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Deliverable D3.2

Report on communication and warning system

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Consortium - List of partners

Partner No	Short name	Name	Country
1	UIC	International Union of Railways	France
2	VTT	VTT Technical research centre of Finland Ltd	Finland
3	NTNU	Norwegian University of Science and Technology	Norway
4	IFSTTAR	French institute of science and technology for transport, development and networks	France
5	FFE	Fundación Ferrocarriles Españoles	Spain
6	CERTH-HIT	Centre for Research and Technology Hellas - Hellenic Institute of Transport	Greece
7	TRAINOSE	Trainose Transport – Passenger and Freight Transportation Services SA	Greece
8	INTADER	Intermodal Transportation and Logistics Research Association	Turkey
9	CEREMA	Centre for Studies and Expertise on Risks, Environment, Mobility, and Urban and Country planning	France
10	GLS	Geoloc Systems	France
11	RWTH	Rheinisch-Westfaelische Technische Hochschule Aachen University	Germany
12	UNIROMA3	University of Roma Tre	Italy
13	COMM	Commsignia Ltd	Hungary
14	IRU	International Road Transport Union - Projects ASBL	Belgium
15	SNCF	SNCF	France
16	DLR	German Aerospace Center	Germany
17	UTBM	University of Technology of Belfort-Montbéliard	France

Executive summary

The purpose of Task 3.2 is to consider and evaluate emerging and existing communication standards to transmit the risk and hazard information detected by the smart detection system at LCs to all concerned road users, road and rail traffic managers. Some LCs have reduced visibility (turn, presence of trees) with higher safety risk due to impaired geographical and/or weather and daytime conditions. In this task, we evaluate the performance of communication systems in this condition.

In this Task, we analyse the performances of existing communication technologies (LTE, ITS G5) in LC context. LC smart closing system triggered by the Geo localization of the train is also evaluated. Two pilot tests (Thessaloniki and RWTH Aachen) were used to evaluate and validate the smart communication systems. The Evaluation methodology and key performance indicators (KPI) of the communication systems are defined and calculate for each scenario. These KPI shows the capabilities of the technological solutions to exchange the data between smart detection system, LC, control room road and rail users.

Acronyms

CABS: standard Cooperative Awareness Basic Service

CAM: Cooperative Awareness Message

CPM: Cooperative Perception Message

DENM: Decentralized Environmental Notification Message

GNSS: Global Navigation Satellite System

ITS- G5: Intelligent Transportation systems G5

KPI: key performance indicators

LC: level crossings

LTE: Long Term Evolution

OBU: onboard units

RSU: roadside units

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1. INTRODUCTION

1.1. Objectives of SAFER-LC project

The SAFER-LC project (Safer level crossing by integrating and optimizing road-rail infrastructure management and design) aims to improve safety of level crossings (LCs) by minimizing the risk of LC accidents. This will be done by developing a fully integrated cross-modal set of innovative solutions and tools for the proactive management of LC safety and by developing alternatives for the future design of level-crossing infrastructure.

The project focuses both on technical solutions, such as smart detection services and the application of advanced infrastructure-to-vehicle communication systems to adapt infrastructure designs to road user needs and to enhance coordination and cooperation between different land transportation modes. The challenge is to demonstrate the acceptance of the proposed solutions by both rail and road users and to implement the solutions cost-efficiently.

Technically, there are three main objectives of the project, regarding the use of advanced vehicular communications technology:

- warn drivers of road and rail vehicles about dangerous traffic situations encountered in LCs,
- assist road users to escape from dangerous situations,
- assist road and rail vehicles drivers in the avoidance of dangerous situations

by **collecting** relevant environmental information and **sharing** this information among road and rail users in order to help them to react and prepare corrective actions.

1.2. Objectives of WP3 and Task 3.4

The goal of WP3 is to develop technological solutions (smart detection and smart communication systems) to improve safety at level crossings as well as at working zones.

The information of LC status is shared and send to trains/vehicles drivers approaching/arriving to level crossings and to workers at or near train passing zones.

The objectives of this WP are:

- Develop an advanced video surveillance system for modelling and analysing LC users' behaviour,
- Develop an automatic closure of the level crossing triggered by the Geolocalisation of the train;
- Develop and evaluate the smart communication system used to share the information concerning the LC status between LC (control room), Train and road drivers.

Within WP3, the task 3.2 is focused to evaluate the smart communication system. In this task, we analyse the performances of existing communication technologies (LTE, ITS G5) in LC context. Therefore, we test these solutions in pilot sites and in real conditions and we then evaluate the performance of these solutions and their limitations. The Evaluation methodology and key performance indicators (KPI) of the communication systems are defined and calculate for some scenarios. The tested scenarios are defined as being most likely on an LC.

1.3. Purpose of this deliverable

In this document, in the one hand we give the description of two smart communication systems (LTE, ITS G5) used at two pilot sites. We then describe the new Cooperative Perception Messages (CPM) of ITS G5 technology used and evaluate in this task. We also provide in this deliverable the test scenarios defined by all WP3 partners. In the second hand, for each technology the Key Performance indicators (KPI) are given and calculated in order to evaluate the smart communication system.

2. METHODOLOGY

At first, the most likely scenarios concerning the LC were adopted based on WP1 inputs. After several meetings (Skype or physical) organized to share the work between all partners, two solutions (LTE and ITS-G5) were chosen to be tested. These solutions fulfil most of the requirements, constraints, and applications such as time latency and range. The new Cooperative Perception Messages (CPM) of ITS G5 technology was also chosen to be tested.

In Aachen, we organised three campaigns of measurements in order to evaluate the performance of ITS G5 and connection with smart detection solution. The interface between smart detection and communication solution was also developed, tested and evaluated in real conditions.

In Thessaloniki, the solution called ‘LC and train proximity in-car alert’ belonging to the general categories of ‘Warning devices’ was tested and evaluated. It provided up-to-date information about the status of LC, through an indication in the existing vehicle’s GNSS navigation screen and utilization of LTE technology, when a taxi was approaching a level crossing.

Then, the Key Performance indicators (KPI) were defined and calculated in order to evaluate each solution. Some meetings (by skype) were then hold between all task 3.2 partners in order to define the structure of this deliverable.

3. SCENARIO

The level crossing setting is considered to be a particularly relevant environmental factor affecting safety at railway LCs. There are features of the level crossing that can impact the conspicuousness of the crossing and trains, and most notably the sight distances. For example, sight distances can be obstructed by trees, buildings, and the roadway-crossing geometry as well. Poor sight distance and impediments to level crossing visibility is of particular importance at unprotected crossings where the decision to cross safely depends on the ability to detect an oncoming train within safe time margin for stopping. From classical accident research, collisions at LCs can be linked to errors of perception, knowledge or decision-making.

The experimental scenarios of SAFER-LC focused on the smart use of functionality provided by the V2X technology with the integration of a camera-based smart object detection system (SDS). Information generated by the cooperative V2X technology can be used by sharing ITS-G5 awareness messages in a standard way using rail specifically modified structure of standard protocols.

The integration of SDS into recent V2X technology is still an open issue. Commsignia suggested the experimental use of the new Cooperative Perception Message (CPM) technology. The usage of this new methodology is further explained in this document later.

4. DESCRIPTION OF THE SMART COMMUNICATION SYSTEMS

4.1. ITS-G5 system

4.1.1. Description of the ITS-G5 system

In recent years, various communication standards have been developed to enable vehicular communication, either dedicated standards or cellular based ones. Whatever the choice is, standardization bodies keep in mind that vehicular communication has stringent requirements. In fact, it needs to offer a secure communication in a highly mobile environment for time-critical messages from many mobile stations. Hence, the end-to-end latency, reliability, communication range, data rate, mobility, network density and security all should be taken into consideration to choose the appropriate wireless solution.

ITS (Intelligent Transport System) standards for dedicated communication have been investigated by ETSI. They adhere to a general architecture defined in ETSI EN 302 665 and ISO 21217. The core element is the ITS station, which represents vehicles, personal devices, and roadside units.

The access technologies (PHY and MAC layers), commonly known as ITS-G5, are derived from IEEE 802.11p and have been adapted to European requirements. ITS-G5 operates in 5 subbands from A to D, with different 10 MHz channels each. The ITS-G5A, is the primary frequency band. With 30 MHz bandwidth, it is dedicated to safety and traffic efficiency applications. ITS-G5B has 20MHz, allocated to non-safety application. The ITS-G5C is shared with the RLAN/WLAN/BRAN band. While the ITS-G5D band is set aside for future usage of ITS road traffic applications.

On top of the access layers, ITS standards define other layers, among which the Facilities layer. The later specifies requirements and functions supporting applications, communication, and information maintenance. The most relevant standards cover messaging for ITS applications, such as CAM and DENM, which have defined in EN 302 637.

Cooperative Awareness Message (CAM) is a periodic message exchanged between ITS stations to maintain awareness of each other and support cooperative performance of vehicles. It is composed of several containers, thus ensuring a flexible message format, easily adapted to the needs of the target application. The basic container conveys the station type and its position. While other relevant information, i.e vehicle heading, speed, and acceleration, can be added in other containers if needed.

Decentralized Environmental Notification Message (DENM) is an event-driven safety information, exchanged in a specific geographical area surrounding the event. When an ITS station detects a dangerous situation, a DENM message is generated defining the specific event, its detecting ITS station, its lifetime and relevance area, among many others. DENM has several mechanisms to keep disseminating the event information in its relevant during its lifetime. For instance, the detecting ITS station can repeat the DENM message to ensure that the vehicles entering the relevant area are informed.

