THE BRENNER MOTORWAY AS A LIVING LAB FOR TESTING CCAM

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ABSTRACT

Autostrada del Brennero stands as a real laboratory, in Italy and in Europe, of connected driving. The focus is on I2V communication, i.e. between the intelligent infrastructure (the motorway operator) and the vehicles, which are in turn interconnected with each other.
The great leap forward will only be made when the motorway is able to communicate directly with vehicles, giving and receiving information, thus reducing human error and increasing the capacity of existing motorways without further land consumption.
Following the diffusion of C-ITS systems, road operators are called to prepare the infrastructure in a way to allow the use of cooperative systems for the communications exchange between vehicles and infrastructure (V2I - I2V). It is necessary to work in synergy with all players involved in infrastructure-to-vehicle communication, i.e. service providers, road operators and the automotive industry. This is the big step to take. And the Brenner Motorway has started by setting up a C-ITS infrastructure that guarantees this communication, which is above all harmonised at European level and ensures system interoperability across borders. The main achievement was to develop a message transmission protocol that would reach the vehicles via a C-ITS server.
This infrastructure has been intensively tested as part of different European projects and Autostrada del Brennero has also hosted tests of Truck Platooning and Highway Chauffeur, two connected driving applications that have benefited from the messaging received by the infrastructure.

BACKGROUND

The theme of the mobility of the future, in its most technologically advanced declinations and evolutions, from smart roads to connected vehicles, technologically advanced road infrastructures, self-driving cars (automated cars) as well as technological innovations for the freight and logistics sector, is at the center of the most recent debate on the perspectives of smart mobility.

Autostrada del Brennero SpA has in the past and is still participating in investment projects for digital transformation, relating to the increasingly pervasive use of ICT (Information and Communication Technologies) in mobility. The objective pursued by the company is to equip the infrastructure with an infrastructure-to-vehicle communication system capable of managing vehicle traffic in the future in a manner not dissimilar to rail traffic, overcoming the current aleatory way of using the infrastructure, in order to increase the capacity of the artery, reduce polluting emissions and progressively eliminate human error, which is today the main cause of accidents. The process of 'transforming' the A22 into a Smart Highway has as its short- to medium-term objective the improvement of technologies to inform users in real time, improve traffic flow management and reduce emissions while, as a long-term objective, it has the development of efficient Cooperative Intelligent Transport Systems (C- ITS) to monitor the condition of the motorway in real time and guarantee an optimal level of user safety.

Autostrada del Brennero was the first Italian motorway to be equipped with a C-ITS infrastructure, developed entirely by qualified internal staff, capable of transmitting messages to vehicles equipped with the technology to receive them and to have tested, within the framework of the European project C-ROADS ITALY (1), two innovative applications, Truck Platooning and Highway Chauffeur, respectively managed by the truck manufacturer Iveco and the car manufacturer Stellantis.
In addition, the company has been involved in other European projects over the past 15 years with the main theme of implementing Connected, Cooperative and Automated Mobility technology, such as DRIVE-C2X, COOPERS, SAFESTRIP, ICT4CART (2), 5G-CARMEN (3) and PoDIUM (4).

A22 C-ITS INFRASTRUCTURE

With the aim of implementing and testing, in real traffic conditions, cooperative communication systems based on V2X technology and their interaction with such automation applications, Autostrada del Brennero adjusted its infrastructure in order to guarantee the possibility of using C-ITS services to vehicles in transit, by adopting DSRC (Dedicated Short-Range Communication) ITS-G5/ 802.11p wireless technologies (5).

The infrastructural adaptation concerned in particular the study and development of use cases, the updating of the pre-existing traffic control systems, the development of the elements of the C-ITS infrastructure necessary for the codification of the information of the use cases and the related interfaces, the infrastructure and the equipment of the motorway axis with ITS-G5 transmission technologies.

