure 1 – Roadside and Cloud Architecture.

Roadside Infrastructure

The roadside equipment (figure 2) was developed in a partnership between A-to-Be and Instituto de Telecomunicações, being composed of an embedded PC and an ITS-G5 board of the VERA V2X series from u-blox. It also includes an LTE module for cellular communications and a GNSS receiver for positioning and time synchronization.

Figure 2 – Roadside Equipment (ITS-G5 unit on the left and enclosing cabinet on the right).

The current software implementation of the RSU platforms is characterized by a multi-layered OSI-like architecture. This architecture is based on the ETSI ITS-G5 protocol stack for vehicular communications. Both the layers' organization and the interface definition follow the structure proposed in the standards. Each layer is associated with a running service where inter-process communications are made through the ZeroMQ networking library. Five vertical services plus a parallel service compose the architecture (figure 3).

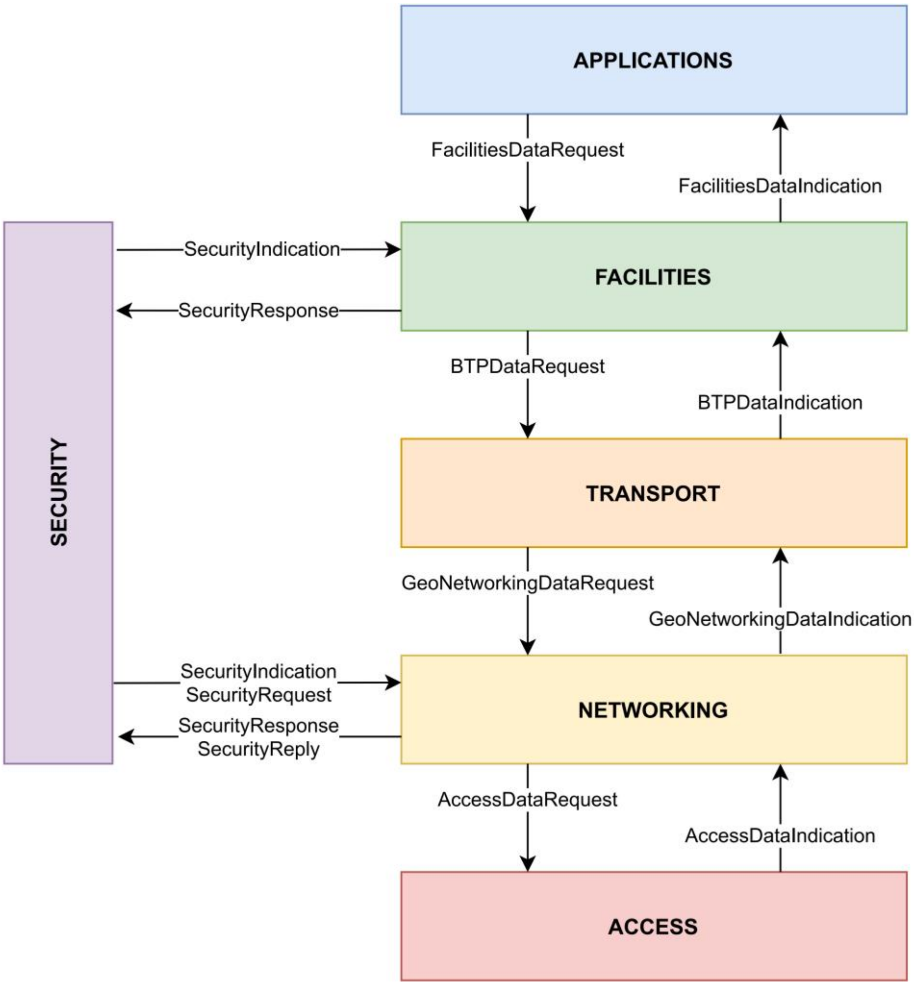

Figure 3 – ITS-Station (ITS-S) implemented service architecture.

- The **access** service is responsible for the lowest OSI layer in our architecture, managing the access technologies and decapping and encapping the packets' Ethernet protocol headers, namely the Media Access Control (MAC) and Logical Link Control (LLC) headers;
- The **networking** service mainly implements the GeoNetworking protocol, a geographical addressing and packet forwarding system for point-to-point and point-to-multipoint communications. It's responsible for decapping and encapping a packet's GeoNetworking header;