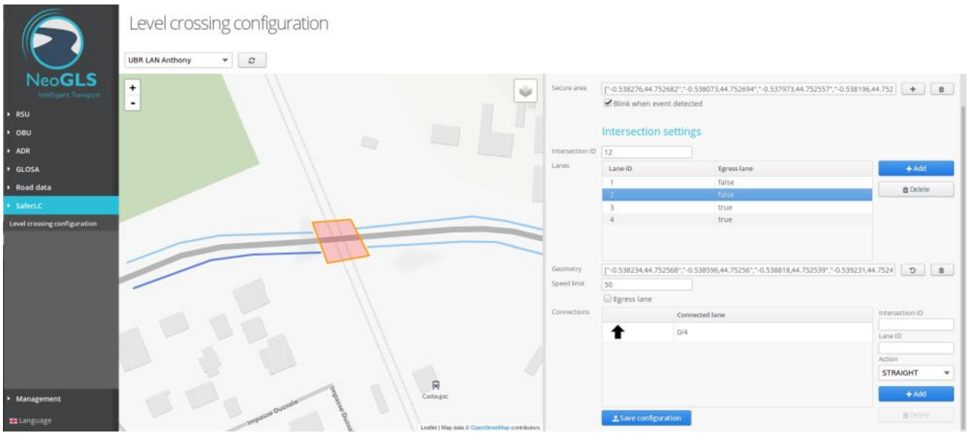
In addition to the facilities layer, ITS standards define mechanisms for security and privacy protection, including private key infrastructure (PKI) enrollment and authorization management protocols, confidentiality, and data integrity.

As we have seen through this brief description, overall, ITS-G5 is a mature technology designed to convey road safety messages. Therefore, it is the most suitable solution for the intelligent communication system of the level crossing.

4.1.2. Description of the ITS-G5 system

The demonstration is based on software provided by NeoGLS which is a supplier of cooperative intelligent transportation systems (C-ITS). NeoGLS provided C-ITS software which is compatible with C-ITS hardware coming from several suppliers (figure1). In order to implement the SAFER-LC demonstration, their software has been updated to be able to communicate with the video detection system and with the new protocols deployed by Commsignia.

For the demonstration, a Roadside Unit has been deployed on the rail crossing and was connected on one side to the barrier and on the other to smart video system. An On-Board Unit has also been deployed in a vehicle in order to demonstrate all the use cases defined in SAFER-LC. This On-Board Unit was connected to an android tablet in order to receive and visualize the alerts created by every use case on an HMI.



UBR LAN Anthony

Secure area: ["-0.538276,44.752682","-0.538073,44.752694","-0.537973,44.752557","-0.538196,44.752

☑ Blink when event detected

Intersection settings

Intersection ID: 12

Lanes

Lane ID	Egress lane
1	false
2	false
3	true
4	true

Geometry: ["-0.538234,44.752568","-0.538596,44.75256","-0.538818,44.752539","-0.539231,44.7524

Speed limit: 50

☐ Egress lane

Connections

	Connected lane
⬆	0/4

Intersection ID:

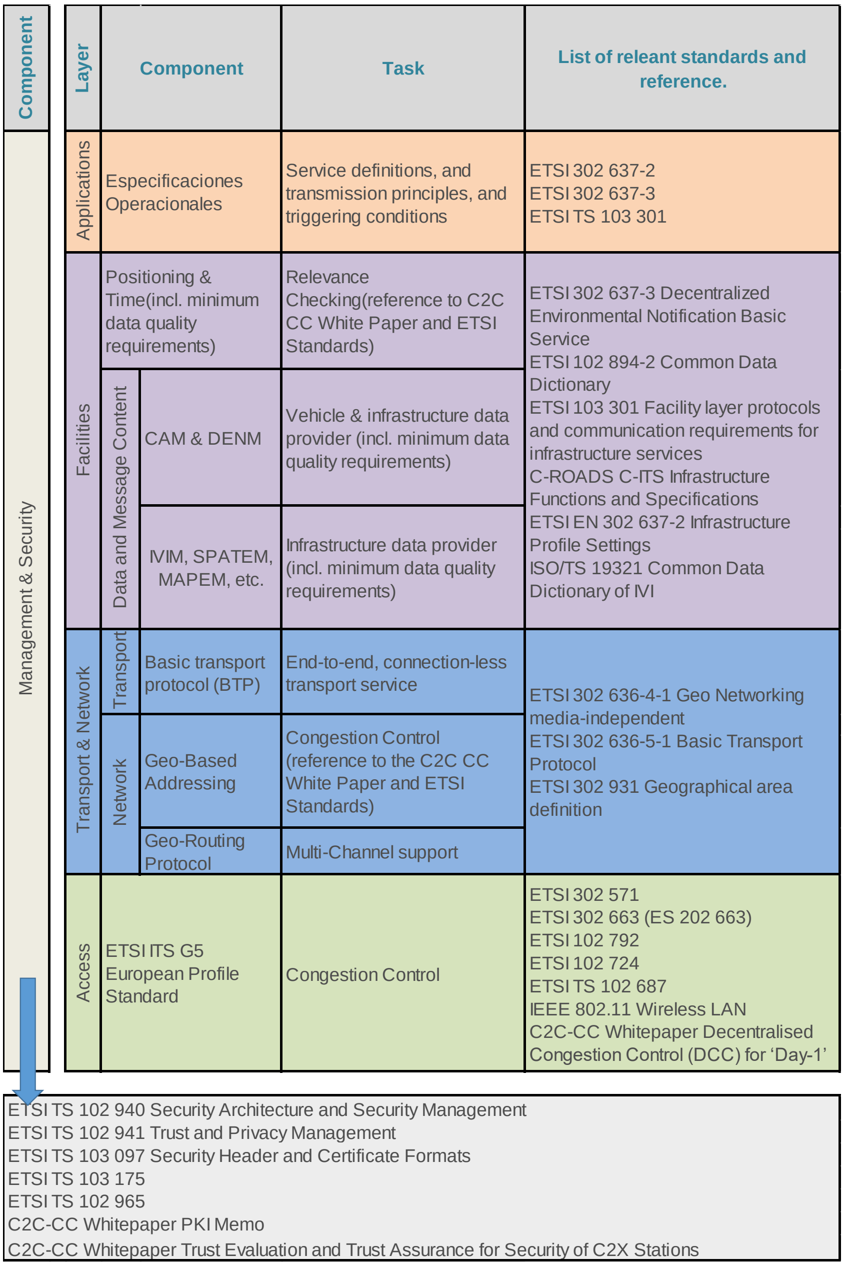
Lane ID:

Action: STRAIGHT

Figure 1: C-ITS software developed by NeoGLS

The software used in the C-ITS stations is fully compatible with the previously mentioned ETSI standards which permits the deployment of a global system interoperable with vehicles already equipped with C-ITS On-Board Units. The IFSTTAR vehicle which was equipped with a Cohda wireless On-Board Unit and proprietary ITS stack was used in order to test this interoperability.

The ITS-G5 equipment integrates the latest ETSI standards and the most recent hardware components (Figure 2):



Component	Layer		Component	Task	List of releant standards and reference.
Management & Security	Applications		Especificaciones Operacionales	Service definitions, and transmission principles, and triggering conditions	ETSI 302 637-2 ETSI 302 637-3 ETSI TS 103 301
	Facilities		Positioning & Time(incl. minimum data quality requirements)	Relevance Checking(reference to C2C CC White Paper and ETSI Standards)	ETSI 302 637-3 Decentralized Environmental Notification Basic Service ETSI 102 894-2 Common Data Dictionary ETSI 103 301 Facility layer protocols and communication requirements for infrastructure services C-ROADS C-ITS Infrastructure Functions and Specifications ETSI EN 302 637-2 Infrastructure Profile Settings ISO/TS 19321 Common Data Dictionary of IVI
		Data and Message Content	CAM & DENM	Vehicle & infrastructure data provider (incl. minimum data quality requirements)	
			IVIM, SPATEM, MAPEM, etc.	Infrastructure data provider (incl. minimum data quality requirements)	
	Transport & Network	Transport	Basic transport protocol (BTP)	End-to-end, connection-less transport service	ETSI 302 636-4-1 Geo Networking media-independent ETSI 302 636-5-1 Basic Transport Protocol ETSI 302 931 Geographical area definition
		Network	Geo-Based Addressing	Congestion Control (reference to the C2C CC White Paper and ETSI Standards)	
			Geo-Routing Protocol	Multi-Channel support	
	Access		ETSI ITS G5 European Profile Standard	Congestion Control	ETSI 302 571 ETSI 302 663 (ES 202 663) ETSI 102 792 ETSI 102 724 ETSI TS 102 687 IEEE 802.11 Wireless LAN C2C-CC Whitepaper Decentralised Congestion Control (DCC) for 'Day-1'

ETSI TS 102 940 Security Architecture and Security Management
ETSI TS 102 941 Trust and Privacy Management
ETSI TS 103 097 Security Header and Certificate Formats
ETSI TS 103 175
ETSI TS 102 965
C2C-CC Whitepaper PKI Memo
C2C-CC Whitepaper Trust Evaluation and Trust Assurance for Security of C2X Stations

Figure 2: ITS-G5 and ETSI standards.

4.1.3. Dissemination of perception data provided by the smart detection system

V2X communication systems generate and share environmental information among road users on a large scale. Location and kinematic data of vehicles residing in the same geographical region is normally disseminated by using the standard Cooperative Awareness Basic Service (CABS), which provides a cooperative awareness service to neighbouring nodes by means of periodic sending of status data of communicating vehicles. This facility layer service generates and distributes Cooperative Awareness Messages (CAMs) in the ITS-G5 network in a deterministic timely basis (from 1 to 10 Hz frequency, depending on the context). This provides information of presence, positions as well as basic movement status of communicating ITS-S (ITS Communication Station) stations to neighbouring ITS-S stations that are located within a single hop distance.