Information concerning potentially dangerous situations on the motorway axis detected by sensors, cameras and reports from professional operators responsible for traffic control is validated by the Traffic Control Centre (TCC) of Autostrada del Brennero and included in its management system.

Events are notified to the C-ITS Server (C-ITS-S) with push methodology, using a DATEX

II-based protocol without extensions. This structure allows the easy realization of a possible interconnection with a generic TCC.

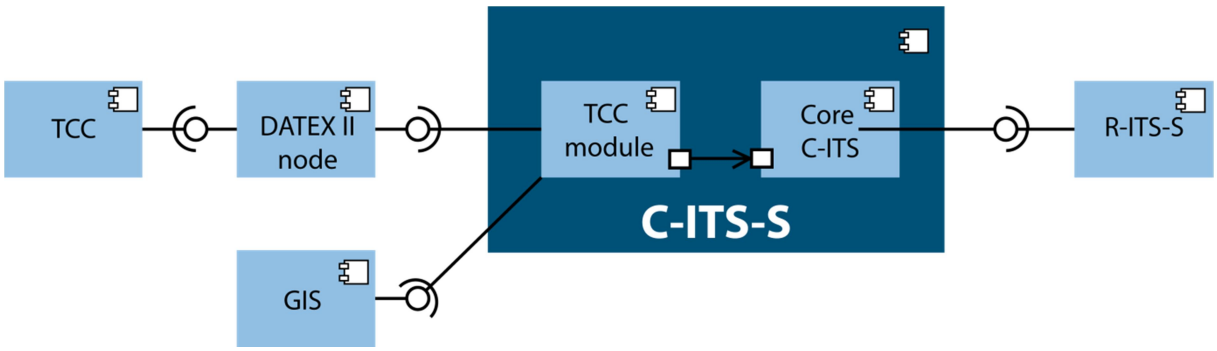

Figure 1. Autostrada del Brennero SpA. Logical scheme of the A22 C-ITS infrastructure

The C-ITS-S represents the heart of the infrastructure:

- it integrates information of current events coming from the TCC with detailed geographical data in the area concerned by the events;
- it precodes information in a suitable format (pre-coding of DENM, IVIM, CAM structures) to air transmission for the Road Side Units (RSUs);
- it interfaces with the Public Key Infrastructure (PKI) to guarantee the authenticity and integrity of Infrastructure-to-Vehicle (I2V) and Vehicle-to-Infrastructure (V2I) communications;
- it manages the dissemination policies of C-ITS messages along the motorway axis, activating the transmission of I2V communications in an area of interest according to the event, its location and the RSUs next to it;
- it integrates a management web interface dedicated to the management and visualization of the events in progress on an interactive map and to the management of the C-ITS infrastructure.

The RSUs distributed along the motorway axis manage the transmission and reception of the I2V and V2I messages on the DSRC ETSI ITS-G5/802.11p wireless network and are equipped with Power Over Ethernet technology in order to simplify the connection with the A22 network access devices in optical fiber.
The RSUs are interconnected to the C-ITS-S through a proprietary interface over IP, collect the V2I information, complete the structures precoded by the C-ITS-S by managing Facility, Network and Access Layer of the ITS-G5 stack, manage G5 security with encrypted keys, transmit on wireless interface the I2V information, standardized to what is defined by the C-Roads platform, thus granting interoperability with the C-ITS services implemented by the other Member States.

HYBRID COMMUNICATION

The ETSI ITS-G5 DSRC technology allows to exchange information based on low latency and low overhead broadcast techniques. From the infrastructure point of view this grants the delivery of information even with reduced stays in limited coverage areas. This is, for

example, the case of a vehicle transiting at high speed near a transceiver with limited coverage (hundreds of meters). In addition, vehicles can establish communications between themselves without the need for negotiation by an external network node, allowing the development of particularly stringent services from the point of view of reaction times, such as for example automated driving functions based on the exchange of cooperative information.