- The **transport** service mainly implements the Basic Transport Protocol (BTP), a transport layer protocol in the same vein as TCP or UDP. BTP provides port numbers to address upper layer services. The transport service is responsible for processing a packet's BTP header.
- The **facilities** service, composed by several sub-services, provides support to various ITS-G5 standard defined applications. It currently provides support for the processing of Cooperative Awareness Messages (CAMs) through the Cooperative Awareness (CA) basic service, Decentralized Environmental Notification Messages (DENMs) through the Decentralized Environmental Notification (DEN) basic service, and Infrastructure to Vehicle Information Messages (IVIM) through the V2I oriented Infrastructure to Vehicle (IVI) basic service;
- The **security** service is aimed at providing packet authenticity and management of trust. It's responsible for verifying and processing a packet's GeoNetworking Secured Header and for the triggering of local identity changes across layers for privacy purposes;
- The **applications** service, a standard agnostic implementation aimed at providing support for specific applications and interactions with the ITS-S. In practice, and in the context of C-ROADS project, this service establishes the interconnection with the cloud C-ITS platform (through the MQTT broker) for ITS message forwarding and system monitoring.

In the inter-process communications done through ZeroMQ, service data units (SDUs) are exchanged between services. The format of these SDUs follow defined structures using the Abstract Syntax Notation One (ASN.1) description language, which aims at providing future service interoperability and ease code development, due to ASN.1 modularity and readability features.

Cloud Infrastructure

Other than an available SSH connection used for RSU setup or any other sporadic connection, a persistent MQTT-based approach using the Mosquitto library is used as a communication bridge between the RSU (running a MQTT client) and the cloud system (where the MQTT broker is running). ITS messages received by the RSU through ITS-G5 are forwarded to the central C-ITS platform (MOBICS) through MQTT. ITS messages, like manually triggered DENMs and IVIMs, can also be injected into the ITS-G5 environment by specific RSUs chosen using a MQTT geographical-based topic system to which the C-ITS platform publishes to. The used topic system obeys the following naming structure:

its_center/[QUEUE-TYPE]/[MESSAGE-FORMAT]/[STATION-ID]/[ITS-MESSAGE-TYPE]/[LOCATION-QUADTREE]

where "QUEUE-TYPE" is the message destination (*inqueue* for messages published by the RSUs or *outqueue* for messages published by MOBICS), "MESSAGE-FORMAT" is the message encoding type (e.g. binary or XML), "STATION-ID" is the ITS-S identifier number, "ITS-MESSAGE-TYPE" is the type of ITS message (e.g. CAM, DENM or IVIM), and "LOCATION-QUADTREE" is the current location of the RSU following a quadtree map system representation. For example, an RSU stationed at (+40.6341589, -8.6599125) (World Geodetic System 84) with a station ID equal to 23, that would receive a UPER DENM from the ITS-G5 environment could encode it as XML (currently, the only message format used in the implemented MQTT system) and would publish it under the topic:

its_center/inqueue/xml/23/DENM/0/3/3/1/1/0/0/1/1/3/0/3/0/1

In this case, the system uses a quadtree of zoom level 14. RSUs are also subscribed to various topics which the MOBICS platform can use to disseminate messages. An RSU is subscribed to the ***outqueue*** instead of the ***inqueue***, to the station ID 1 (used as the identifier for the MOBICS platform), to all C-ITS messages types and to all quadtree zoom levels from zero to 14 (as it was our predefined option). For example, using the RSU characteristics of the previous example, it would subscribe to:

its_center/outqueue/xml/1/+
its_center/outqueue/xml/1/+/0
its_center/outqueue/xml/1/+/0/3
…
its_center/outqueue/xml/1/+/0/3/3/1/1/0/0/1/1/3/0/3
its_center/outqueue/xml/1/+/0/3/3/1/1/0/0/1/1/3/0/3/0
its_center/outqueue/xml/1/+/0/3/3/1/1/0/0/1/1/3/0/3/0/1

Furthermore, the RSU also subscribes to all messages directed to its specific station ID:

its_center/outqueue/xml/23/#

Following this schema, MOBICS can choose to publish messages affecting one or several regions by using a combination of topics with different quadtrees and zoom levels and can also choose to publish messages to specific RSUs.

The RSU also implements a type of heartbeat mechanism by which its current operating status is periodically published to the MQTT broker. These heartbeat messages include summarized information, such as current CPU and memory usage, current IP address and active C-ITS events under its coverage area.

On the C-ITS platform side (MOBICS), all the messages from the ITS-G5 environment, either periodic (e.g. CAMs) or event-driven (e.g. DENMs and IVIMs) can be visualized in a dashboard, as well as the current state of each one of the RSUs on the field (figure 4). MOBICS also allows the generation of road traffic events in a user-friendly manner through the graphical interface. This way, it is possible to monitor all road activity and control the dissemination of warnings whenever needed.