In contrast to CABS, Decentralized Environmental Notification (DEN) service handles messages (DENM) in an event driven manner and provides the key messaging functionality for hazard warning. Both CAM and DENM services are standard features of ITS-G5 technology, see, and are triggered by a particular ITS-S application (i.e., an OBU or RSU).

A DENM contains information related to an event that has potential impact on road safety or traffic efficiency. DENM messages are delivered to vehicles in a particular geographic region: to the area affected by the triggering event in a multi-hop way.

Cooperative Perception (CP), is a new V2X service which aims at disseminating sensory information about the current driving environment by letting vehicles and road infrastructure elements transmit data about detected objects (i.e., about the behaviour of other road participants, obstacles and dynamic road hazards) in abstract descriptions. These descriptions then will be included in broadcast messages called CP messages (CPMs).

Typical sources of sensor information are the following:

- Cameras (both roadside and vehicle onboard cameras). Cameras are used to specify locations and perspectives in 3D space. They are capable of detecting dynamically changing behaviour and movement characteristics of objects, such as vehicles and other vulnerable road users.
- Radar (both roadside and vehicle onboard radars). The application of radar technology is analogous to cameras and they are complementary to each other.
- LIDAR (typically onboard devices).
- V2X communication. V2X technology works to provide a wide range of sensor information through sharing onboard detected traffic related and environmental data.

The objective of CPM and DENM services are rather similar since they are both event driven data dissemination protocols. However DENM service focuses on traffic and road related hazards (emergency breaking, priority vehicle warning, compromising road conditions etc.) while CPM focuses on various sensor information dissemination. Because of the different performance requirements and other operational conditions characterised below, it was reasonable to implement the two services separately. The main differences between DENM and CPM are the following:

- CPM is about cooperative fusioning of the received sensory data and distribution of this information in the immediate geographical vicinity. This necessitates the use of a distribution logic different from DENM services.
- While DENM message repetition is related to the same event type i.e., the triggering hazard event generates a DENM message whose content remains the same until the hazard stays, CPM messages are sent out with continuously refreshed data content thus being capable to share information about moving objects in the 3D space.

The CPM standardization is currently ongoing and POC implementations are on trial. According to the latest draft definitions of CPM services an originating ITS-S station (i.e., the station, which generate the sensory information) continuously transmits CPMs carrying abstract representations about the status of detected objects. It is the originating stations' responsibility to select objects to be shared between traffic participants. These are objects (both static and dynamic ones) which represent safety risk in the traffic situations, and therefore are to be included in the CPM for information sharing, with the objective of warning other traffic participants.

Static detected objects are fixed stationary elements of the infrastructure, or vehicles and other temporal road objects in the dangerous zone of the LC. Dynamic detected objects are moving objects, such as e.g., pedestrians walking, or moving cars entering the dangerous zone of the LC.

In order to reduce radio congestion and messaging complexity, originating stations have to use a censoring system and select only objects for transmission that might be “directly” relevant in a particular safety context. This means that all nonrelevant object like fix infrastructure elements along the carriageway and/or pedestrian walking in a direction which does not affect the safety zone must be filtered out and exclude from transmission.

4.1.4. Detection and object annotation

The cooperative perception scenario applied to SAFER-LC is depicted in Figure 3. The cooperative scenario consists of a V2X enabled smart detection system (SDS), V2X enabled road and rail vehicles and other vulnerable road users in the LC.

The camera works as sensor input for the smart detection system (SDS) which performs the object detection continuously in the following steps.

1. SDS detects and follows the movement of the objects in the image space of the camera or other sensors and makes choice between relevant and not relevant objects regarding the safety context in question.
2. By considering a detected object relevant in certain sense, the object is selected for annotation. Annotation is a special data characterization process in which a relevant object is parameterized.
3. Annotated objects are then passed over to the V2X communication for dissemination using the CPM methodology.

Object annotation is the enveloping process performed by the SDS and the V2X communication system together in which the descriptions of selected objects are assigned with their physical parameters upon which the object can always be reconstructed on the receiver side.

Technically, object annotation is the construction of the CPM data structure. The structure of a typical CPM message is shown in Figure4.

The high-level structure of the CPM is inherited from the CAM message. **ItsPduHeader** (as defined in [5]) is followed by the specific CPM structure containing the three main container types, i.e., **OriginatingStationContainer**, SensorInformation **Container** and **PerceivedObjectContainer**.

The parameters of **PerceivedObject Container** and **SensorInformationContainer** can be determined by the SDS using camera specific and detection information which are passed over to the communicating ITS-S station. **OriginatingStationContainer** is then completed by the ITS-S station (in this case the RSU) of the V2X communication system.

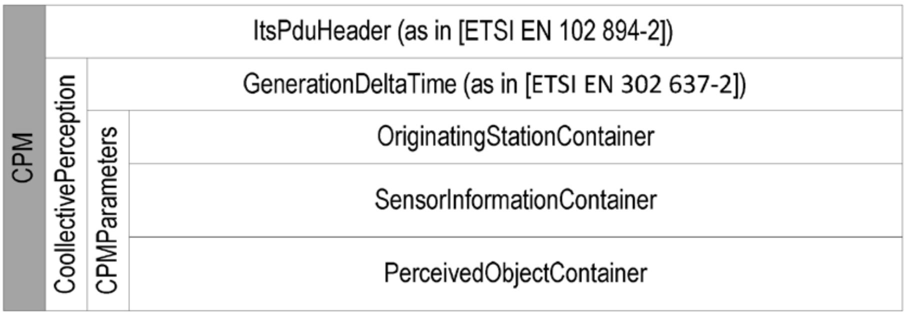


Figure 3: CPM data structure

The object descriptions generated by the detection system are represented in a local coordinates system which depends on the type of CPM originating station. In case of SAFER-LC detection scenario the originating station an RSU placed in the LC and connected to a stationary camera looking at a centre point of LC activity.

The overall adopted system is, therefore, centred in the camera coordinates system which is called RSU’s reference point.

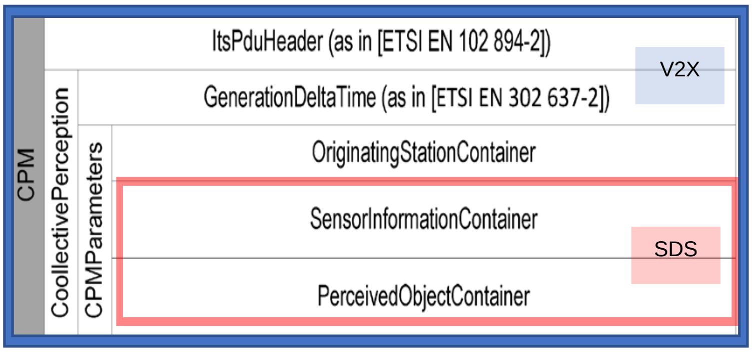


Figure 4: Interoperation and complementary functions of SDS and V2X systems in object detection and annotation

PerceivedObjectContainer consists of a sequence of data elements each providing an abstract description of a detected object. Each detected object is marked with an identifier in order to let the receiver track it as long as possible. Moreover, the identifier of the sensor with which the object is detected must also be included in order to retrieve the corresponding sensor information from the Sensor Information Container.

Other mandatory data elements are the time of measurement, as well as the object’s distance with respect to the originating station’s reference point in the originating station’s coordinates system. In order to correctly interpret this data at the receiving side, the data shall also contain the position of the object’s reference point considered for the calculation. Object classification of the detected object (e.g. pedestrian, bicycle, passenger car, etc.) is also provided in the data field. Several other object description elements are allowed as optional (relative speed and acceleration with respect to the originating station, yaw angle, dimensions, dynamic status etc.).

Based on the above, the SDS shall focus on the generation of the data needed for **PerceivedObjectContainer** container. At the same time, the communicating ITS-S station (RSU) needs to receive the following object information from the corresponding SDS. The CP service running at the V2X communication module (RSU) will complete the definition of the CPM data structure and generate the CP messages. This includes the frequency of CPM transmissions and their final content.

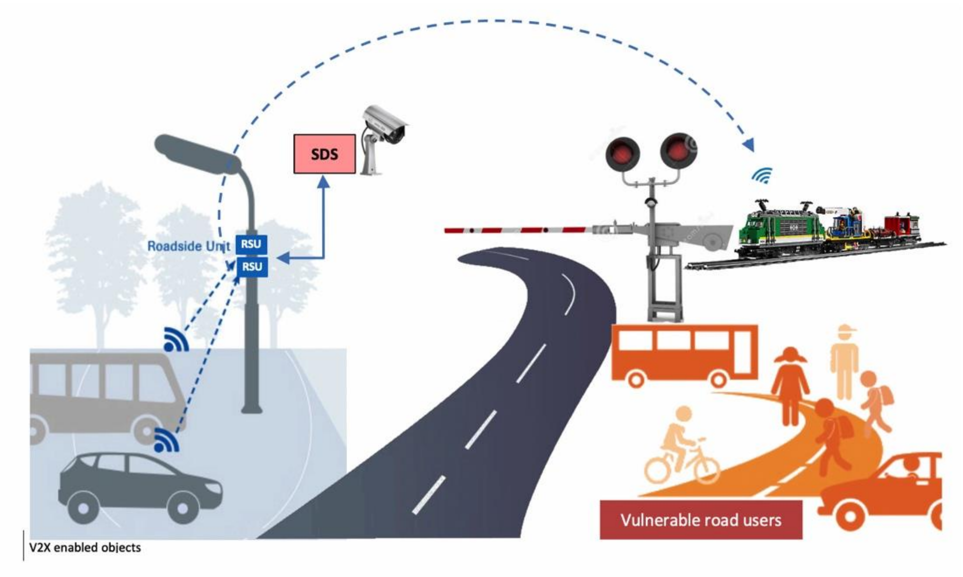


Figure 5: The cooperative perception scenario of SAFER-LC.