In the hybrid approach, solutions based on ETSI ITS-G5 technology are combined and integrated with solutions based on mobile network technologies using a cloud-based solution.
The distribution of ETSI messages occurs through the TCP-IP stack, relying on the network infrastructure offered by the providers, to make the service available even in areas not directly covered by the G5. This approach has the advantage of maximizing coverage, but also the disadvantage of a higher communication latency compared to direct short range communication between vehicles and infrastructure. Experts are discussing at European level how to provide the service via an IP network, in particular to allow the exchange of events between operators of different countries.

In this regard, an efficient solution, proposed at European level, was studied and implemented. It involves the transport of ETSI messages in ASN.1 UPER binary coding on AMQP protocol adopted for real-time communication in the creation of telemetry services and B2B applications. The AMQP protocol was chosen because it is a non-proprietary protocol and widely usable on different environments through open-source libraries and applications that make it easy to be adopted by everyone without the need to bind users to proprietary service providers. The hybrid communication architecture foresees three players:

- the producer (typically a virtual RSU), delivering messages
- the consumer (typically the OBU), subscribing and receiving messages
- the broker: acting as a mediator and redistributing to consumers the messages obtained by the producers.

The connection between producers / consumers and the broker is persistent and the forwarding of messages is asynchronous, thus allowing to have a real-time notification not requiring continuous interrogations by users as the paradigm foresees an initial subscription mechanism.

Within the project, it was decided to adopt as a broker the open-source implementation of the ActiveMQ project, which is currently the most supported one, offering the best performance and being horizontally scalable (and therefore it will allow the system to be painlessly extended when data traffic generated will increase).
ActiveMQ is a broker ready to use as is and requires no software development, only system operations such as creating accounts, adjusting data access policies and managing the scalability of the service through clustering.

To prevent data traffic congestion towards consumers, a quadtree/geohashing-based spatial information partitioning mechanism has been implemented. It allows to create AMQP logical channels associated to a specific geographic area. The consumer is able to subscribe to the

messages of interest of a subset of geographic areas thus limiting the number of incoming events to that of interest and reducing both the burden of computation borne by the OBUs and the broker and the band used.

To maximize the compatibility of the cloud/hybrid solution with the existing solution, a gateway point called "virtual RSU" has been created. It appears to the C-ITS-S server as a normal RSU, but instead of sending messages via radio, it forwards them as a producer to the AMQP broker in the cloud via the TCP-IP stack.

The direct transportation of messages in the ASN.1 UPER binary format allows users (usually the onboard unit, OBU) to directly benefit from the payload without having to make conversions, as this format is the same adopted in the coding on G5/Wave stack. Therefore, the on-board application doesn't need to be adapted to use the information coming from the cloud except for the minimum interfacing and subscription to the AMQP messaging which, as already mentioned, is widely available in the open software park in the form of libraries for the most varied OS and languages.

To date, a first complete implementation of AMQP broker, virtual RSU and AMQP reception from the OBU is already active, even if in continuous development phase.

