DRIVing implementation and Evaluation of C2X communication technology in Europe

DRIVE C2X

Accelerate cooperative mobility

Deliverable D44.1

Technical performance of DRIVE C2X functions in full-scale FOT operations

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SEVENTH FRAMEWORK PROGRAMME

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Executive summary

The DRIVE C2X reference system, including the facilities and functions, has been tested in sub project SP2 "FOT Framework", validated and updated on the Test Sites during the Piloting phase in sub project SP3 "FOT Operations". Technical Evaluation is the next and final step for testing the DRIVE C2X reference system as part of sub project SP4 "FOT Evaluation".

The main objective of Technical Evaluation is to evaluate the technical performance of the DRIVE C2X functions in full-scale FOT operations. Technical performance is defined by a set of performance characteristics or metrics. The most important characteristics for all functions are the latency or delay of events on the HMI, and the accuracy of the warning distances and warning times to the drivers. Many underlying criteria that have been evaluated are often function-specific. The performance of the DRIVE C2X reference system is evaluated for example on the accuracy in timing and positioning, and communication performance of the ITS stations. The DRIVE C2X functions are evaluated for example by the latency of processing steps and end-to-end time delays for warning drivers, the accuracy of the location and timing of event triggers in the functions, and the accuracy of first warnings and the revocation of warnings from the HMI.

Technical performance is evaluated for the DRIVE C2X functions (sections 3 – 11): Motorcycle Approaching Indication (MAI), Approaching Emergency Vehicle (AEV), Slow Vehicle Warning (SVW), Green Light Optimised Speed Advisory (GLOSA), Obstacle and Road Works Warning (OWRWW), In-Vehicle Signage (IVS), Traffic Jam Ahead Warning (TJAW) and Weather Warning (WW).

To assess the overall technical performance of DRIVE C2X functions, the functions can be organised by the method used for defining and triggering events:

<u>The event and advice area are defined by a trace</u>

> Functions like OWRWW and GLOSA trigger an event when the subject vehicle reaches a trace or reference track. A vehicle can match its local position on the trace. The trace can be defined in a Decentralized Environmental Notification Message (DENM) as for OWRWW, or in a topology (TOPO) message for GLOSA.
>
> The OWRWW function triggers the HMI as soon as the vehicle maps onto the trace or track, and the HMI event is revoked at some predefined distance after the end of the trace. The deviation of first and last HMI event locations is in the order of 30 to 40 m, which is sufficiently accurate for OWRWW (section 8).
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> In all GLOSA events, the vehicle could match its position onto the reference track for the intended lane with an offset of within 5 m. The time delay for lane matching is about 15 ms on average. However, the delay for decoding the topology message is substantial and can be up to 600 ms on average. The total delay for triggering an HMI event is over 1 sec but that is not noticeable by the driver because the traffic light controllers in Sweden are static allowing reliable driver advices for speed or remaining time to green.

Trace matching is a reliable method and did not yield false positive HMI events. However, trace matching is sensitive to inaccuracies in the location of trace points, otherwise event triggers are delayed or missed.

An event is defined by a relevance area and the advice area is defined by a trace

The IVS function defines an event in a DENM by the location of a traffic sign and a trace to mark the route where the traffic sign remains applicable. The first IVS driver advice is triggered when the vehicle enters a relevance area around the traffic sign location while driving in the direction of the trace. The first driver advices are correctly triggered within the first position update inside the relevance area. Typically this results in an update within 0.1 sec when positioning is updated with frequency of 10 Hz.

Matching of the relevance area and trace is a reliable method. Alternative configurations of the DENM messages were found that affected the technical performance even though the events were tuned by the test sites in such a way that it did not result in erroneous HMI events.

An event is defined by a relevance area and the advice area is defined by a warning distance and driving direction towards the area

The WW function defines a weather event in a DENM by a relevance area in a DENM. HMI events are triggered when the vehicle drives towards the relevance area and reaches a predefined distance. The function revokes the warning a few seconds after entering the relevance area. The warning distance is a configuration parameter of the vehicle, and is set differently at the various test sites. First warnings are generated correctly and are triggered at least 15 seconds before the event area. Also the aggregation of local weather events and triggering conditions worked as specified.

The AEV function defines an event by the location and driving direction in a DENM. Drivers in other vehicles receive a warning within a predefined distance and while in driving direction of the emergency vehicle. Advices are triggered within 400 ms and the distance warning is within 40 m accurate.

The triggering method based on a distance and direction towards an event triggers or revokes HMI events unintentionally in complex road topologies such as in bends, curved roads, parallel roads or roundabouts.

The event and advice area are derived from cooperative awareness assessment at the host vehicle

Functions like MAI and SVW run only locally on the host or subject vehicle of the driver. The local applications assess the risk for a collision only from the CAMs received from the motorcycle or slow vehicle respectively. The host vehicle has to determine a potential collision path somehow, for example from the driving directions and relative distance between the vehicles.