4.2. LTE communication solution

The measure piloted in Thessaloniki, called ‘LC and train proximity in-car alert’ belongs to the general categories of ‘Warning devices’ and ‘Improvement of the detection of approaching train’ and can be characterized as a ‘Technical, high-tech’ solution, following the definitions in D2.2.

It provides up-to-date information about the status of LC, through an indication in the existing vehicle’s GNSS navigation screen when a taxi is approaching a level crossing.

The warning also includes an estimated time of arrival for the case of an incoming train (figure 6). In all cases, a short audio alert will be generated as well.

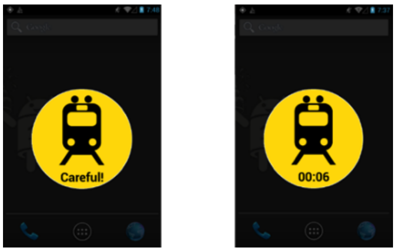


Figure 6: In car warning when no train is approaching (left)

and when the train is estimated to reach the LC in 6 seconds.

The measure was developed by the Center for Research and Technology Hellas- Hellenic Institute of Transportation (HIT) and was implemented for all types of level crossing (e.g. passive, active with light signals, active with barriers and light signals).

In fact, its application is feasible independently of LC and train type or state of other variables and circumstances (e.g. weather conditions) as the only dependency of the system is a predefined polygon (area) of interest around the monitored LC, in which road users will receive the warnings.

4.2.1. Polygon definition

The polygon areas were manually defined in a case by case approach, due to the different nature and topology of each LC and nearby road network (Figure 7).

The road segments inside each polygon are short and close to the LC, as a result it is considered appropriate that all vehicles entering a polygon should receive the warning.

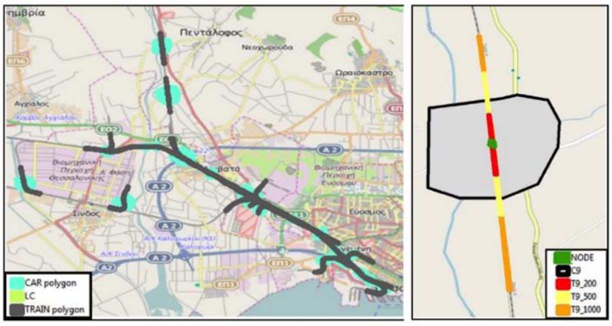


Figure 7: Polygons of the alert system implemented in Thessaloniki.

4.2.2. Train monitoring and estimation of time to arrive at LC

TRAINOSE SA is the main provider of rail transport for passengers and freight in Greece. Most of the trains are equipped with GNSS enabled devices which record and transmit kinematics data every 10 seconds, regarding the train id, line, timestamp, current speed and geolocation. A public RESTful web service provides real time access to the data. The service provides two datasets in JSON format:

- concerning the railway infrastructure, including stops and paths and
- data about the position of the running trains in almost real time.

HIT utilized its infrastructure to store and process the train kinematics data and detect the direction of trains and distance to the LC it is approaching.

When the distance is less than 1000 meters, a machine learning algorithm estimates the time of arrival to the LC, as analysis reveal that time of arrival and speed through a LC is a function of more variables than just instantaneous speed. The predictive algorithm also considers the timestamp of the event, the train id and the LC id.

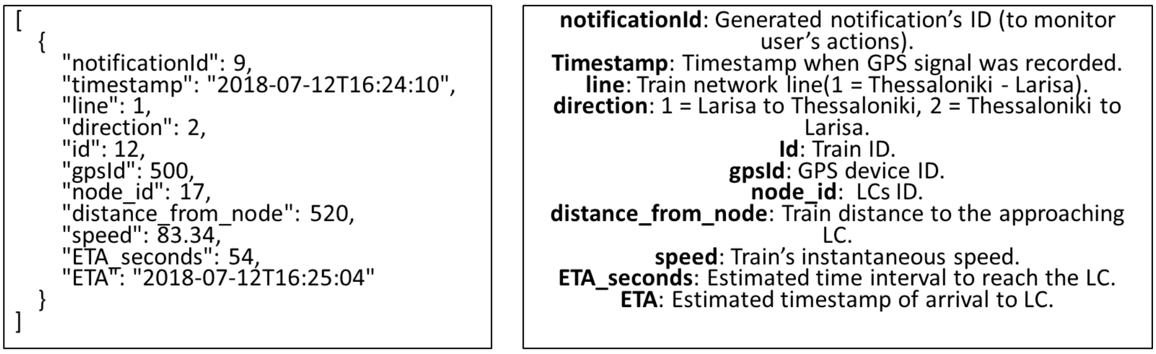
The final choice of the algorithm was finalized after comparing the performance of several predictive models, including an Artificial Neural Network. Despite the lack of extensive historical data, the developed state-of-the-art Neural Network (N.N.) outperformed the rest of the models and achieved a prediction accuracy that is definitely considered acceptable for the objective.

4.2.3. Taxi monitoring and communication

The mobile application developed by HIT was installed in tablets of more than 1000 taxis operating in Thessaloniki by taxi association ‘TaxiWay’. All taxis are already equipped with tablets for navigation and fleet monitoring purposes. The application runs on the tablet, continuously monitoring the location of the vehicle, provided by the tablet’s GPS sensor. When the vehicle enters a LC polygon, the application:

- Generates an alert, informing the driver of the existence of level crossing nearby.
- Starts polling the dedicated web service provided by the HIT’s back-office server over secure https communications channel. It requests train proximity for the specific LC until the vehicle exits the polygon.

The request is posted to HIT’s custom developed API utilizing internet connectivity over 3G or 4G network. If a train is within the distance of 1000 meters and approaching the LC, then HIT’s API responds the pre-calculated ETA of the train [figure 8], which then appears on the on-board navigation device to inform the driver of the oncoming train. If no train is within the distance the response is empty.



```
[
  {
    "notificationId": 9,
    "timestamp": "2018-07-12T16:24:10",
    "line": 1,
    "direction": 2,
    "id": 12,
    "gpsId": 500,
    "node_id": 17,
    "distance_from_node": 520,
    "speed": 83.34,
    "ETA_seconds": 54,
    "ETA": "2018-07-12T16:25:04"
  }
]
```

notificationId: Generated notification’s ID (to monitor user’s actions).
Timestamp: Timestamp when GPS signal was recorded.
line: Train network line(1 = Thessaloniki - Larisa).
direction: 1 = Larisa to Thessaloniki, 2 = Thessaloniki to Larisa.
Id: Train ID.
gpsId: GPS device ID.
node_id: LCs ID.
distance_from_node: Train distance to the approaching LC.
speed: Train’s instantaneous speed.
ETA_seconds: Estimated time interval to reach the LC.
ETA: Estimated timestamp of arrival to LC.

Figure 8: H.I.T. server response (left) and explanation of variables (right). Response explanation: Train with ID 12 travelling in line 1 (Thessaloniki-Larisa) with direction 2 (from Thessaloniki to Larisa) is approaching LC with ID 17. Distance is 520 meters; instantaneous train speed is 83.34 km/h and estimated time of arrival is 54 seconds.

4.2.4. System architecture

The whole system that HIT has developed for testing in real-life conditions in Thessaloniki is illustrated in Figure 9.

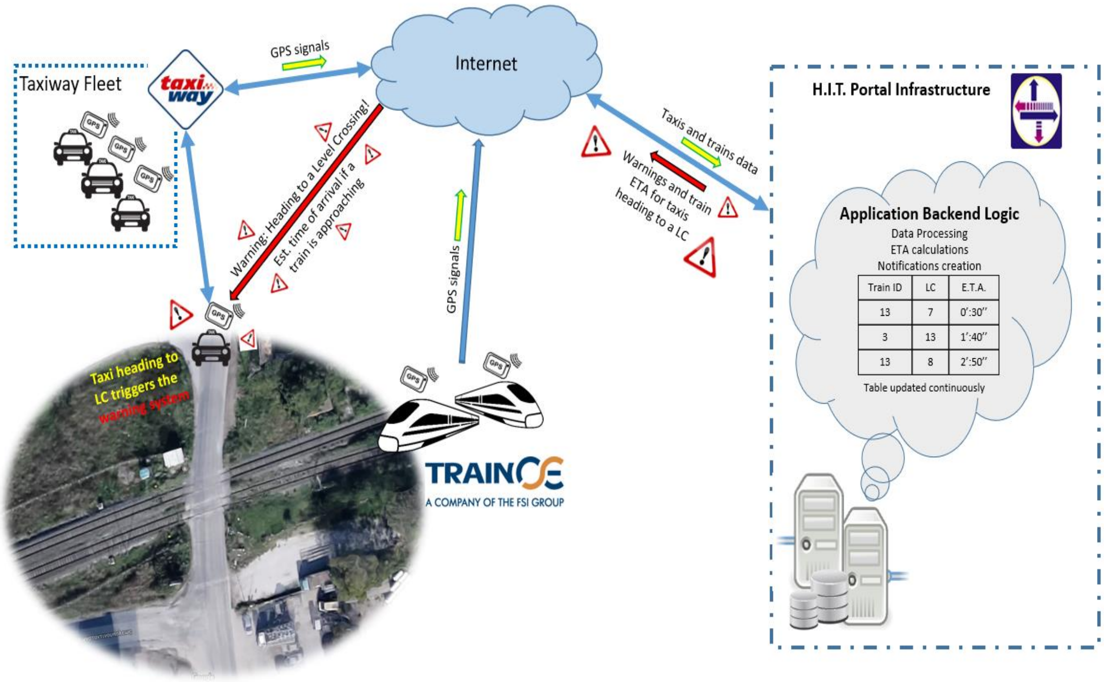


Figure 9: The architecture of the measure developed by CERTH-HIT

4.2.5. Evaluation data and indicators

Several datasets were recorded during the pilot test period in Thessaloniki, Greece. The application had access to the device's Global Navigation Satellite System (GNSS) sensor and records Floating Car Data (FCD) when the vehicle was detected inside a LC polygon.