In summary, this central C-ITS platform works as a traditional Traffic Management System but enabled with V2X features for communication with road devices (RSUs and OBUs) and possibly advanced road sensors to be installed in the future (e.g. traffic radars and cameras). It allows a traffic management operator to check RSU status, setting rules for the automatic generation of events or manually creating them, and filtering out received messages.

MOBICS adopts an open architecture that makes the cooperation with other central systems possible which can lead to a higher degree of automation or with an access point (e.g. NAP) for the exchange of information e.g. regarding traffic events. At present, the platform can interpret CAM, DENM and IVIM messages received or sent to the MQTT broker.

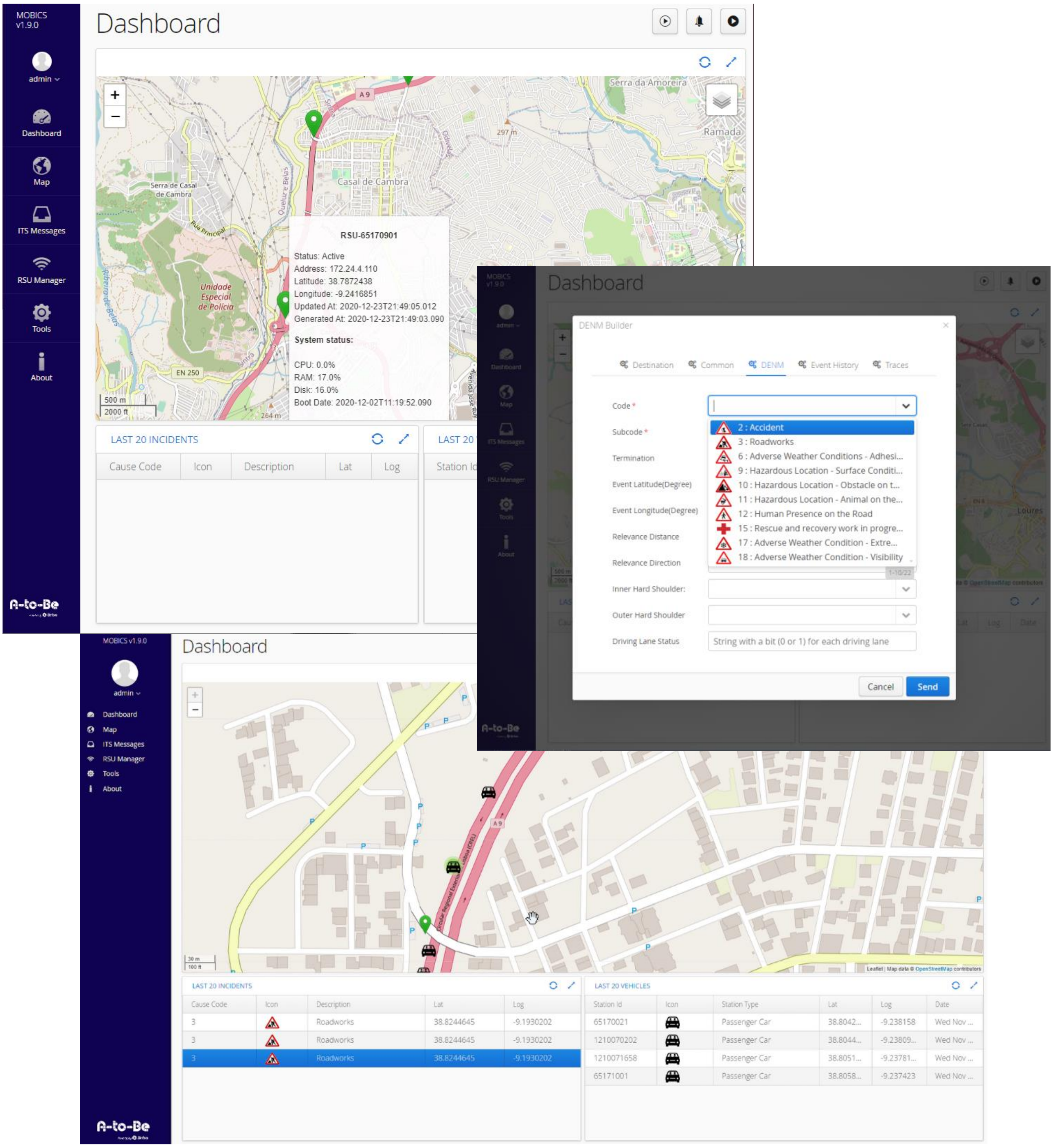

Figure 4 – MOBICS dashboard interface.