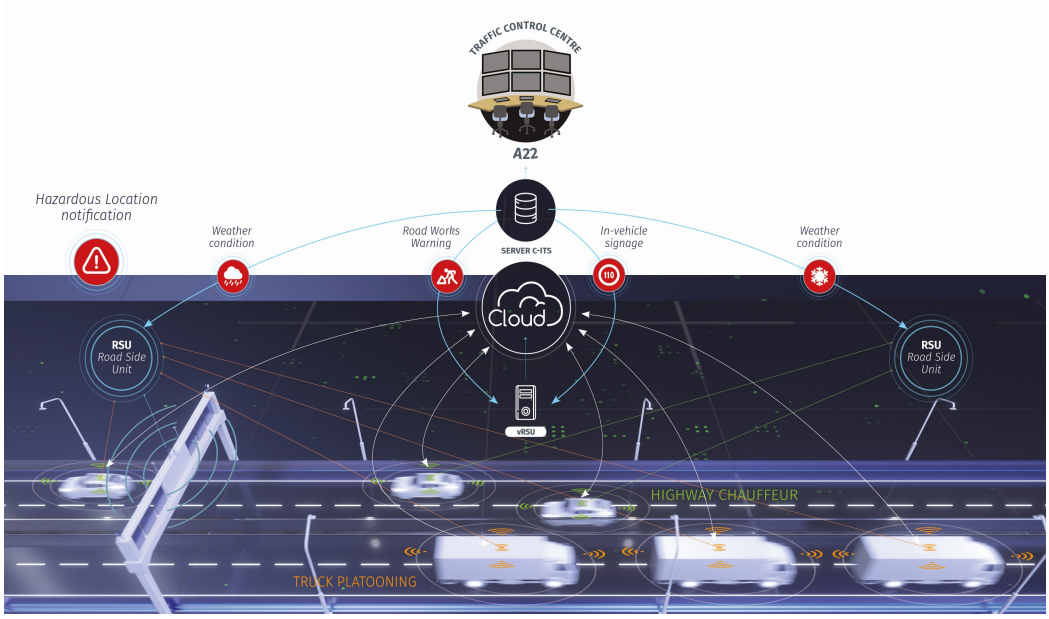

Figure 2. Autostrada del Brennero SpA. Hybrid communication architecture

DAY-1 SERVICES

Over the years, numerous activities have been undertaken to improve infrastructure-to-vehicle (I2V) communication, with a focus on motorway mapping on the one hand, and georeferencing of messages on the other, to ensure that vehicles only receive messages of potential interest to them based on their location.
The European strategy for C-ITS systems, published in Brussels on 30/11/2016, identifies a list of services (Day C-ITS Services List) (6) to be provided by intelligent transport systems

to users along European road networks: to date, Autostrada del Brennero is able to generate and transmit to connected vehicles several Day-1 services.
In a first phase special priority was given to the development and implementation of safety-oriented services, allowing the exchange of information on road works in progress (Road Works Warning), road signs and information usually displayed on variable message signs (In-Vehicle Signage) as well as announcements of potentially dangerous areas due to other causes such as accidents, traffic jam, weather conditions, road hazards (Hazardous Location Notification).
The Day-1 services currently implemented by A22 are summarized in the following table:

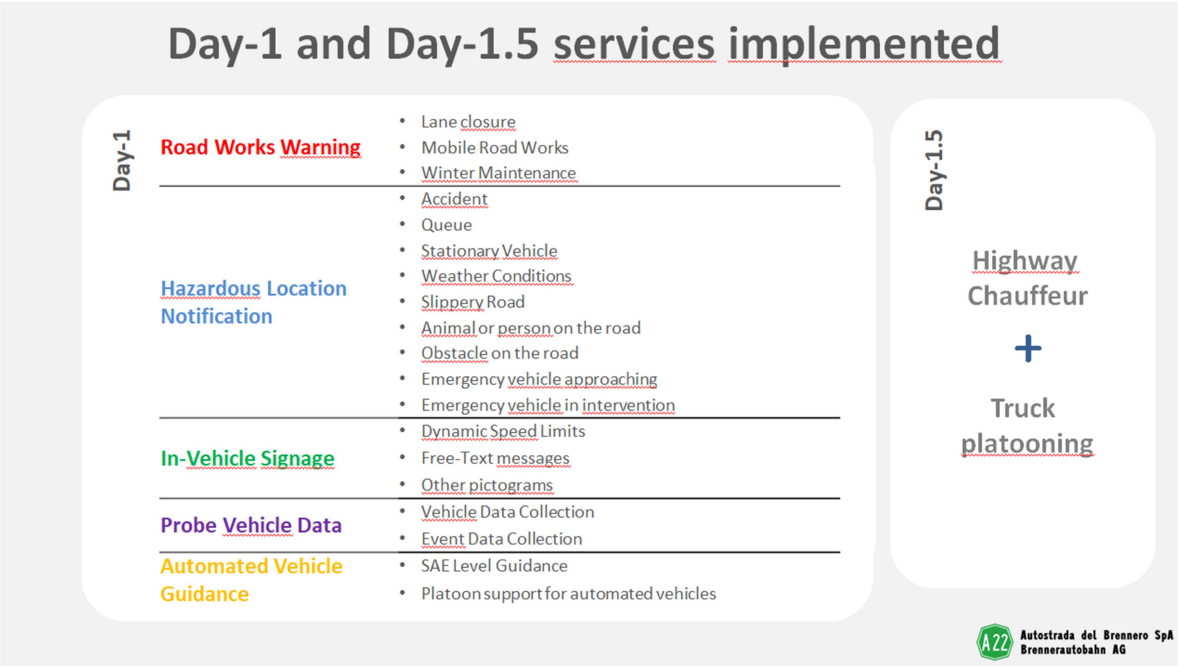

Figure 3. Autostrada del Brennero SpA. Day-1 and Day-1.5 services implemented

Three more Day-1 Services will be available shortly:

- **RWW – Winter Maintenance (RWW-WM)**
  The objective of this use case is to alert road users that will encounter an operating winter maintenance vehicle so that they can adapt their driving behavior accordingly.
- **RWW – Road Works Mobile (RWW-RM)**
  The objective of this use case is to inform a road user of a mobile work zone where he will encounter operating agents in the zone. However, road work equipment / workers might not be present / visible on the whole section.
- **HNL – Emergency or Prioritized Vehicle Approaching (HLN-EPVA)**
  This use case can be used to warn road users about an approaching emergency or prioritized vehicle in order to facilitate free passage of such emergency or prioritized vehicle, when they are on a mission.

USE CASES

TRUCK PLATOONING

Autostrada del Brennero has launched, together with Iveco, international brand of commercial vehicles of the CNH Industrial Group, the experimentation of a Truck Platooning application, i.e. a convoy of vehicles travelling in column, linked together like a train, where the first is equipped with a driver who establishes the route to be taken and the speed to be maintained, the others, without a driver, thanks to a wireless system and with special semi-automatic driving technologies, maintain the same pace and safety distance. The application, which involves a system in which several trucks communicate their longitudinal (acceleration/braking actions) and possibly lateral driving dynamics and are able to maintain a distance of about 10 to 15 metres between the individual trucks, was tested along the A22 for no less than 300,000 km and supported conditional automated driving up to 90 km/h on motorways.

Figure 4. Autostrada del Brennero SpA. Truck Platooning along the A22 motorway

HIGHWAY CHAUFFEUR

Thanks to vehicle-to-vehicle and vehicle-to-infrastructure (V2X) communication, the car receives localized and in real time updated information on the presence of vehicles or dynamic road conditions, for example the dynamic narrowing of the roadway or temporary speed limits, informing the vehicle already a few hundred meters in advance, i.e. beyond the vehicle sensing range. This represents a huge potential, especially for preventive safety, i.e. when the anticipation can still allow a comfortable change of speed or trajectory.

FCA-CRF integrated V2X into prototype vehicles implementing the Highway Chauffeur

application. Thanks to the infrastructure, vehicles receive notifications of events such as road works, stationary vehicles, heavy traffic, adverse weather, dynamic signs (speed), presence of toll booths. Thanks to the other cooperative vehicles, cars receive the presence and maneuver data (speed, acceleration, yaw, direction indicators, etc.) of all neighboring vehicles equipped by V2X, including critical events such as emergency braking. V2X messages are geo-referenced, so that vehicles can filter its content according to its own position and trajectory.
V2X data are available as standard "C-ITS information" in the aforementioned hybrid approach.