The recording frequency was set to 1 Hz. When the vehicle exits the polygon, it transmits the collected data to the main server with metadata regarding the issued warning messages. The train kinematics data which are continuously retrieved from the train operator, are also stored in a database. Furthermore, the system's server stores data whenever requests for the estimated time of train arrival are issued by any of the test vehicles. Those datasets enable the detailed reconstruction of vehicle trajectories through LCs, accompanied with relevant information about the position of nearby trains and the status of the mobile application (if and when a request to the server was issued, if and when a warning message was displayed etc).

The datasets described above will be fused to characterize each taxi trajectory and detect false positive cases, when a warning was issued to the driver, but the vehicle was not approaching the LC, and false negative cases, when a vehicle approaching a LC did not receive a warning. This indicator will be used to assess the system's performance from a technical point of view.

The effect of the warning system of the drivers' behavior will be assessed by constructing and analyzing the speed profile of vehicles when approaching the level crossings to extract indicators including number of stops for safety checking, time duration of stops, distance of stops from LC, rerouting due to closed LC, deceleration of vehicle with respect to distance from LC.

Finally, three questionnaires will be completed by the drivers of test vehicles, before during and after the test period. They are designed collect information about their general beliefs and habits related to driving through LCs and expectations for the safety system (before phase). The during and after-testing questionnaires focus on assessing their experience with the system, as the drivers are asked to rate the system with respect to effects of the system to driver’s safety, and also aspects like acceptance, reliability, usability and ease of use of the system.

5. TECHNICAL EVALUATION

This section addresses the methodology to evaluate potential performance issues the smart Communication system. The objective of technical evaluation is to evaluate the technical metrics that affect smart detection and communication system. This communication system allows to transmit the LC situation to the vehicles (train and vehicle).

The technical input is provided in the form of quantitative answers to following research questions:

- What is the performance of the piloted communication technologies to exchange service information to in-vehicle systems?
- What are the technical limits of these solutions in terms of range, speed, data exchanging?

Technical evaluation is organized by use cases. The first subsection describes the general approach in the methodology for technical evaluation. Following subsections describe the evaluation parameters for each of the use cases.

5.1. General scenario

The evaluation framework consists of the following main elements located in the rail intersection of the test site as depicted in Figure 10:

- Traffic lights with half barrier.
- RSU located at the immediate vicinity of the intersection.
- Video camera and smart object detection system for dangerous object detection.
- V2X and no V2X capable vehicles and objects.
- Control room / Log center.
- Road vehicles in the necessary number and one rail vehicle

The main objectives are to detect the event that occurs at level crossings, through the CCTV system. The CCTV system, after processing, will send the detected information to the RSU. According to the type of scenario involved, the latter will transmit the incident to vehicle drivers using the ETSI ITS G5 standard, but also to train drivers approaching these level crossings by setting up signal repeaters.

The condition of the level crossings will be evaluated and sent to vehicles arriving in these areas as well.

The video surveillance system of Geoloc will also send images of the event to the control room using a wired connection.

Finally, the various incidents that will be detected, will also be sent by adopting the solution of Commsignia through the Geoloc interface. It provides means to elaborate the main structure for defining the different hypothesis, indicators and measurements.

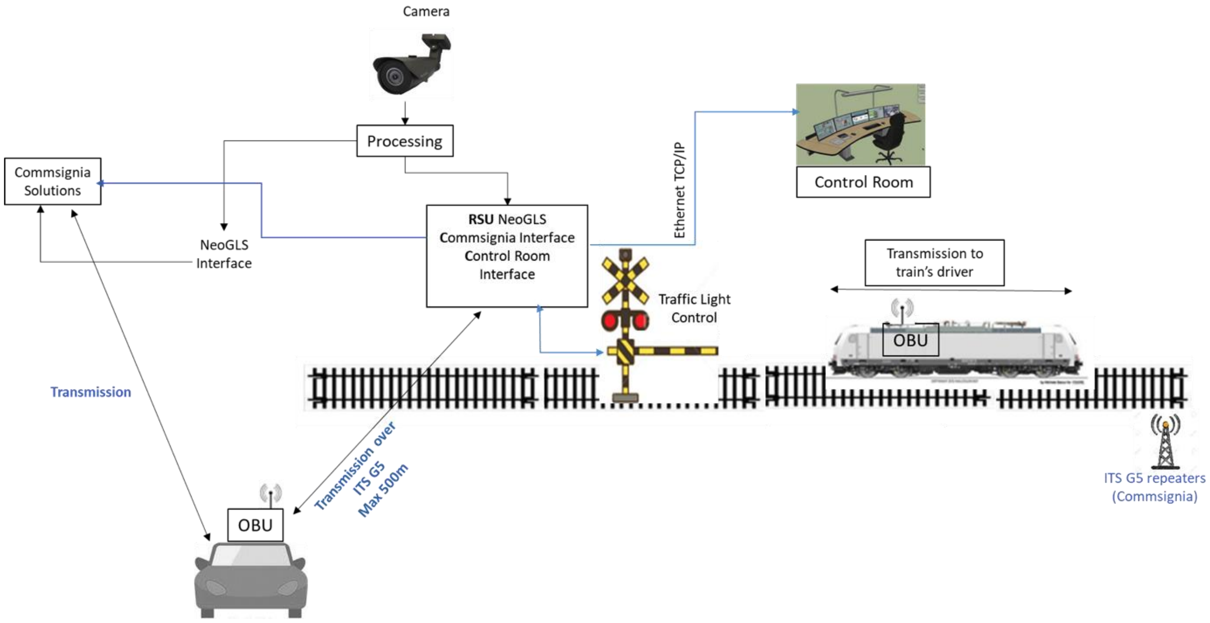


Figure 10: Main structure of various V2X communications scenarios

At the heart of level crossings, depending on the state of the barriers (open, closed), several scenarios may occur. A vehicle equipped with a C-ITS system can travel in an area near a level crossing and the driver receives alert messages or information from one or more applications. The driver has an HMI interface that will allow him to integrate several different application services and obtain the appropriate information to be displayed. Level Crossings will be able to detect the current situation inside their area and transmit this information to vehicles, trains and control centres in case of incidents.

The technical functionality and performance of these applications and services provided with equipment installed in vehicles (car, train) and level crossings will be evaluated, especially in terms of quality and performance of communications between those equipments based on 3 different scenarios.

1. Scenario 1: Detection of the incident and transmission to the road users

In this case, the incident is detected by the video detection system and transmitted to the on-board unit of the cars coming to the level crossings for a graphic visualization of the incident and to allow a better reactivity to the incident.

2. Scenario 2: Detection of the incident and transmission to train driver

In this case, the incident is detected by the video detection system and transmitted to the on-board unit of the train coming to the level crossings for a graphic display of the incident. This will allow the driver to perform upstream the necessary maneuvers to stop the train before the LC.

3. Scenario 3: Detection of the incident and transmission to the room control

In this case, the incident is detected by the video detection system and transmitted to the control center for a complete view of the event.

Three campaigns of tests were realised in Aachen in order to test these scenarios using the following manner (Figure 11):

- **Detection**: potentially dangerous situations are detected by cameras and V2X
- **Communication**: wired communication between the cameras and the LC unit; ITS-G5 communication between the RSUs and LC unit; G5 communication between the LC unit and the road vehicles
- **Measures**: barriers down when the train is approaching based on ETA; in-vehicle messages about a dangerous situation using DENM and CPM

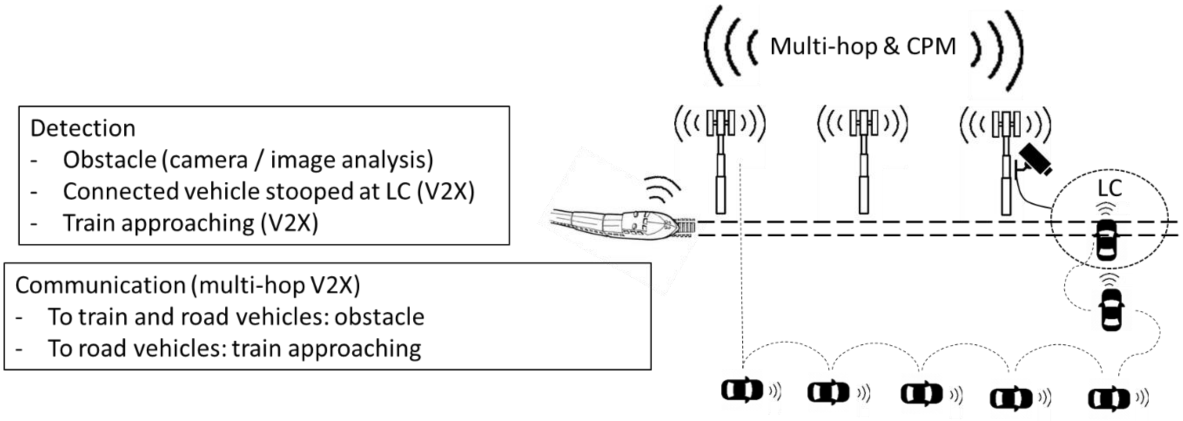


Figure 11: the Detection and communication scenarios tested in Aachen

5.2. Evaluation methodology

In a first step, we give same parameters and indicator definitions. The key indicators of communication performance will be given by PDR, NAR, Range, latency and Delay.