Deployment Scenario

This C-ITS infrastructure is being deployed along several motorways in Portugal, covering the region around the Portuguese capital (Lisbon) and some areas close to the borders with Spain, in order to also test cross-border interoperability aspects. The location of the RSUs already installed or planned for installation by A-to-Be (32 in total) are depicted in figure 5 (as blue pins), as well the corridors covered by the Portuguese C-Roads project (in blue lines). The other corridors are also being deployed by other projects partners who manage the different highways in the country.

Figure 5 – Deployment scenario of the C-ITS infrastructure.

The project will test "Day 1" and "Day 1.5" services over a length of 460 km of roads focusing mostly on I2V pilot use cases, namely Vehicle Data Collection, Animal or person on the road, Weather Condition Warning, Stationary vehicle, Traffic Jam Ahead, Emergency Vehicle Approaching, Accident Zone, Lane closure, Dynamic Speed Limit Information and Embedded VMS "Free Text".

Conclusions and Future Work

Cooperative, Connected and Automated Mobility (CCAM) requires the design and implementation of reliable, scalable and interoperable C-ITS infrastructure that combines both roadside equipment with cloud components, services and platforms. This paper summarizes the roadside and cloud architecture devised for the deployment of C-ITS use cases under the scope of C-Roads project in Portugal. The proposed architecture is aligned with the ETSI ITS-G5 standards, being possible to easily extend it in the future to support other types of ITS messages, such as VAM, CPM, MCM, MAPEM and SPATEM, and also other communications technologies, such as PC5 and 5G New Radio interfaces. The system allows for increasingly higher degrees of automation on both the vehicle and infrastructure sides but copes well with the existing solutions and more direct human intervention. It's also easy to debug as messages are passed using standard communication mechanism like MQTT and using XML encoding.

Acknowledgments

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References

1. C-ROADS - The Platform of Harmonised C-ITS Deployment in Europe. www.c-roads.eu
2. Aniss H. (2016) Overview of an ITS Project: SCOOP@F. In: Mendizabal J. et al. (eds) *Communication Technologies for Vehicles*. Nets4Cars/Nets4Trains/Nets4Aircraft 2016. Lecture Notes in Computer Science, vol. 9669. Springer, Cham. https://doi.org/10.1007/978-3-319-38921-9_14
3. G. Crockford, B. Netten and P. Wadsworth, "Establishing a Common Approach to Evaluating the InterCor C-ITS Pilot Project", 2018 IEEE 87th Vehicular Technology Conference (VTC Spring), Porto, 2018, pp. 1-2, doi: 10.1109/VTCSpring.2018.8417875.
4. CONCORDA (Connected Corridor for Driving Automation). https://connectedautomateddriving.eu/project/concorda/
5. NordicWay. https://www.nordicway.net/
6. P. Karkhanis, M. G. J. v. d. Brand and S. Rajkarnikar, "Defining the C-ITS Reference Architecture", 2018 IEEE International Conference on Software Architecture Companion (ICSA-C), Seattle, WA, 2018, pp. 148-151, doi: 10.1109/ICSA-C.2018.00044.
7. InterCor. Common set of upgraded specifications for Hybrid communication Version 2.1 (Final) https://intercor-project.eu/library/#
8. J. Ferreira et al., "PASMO: An open living lab for cooperative ITS and smart regions", 2017 International Smart Cities Conference (ISC2), Wuxi, 2017, pp. 1-6, doi: 10.1109/ISC2.2017.8090866.
9. R. Blokpoel, M. Fünfrocken, and M. Lu. "Open cloud architecture for connected C-ITS services", 25th ITS World Congress, Copenhagen, Denmark, 17-21 September 2018.

10. G. Larini et al., "Autonomous Driving Progressed by oneM2M: The Experience of the AUTOPILOT Project", 2019 European Conference on Networks and Communications (EuCNC), Valencia, Spain, 2019, pp. 204-208, doi: 10.1109/EuCNC.2019.8801948.

11. 5G PPP H2020 ICT-18-2018 Projects – White Paper. “5G Trials for Cooperative, Connected and Automated Mobility along European 5G Cross-Border Corridors - Challenges and Opportunities”, Version 1.0, October 2020.

12. J. Ribeiro and L. Moura. “A-to-Be experience: deploying a Portuguese highway C-ITS network under C-ROADS Portugal”, Virtual ITS European Congress, 9-10 November 2020.

13. A. Luis Osório, Lara Moura, Rui Costa, & Paulo Borges. (2018). Towards Intelligent Mobility: The Mobility Intelligent Cooperative Systems (MOBICS) Platform. Presented at the 7th Transport Research Arena TRA 2018 (TRA 2018) (TRA2018), Vienna: Zenodo. http://doi.org/10.5281/zenodo.1456444