THE TRANSITION PHASE

The company is addressing, within the framework of European projects, the issue of the transition period from traditional mobility to the introduction of connected vehicles, a safety-critical period in which it will be necessary for cooperative vehicles to be able to receive information from the infrastructure regarding the presence and movement of unconnected vehicles. The company is already experimenting with this technology and, within the framework of the ICT4CART project, it has equipped itself with cameras that detect the presence and movement of vehicles along the motorway and transmit the displacement data to a roadside unit capable of relaying this information in real time to connected vehicles passing through its range. It is a system that is in the development phase, but one that the company will want to equip itself with in order to better cope with this critical period.

RISK MANAGEMENT IN TUNNELS – THE PoDIUM PROJECT

Tunnels are considered special environments along the motorway and special attention must be paid to them when talking about CCAMs. PoDIUM (full name Physical and Digital Infrastructure (PDI) connectivity and cooperation enablers building trust and sustainability for CCAM) is a project started in October 2022. It intends to handle the emerging requirements of connected and automated vehicles and aims to address also the challenge of tunnels, to reach higher levels of vehicle automation.

Autostrada del Brennero represents one of the three Living Labs of the project in which demonstrations of use cases in real-life conditions will be conducted. One of these use cases (UC5) is called Risk Management in a Highway Tunnel. The use case takes place in a motorway tunnel, with real traffic flowing through. RSUs equipped with camera/LIDAR sensors detect vehicles in input/output of the tunnel and count/classify them. The information is collected by a Digital Twin (hosted in the A22 digital infrastructure), processed by an application that computes the real time risk status of the tunnel and announces this information to vehicles. The risk status might make the incoming CAVs to change behaviour or ODD exit in the case the risk of entering the tunnel is high.

The risk status can be computed using several parameters like the number of vehicles in the tunnel, their type, their average speed and/or their speed profile, their mutual position, the presence of vehicles carrying dangerous goods, the drivers' behaviours, the status of connectivity inside the tunnel, etc., but also static information like the presence of roadworks,

the pavement and lighting status, etc.

Inside the tunnel, CAVs obtain positioning information by using two PDI services: their own GNSS receiver and synthetic GNSS signals and V2X messages.

Autostrada del Brennero, will provide vehicles equipped with OBUs supporting hybrid communications.

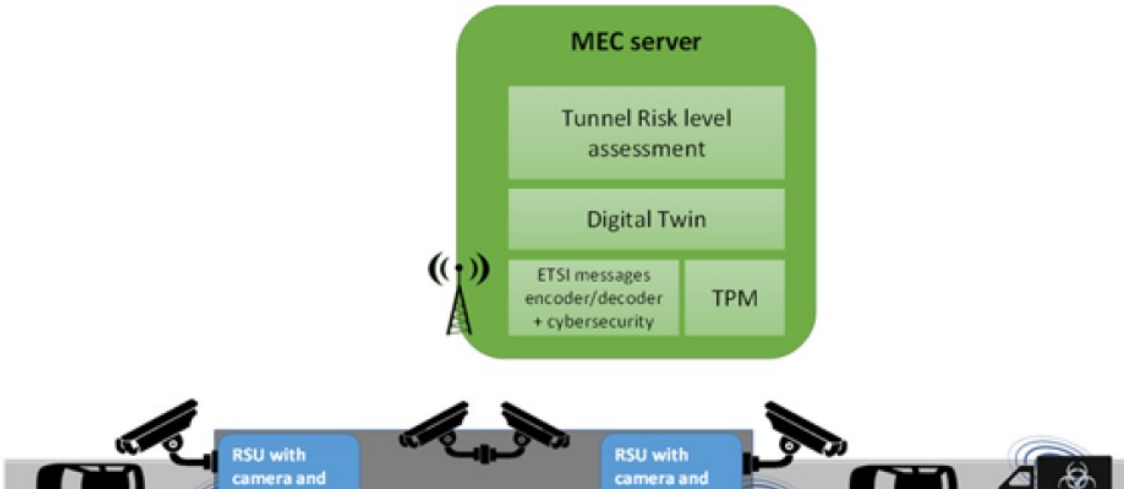

Figure 5. PoDIUM project. Use case "Risk Management in Tunnel"

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