PDR Processing data rate is a measure of communication reliability of a specific sender or receiver and evaluates the ratio of messages successfully delivered during a specified duration in a specified area. It is measured by the ratio of total number of received messages to total number of sent messages.

NAR Neighbourhood Awareness Ratio evaluates the ratio of known neighbour of the station during a specified duration compared to the theoretical number of possible neighbours based on a theoretical communication range. It is calculated by the ratio of the number of ITS-stations or road users in the vicinity of the host of the number of ITS-stations that have been observed/detected by the host in the theoretical communication range.

Effective communication range evaluates the range of communication based on the distance between sender and receiver with minimum PDR. Distance is calculated for each received message using location (latitude and longitude) of sender and receiver. Mean and median values of distances show a coverage range where vehicles can communicate effectively.

Transmit Delay is calculated by the difference between the timestamp of sending messages and the timestamp of receiving message.

The end-to-end delay is an important indicator to measure the minimum time needed for a process between an action A in component A till a reaction B in component B. Derived measure DENM, CAM and CAMI are data useful to calculate technical indicator.

5.2.1. Case where traffic jams occur to the level crossing with barriers open

A vehicle normally crosses the LC and then stops 10 m later. It is followed by several vehicles, creating a traffic jam and the last is on the LC.

- Measure the detection time of the queue.
- Measure the time between detection of the incident and the sending of the DENM Dangerous End of queue by the RSU to the vehicle.
- Evaluate conformity between the message sent and the message received
- Evaluate the maximum range of the communication (between RSU and the receiver vehicle).
- Calculate the maximum number of devices exchanging messages with the RSU
- Evaluate the communication performance in different propagation condition (in the highway, urban area...)

For this scenario the indicators are: PDR, Range and Delay, Speed of vehicles. The data requirements are: Timestamp, Location of RSU, station ID, Message, vehicle Speed, Orientation of sender / receiver.

5.2.2. Case where a car is blocked between the barriers

A car arrives at the LC, stops gradually in the middle and after a while the driver leaves the vehicle and leave the LC

- Measure the detection time of the incident
- Measure the time between detection of the incident and the sending of the DENM Intersection Collision Warning by the RSU to vehicles
- Evaluate conformity between the message sent and the message received
- Evaluate the range of the communication
- Measure the delay to join the central room

For this scenario the indicators are: PDR, Range and Delay, Speed of vehicles. The data requirements are: Timestamp, Location of RSU, station ID, Message, vehicle Speed, Orientation of sender / receiver, Time of occupation.

5.2.3. Case where car is zigzagging with closed barriers

A vehicle with slow speed trying to zigzag the LC
- Measure the detection time of the event
- Measure the time between detection of the incident and the sending of the DENM Intersection collision warning on the road by the RSU to vehicles
- Evaluate conformity between the message sent and the message received
- Evaluate the range of the communication

For this scenario the indicators are: PDR, Range and Delay, Speed of vehicles. The data requirements are: Timestamp, Location of RSU, station ID, Message, vehicle Speed, Orientation of sender / receiver.

5.2.4. Case where a pedestrian/ car stuck in the LC since more than a certain time

A stationary car stopped in the LC and remains there for more a certain period or a pedestrian fell down to the LC and didn't move after a certain time.

- Measure the detection time of the event
- Measure the time between detection of the incident and the sending of the DENM by the RSU to vehicles
- Evaluate conformity between the message sent and the message received
- Evaluate the range of the communication
- Measure the delay to join the central room

For this scenario the indicators are: PDR, Range and Delay, Speed of vehicles. The data requirements are: Timestamp, station ID, Message, Speed, time of occupation.

5.3. Evaluation results

5.3.1. Key Performance indicators (KPI)

Cause code: description of the direct cause for the event [2]

Subcause code: more detailed information for the direct cause [2]

DetectionTime: Timestamp at which an event or event update/termination is detected.

ReferenceTime: Timestamp at which a new, update or cancellation DENM is generated by the DEN basic service.

GN Source position vector specifies the GeoNetworking address, geographical position and optionally other parameters of the source of the received GeoNetworking packet as specified in [2]

GN Area Position: specifies the centre position of the geometric shape as specified in [2]

Event position: the position of the detected event. In case the event covers an area, the event position may be described by a reference position or a geographical description of the event area.

KPI	DEFINITION	ELEMENTS
CONFORMITY	Comparing the cause code and the subcause code between the emitter and the receiver	Cause code its.causeCode Subcause code its.subCauseCode
TRANSMIT DELAY	Calculated by the difference between the timestamp of sending messages and the timestamp of receiving message	Detection time its.timeStamp (1st row) Reception time frame.time_epoch
EMISSION DELAY	Calculated by the difference between the detectionTime and the timestamp of the sending message	Detection time its.timeStamp (1st row) Emission time frame.time_epoch
GENERATION LATENCY	Difference between the reference time and the detection time (referenceTime - detectionTime)	Detection and reference time its.timeStamp
COMMUNICATION RANGE	Difference between the positions (latitude and longitude) of the transmitting station, and the receiving vehicle, for each received message. Mean and median values of distances show a coverage range where vehicles can communicate effectively.	Position of the RSU Gn.sopv.lat Gn.sopv.long Position of the OBU Gn.sopv.lat Gn.sopv.long See on sent CAMs
END TO END DELAY	Difference between the HMI display and detection time: It helps assessing if the car/train driver will have enough time to If display time is not available, we can use receiving time (it will not be an E2E latency however)	
EVENT TO VEHICLE DISTANCE	Distance between the vehicle and the event	Event position (normally) ▪ its.latitude ▪ its.longitude See on sent CAMs

Figure 12: Key Performance indicators

5.3.2. Analysis of results

5.3.2.1. *Scenario 1*

Scenario #1.1	
Scenario title	**Detection of the incident and transmission to the road users**
Objective	It consists of a scenario where a vehicle arrives on the road, stops and waits 30 seconds.
Evaluation data	
Conformity	In this scenario, 2 types of DENMs have been noticed: ▪ a Stationnary vehicle message (cc: 94) ▪ a Collision risk message (cc: 97) All of sent DENMS are received correctly.
Generation Latency	The time between the detection of the event and its creation is: Between 1 and 2 milliseconds for the collision risk message Between 1 and 2 milliseconds for the stationary vehicle message
Emission delay	The time between the detection of the event the sending of the corresponding message is: ▪ Between 1 millisecond and 2 milliseconds for the collision risk message ▪ Between 1 millisecond and 2 milliseconds for the stationary vehicle message
Propagation Environmental	With Non lines of sight the range is between 60 meters and 80 meters In case of LOS the maximum range is about 200 meters

Example of results

Emission interval	Cause code	Subcause Code	Sent DENMs	Received DENMs
15:50:10.77 to 15:51:41.43	94	0	177	177
15:51:40.67 to 15:51:55.83	97	2	30	30

5.3.2.2. Scenario 2

Scenario #1.2	
Scenario title	**Detection of the incident and transmission to train driver**
Objective	It consists of a scenario where a vehicle forces the level-crossing barriers
Evaluation data	
Conformity	In this scenario, 2 types of DENMs have been noticed: - a Collision risk message (cc: 97) - then a Signal violation message (cc: 98) All of sent DENMS are received correctly.
Generation Latency	The time between the detection of the event and its creation is: Between 1 and 2 milliseconds for the collision risk message Between 0 and 2 milliseconds for the stationary vehicle message
Emission delay	The time between the detection of the event the sending of the corresponding message is: Between 1 millisecond and 2 milliseconds for the collision risk message Between 1 millisecond and 2 milliseconds for the signal violation message
propagation Environmental	With Non lines of sight the range is between 60 meters and 80 meters In case of LOS the maximum range is about 200 meters

Example of DENM results

Emission interval	**Cause code**	**Subcause Code**	**Sent DENMs**	**Received DENMs**
15:51:40.67 to 15:51:55.83	97	2	30	30
15:51:55.83to 15:53:02.75	98	1	12	12

All of sent DENMS are received correctly.

5.3.2.3. Scenario 3

Scenario #3	
Scenario title	**Detection of the incident and transmission to the room control**
Objective	It consists of simulating traffic jam use case.
Evaluation data	
Conformity	In this scenario, we have detected a Collision risk message (cc: 97 and scc 2) All of sent DENMS are received correctly.
Generation Latency	The time between the detection of the event and its creation is between 0 and 2 milliseconds.
Emission delay	The time between the detection of the event the sending of the corresponding message is between 1 millisecond and 2 milliseconds.
Propagation Environmental	With Non lines of sight the range is between 60 meters and 80 meters. In case of LOS the maximum range is about 200 meters.

Emission interval	Cause code	Subcause Code	Sent DENMs	Received DENMs
16:31:09:55 to 16:33:13	97	2	96	96

All of sent DENMS are received correctly.

5.3.2.4. Scenario 4

Scenario #4

Scenario title	Where a pedestrian/ car stucked in the LC since more than a certain time
Objective	It consists of a scenario where a human presence has been detected between the closed barriers.
Evaluation data	
Conformity	In this scenario, 3 types of DENMs have been noticed: a Dangerous end of queue message (cc: 27) a Human presence on the road message (cc: 12) a Signal violation (cc:98) All of sent DENMS are received correctly.
Generation Latency	The time between the detection of the event and its creation is between 0 and 2 milliseconds
Emission delay	The time between the detection of the event the sending of the corresponding message is between 1 millisecond and 2 milliseconds
Propagation Environmental	With Non lines of sight the range is between 60 meters and 80 meters In case of LOS the maximum range is about 200 meters

Example of results

Emission interval	Cause code	Subcause Code	Sent DENMs	Received DENMs
16:45:03.37 to 16:45:04.37	27	0	2	2
16:42:34.04 to 16:46:19.45	12	0	24	24
16:41:25.50 to 16:43:49.43	98	1	119	119

5.3.3. Multi-hope solution:

In case of Non lines of sight the maximum range is about 80 meters. This range is very lower than the range notice in the ITS-G5 standards. The solution proposed in project is to use the multi hope approach.

For IFSTTAR, the last campaign of measures was dedicated to the evaluation of the maximum communication range. The nearest vehicles send the same received DENMs to other vehicles coming towards the Level crossing.

All scenarios were tested for the multi-hop e schemas. All DENMS was received correctly if the distance of OBU and RSU is lower, than the maximum range of communication. The same PKI was calculated, and we obtained the same results than previously.

In the case of line-of-sight, the maximum range is about 250 m. In case of NLOS "Non line of sight" the maximum range at the Aachen site (presence of trees.), the maximum range is about 60 to 80 m. With the multi-Hopes solution (Two vehicles are used) the maximum range is between 160 to 180 meters.

5.4. Additional KPIs for long term surveillance:

***Case:* open/ close barriers**

Number of DENMs per event per LC per case: describes the type of events most common for each LC.

Such KPI can be used to adjust safety procedures to each LC.

Total and average number of DENMs per LC per case: describes the LC overall activity**.**

If a LC encounters several events, further safety procedures can be adopted. For instance, if a LC has no barriers, and its total detected events are higher than the average number of events, using barriers would be recommended.

6. CONCLUSIONS

This deliverable was dedicated to technical evaluation of the communication systems. These communication systems share all collected information, by camera-based smart object detection system (SDS), with road and rail users by communication.

Three communication systems were technically evaluated in two pilot tests.
- In Thessaloniki, GNSS system associated to the Communication used 3G or 4G system was used. During and after-testing questionnaires were used to evaluate this solution. These questionnaires focus on assessing the experience of drivers with the system, as they are asked to rate the system with respect to the effects of the system to driver’s safety, and also aspects like acceptance, reliability, usability and ease of use of the system.
- In Aachen, the existing standard ITS G5 and the new version of standard are tested and evaluated. ITS G5 standards allow to exchange some messages, such as CAM and DENM OR CPMs. In our evaluation, we use this message to calculate the PKI. These PKI show that this communication solutions respond according to the restrictions imposed by application.

7. REFERENCES

[1] **ETSI EN 302 637-3**: Decentralized Environmental Notification Messages (**DENM**)

[2] **ETSI EN 302 636-5-1**: Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 5: Transport Protocols; Sub-part 1: Basic Transport Protocol

ANNEXES

For each type of message (DENM and CAM) as well as for each transmitter device (RSU and OBU) these different KPIs can be calculated:

For the DENMs

- **Conformity**
    - ✓ Type of message
    - ✓ Cause code
    - ✓ Subcause code
    - ✓ Time and duration of messages
- **Transmission delay**
    - ✓ Reference time
    - ✓ Detection time
- **Communication range (mean and median)**
    - ✓ GN SOPV (GeoNetworking Source Position Vector)
    - ✓ See GPS.pcap files
- **" End to end " Delay**
    - ✓ Detection time (to be converted from epoch to date)
    - ✓ Reception time (see frame.time in wireshark)
- **Neighbourhood Awareness Ratio**
    - ✓ 2 detected devices
    - ✓ 2 devices theoretically in the vicinity

For the CAMs

- **Conformity**
    - ✓ Type of message
    - ✓ Time and duration of messages
- **Communication range (mean and median)**
    - ✓ GN SOPV (GeoNetworking Source Position Vector)
    - ✓ See GPS.pcap
- **Neighbourhood Awareness Ratio**
    - ✓ 2 detected devices
    - ✓ 2 devices theoretically in the vicinity

Definitions:

detectionTime: Timestamp at which an event or event update/termination is detected [1]

ReferenceTime: Timestamp at which a new, update or cancellation DENM is generated by the DEN basic service [1]

GN Source position vector: parameter specifies the GeoNetworking address, geographical position and optionally other parameters of the source of the received GeoNetworking packet. [2]

Event position: the position of the detected event. In case the event covers an area, the event position may be described by a reference position or a geographical description of the event area [1].

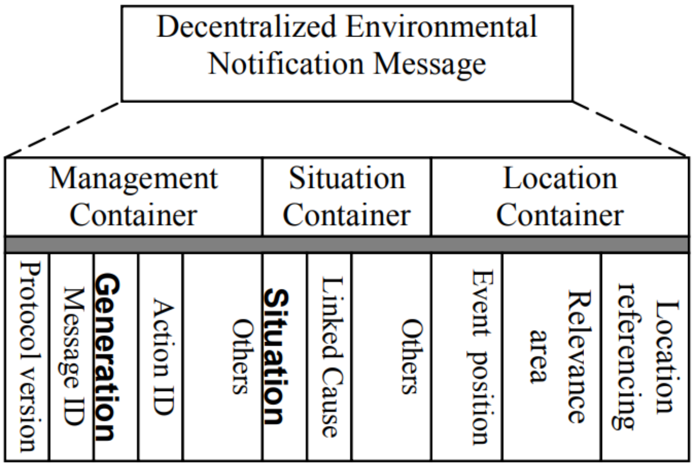
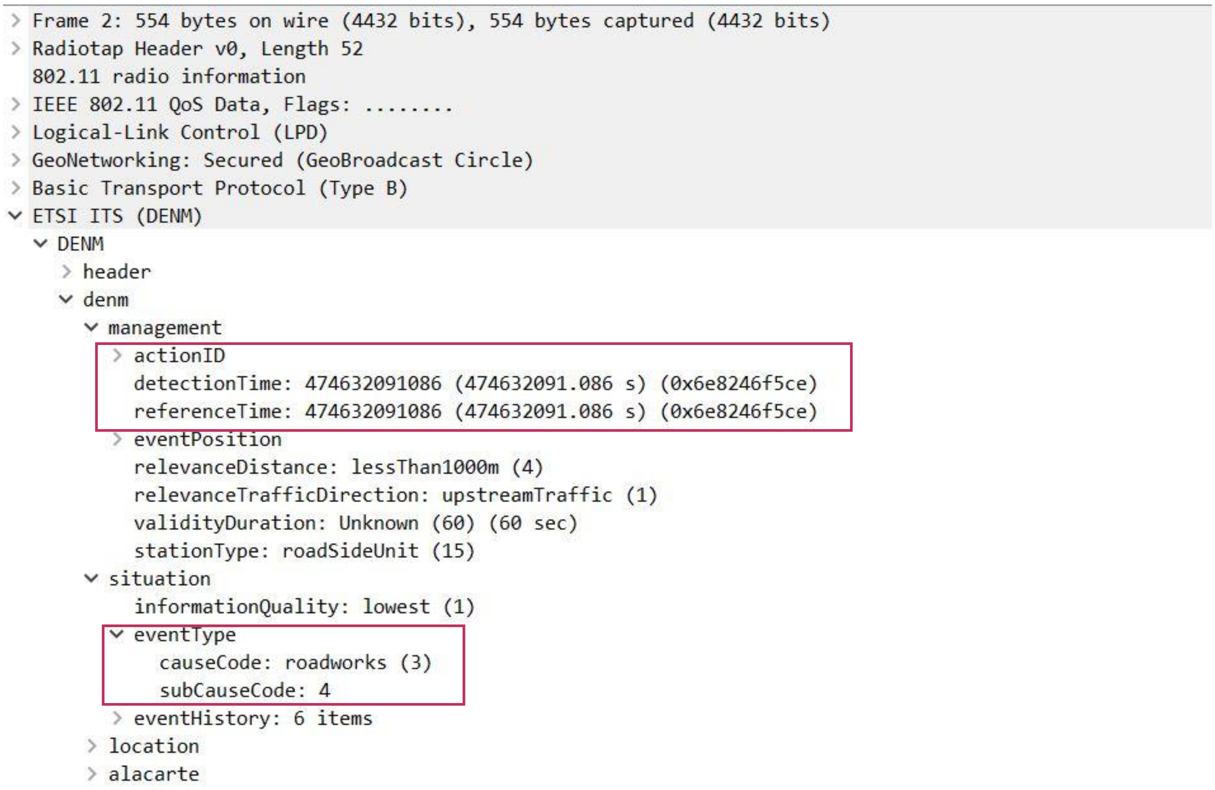


Figure 1: general structure of a DENM [1]

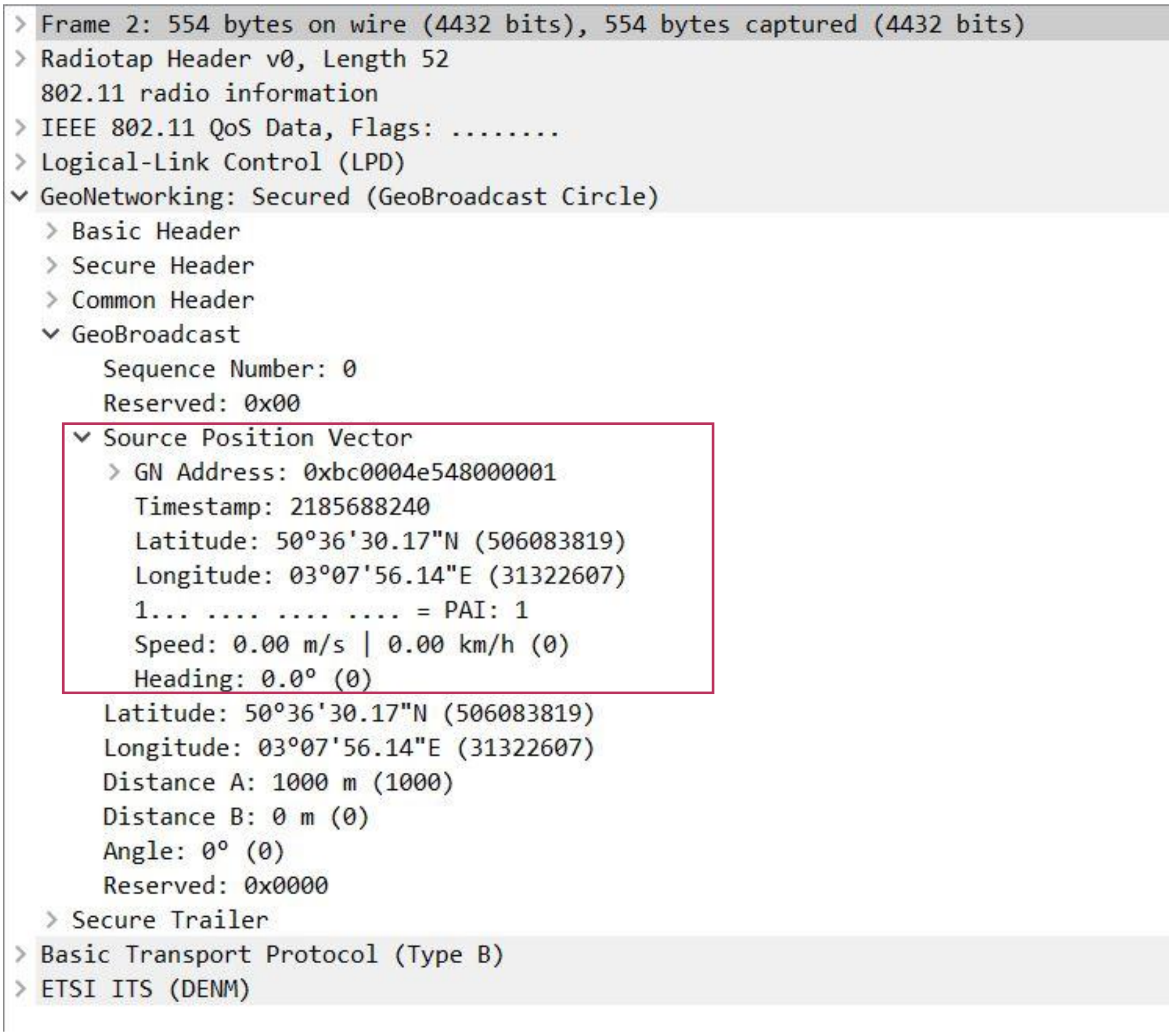
1. DENM and CAM examples

DENM:



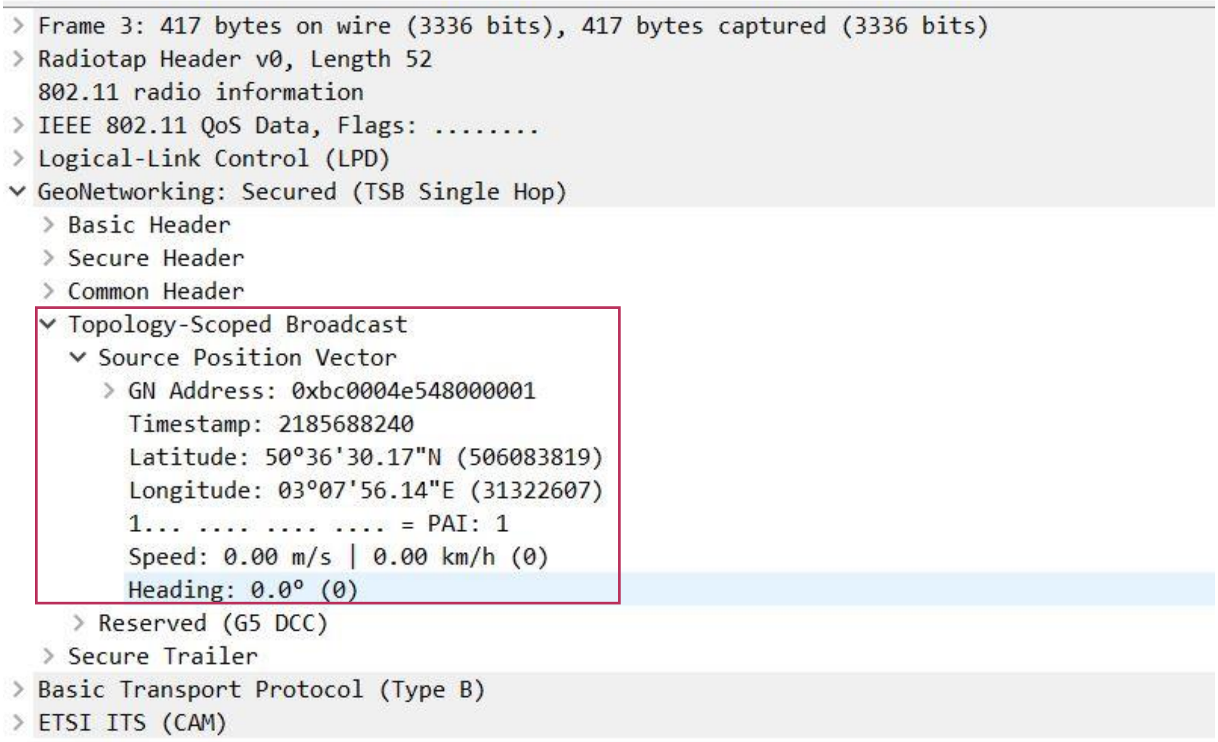
```
> Frame 2: 554 bytes on wire (4432 bits), 554 bytes captured (4432 bits)
> Radiotap Header v0, Length 52
  802.11 radio information
> IEEE 802.11 QoS Data, Flags: ........
> Logical-Link Control (LPD)
> GeoNetworking: Secured (GeoBroadcast Circle)
> Basic Transport Protocol (Type B)
v ETSI ITS (DENM)
  v DENM
    > header
    v denm
      v management
        > actionID
          detectionTime: 474632091086 (474632091.086 s) (0x6e8246f5ce)
          referenceTime: 474632091086 (474632091.086 s) (0x6e8246f5ce)
        > eventPosition
          relevanceDistance: lessThan1000m (4)
          relevanceTrafficDirection: upstreamTraffic (1)
          validityDuration: Unknown (60) (60 sec)
          stationType: roadSideUnit (15)
      v situation
          informationQuality: lowest (1)
        v eventType
            causeCode: roadworks (3)
            subCauseCode: 4
        > eventHistory: 6 items
      > location
      > alacarte
```

Geonetworking in a DENM:



```
> Frame 2: 554 bytes on wire (4432 bits), 554 bytes captured (4432 bits)
> Radiotap Header v0, Length 52
  802.11 radio information
> IEEE 802.11 QoS Data, Flags: ........
> Logical-Link Control (LPD)
v GeoNetworking: Secured (GeoBroadcast Circle)
  > Basic Header
  > Secure Header
  > Common Header
  v GeoBroadcast
      Sequence Number: 0
      Reserved: 0x00
    v Source Position Vector
      > GN Address: 0xbc0004e548000001
        Timestamp: 2185688240
        Latitude: 50°36'30.17"N (506083819)
        Longitude: 03°07'56.14"E (31322607)
        1... .... .... .... = PAI: 1
        Speed: 0.00 m/s | 0.00 km/h (0)
        Heading: 0.0° (0)
      Latitude: 50°36'30.17"N (506083819)
      Longitude: 03°07'56.14"E (31322607)
      Distance A: 1000 m (1000)
      Distance B: 0 m (0)
      Angle: 0° (0)
      Reserved: 0x0000
  > Secure Trailer
> Basic Transport Protocol (Type B)
> ETSI ITS (DENM)
```

Geonetworking in a CAM:



```
> Frame 3: 417 bytes on wire (3336 bits), 417 bytes captured (3336 bits)
> Radiotap Header v0, Length 52
  802.11 radio information
> IEEE 802.11 QoS Data, Flags: ........
> Logical-Link Control (LPD)
v GeoNetworking: Secured (TSB Single Hop)
  > Basic Header
  > Secure Header
  > Common Header
  v Topology-Scoped Broadcast
    v Source Position Vector
      > GN Address: 0xbc0004e548000001
        Timestamp: 2185688240
        Latitude: 50°36'30.17"N (506083819)
        Longitude: 03°07'56.14"E (31322607)
        1... .... .... .... = PAI: 1
        Speed: 0.00 m/s | 0.00 km/h (0)
        Heading: 0.0° (0)
    > Reserved (G5 DCC)
  > Secure Trailer
> Basic Transport Protocol (Type B)
> ETSI ITS (CAM)
```