MAI and SVW are both safety functions and the delay for first warning of the driver in the host vehicle is an important performance characteristic. The total delay between the generation of a CAM on the motorcycle and the risk assessment and presentation on the subject vehicle is less than 60 ms on average. The relative error in of the distance in the advice, based on the host vehicle log data, is less than 6 m.

The total delay for SVW is 555 ms (section 6.6), and the relative deviation in distance is less than 10 m for more than 80% of the events. Although the total delay for SVW is relatively larger than for MAI, it is unlikely to be noticeable by a driver as the advices are generated well in advance of a potential collision. False HMI events were generated after periods without reception of CAMs from the slow vehicle.

Like the WW and AEV, the triggering method based on a distance and direction towards an event triggers or revokes HMI events unintentionally in complex road topologies such as in bends, curved roads, parallel roads or roundabouts.

Overall, the DRIVE C2X functions performed as specified from a technical point of view; i.e. function and HMI events to inform or warn drivers are generated at the right location, on time, and with the correct information.

Some flaws have been identified in the design and specification of a few functions that occasionally lead to incorrect HMI event triggers. These are analysed in detail in the function specific sections, where adaptations are suggested from other functions to resolve these flaws and the incorrect events are identified for removal in further analyses of the DRIVE C2X system. Most notably, the triggering method based on a distance and direction towards an event, as used in WW, AEV and SVW, triggers or revokes HMI events unintentionally in complex road topologies such as in bends, curved roads, parallel roads or roundabouts. This problem can be avoided using trace matching as used in OWRWW, GLOSA, IVS, if the trace is accurately defined in the DENM or MAP message. Alternatively, map matching can be used on the host vehicle as in TJAW.

Technical evaluation is organised in a three step approach:

1. All batches of DRIVE C2X log data from test sites Finland, Italy, Spain and Sweden are automatically processed with LogMover (section 2) to verify the quality and plausibility for technical evaluation. In total, 1488 test runs, 7497 hours and 19352 events are analysed and evaluated. The automated data analysis includes data quality checks for example on the availability of required log parameters, consistency of motion state parameters, and the consistency between events in the DENMs, function triggers and HMI events. Events are also automatically detected and a subset of indicators per event is computed. The output is a short list of events and log files per function that provides the input for detailed function evaluation.
2. Detailed evaluation of all events per function. Scripts have been developed to semi-automatically analyse and evaluate every event in detail from the log files. The scripts are function-specific, calculate all performance indicators, and detect any known anomalies in function behaviour or event definitions. For several functions additional log data is also used to evaluate events from test sites Germany and France and from piloting tests.
3. Anomalies are analysed in detail to determine the cause and assess the effects on function behaviour. Usually, the anomalies result from interactions between event configuration and function implementations, and the findings are fed back to test sites and data analysts for impact assessment.

This deliverable provides a summary of the evaluated performance criteria and results that are most relevant to assess the overall performance of the functions and impact on the quality of the provided driver support. It also assesses the performance with respect to technical issues identified during system validation (Maas, et al., 2012). Detailed technical evaluation plans and reports per function are working documents provided on Project Place.

The road side and vehicle ITS stations in the FOTS are not time synchronised. The national field test sites are not equipped to measure or correct the absolute time offsets. This technical evaluation shows that time offsets do not affect the performance of the DRIVE C2X functions MAI, AEV, SVW, OWRWW, IVS and TJAW. Apparently the function implementations are made robust against time offsets in the information received from V2V or I2V communication. This could lead to erroneous events and HMI triggers though when outdated data is still used (e.g. SVW).

The time offsets do affect the technical evaluation of performance characteristics that require log data from different stations or the generation time of received messages. Time offsets result in a time shift of the log data between the stations and introduce errors in the evaluation of for example warning distances and time to events. For the evaluation of functions like MAI, AEV, SVW and GLOSA corrections are required to align the log data. Several algorithms have been used (Annex B). The other functions are less time critical and the effect of the time offsets on the performance characteristics are not considered as 'noticeable'.

Communication performance is evaluated for test scenarios involving multiple vehicle stations for which sufficient log data is available (section 3). The Packet Delivery Ratio (PDR) is evaluated for single hop CAMs from Finland, France, Italy, the Netherlands and Sweden.

- Evaluation showed reasonable and good performance across the test sites.
- The effective communication range with 80% PDR is on average 150m for vehicle to vehicle (V2V) communication, and 600m for vehicle to infrastructure (V2I) communication.
- As expected, the effective range for I2V is larger than V2V communication. Communication range for I2V can be 2 to 4 times larger than for V2V due to higher antenna positioning of RIS.
- As expected, the communication equipment and installation can have a significant impact on communication performance of ITS stations. The average single hop communication range, with 50% probability of packet delivery varies between 400 and 150 m for V2V communication.
- As expected, the effective communication range in highway environments is better than in urban areas due to the harsh propagation environment, including frequent Non Line of Sight (NLOS) conditions due to surrounding objects (e.g. other vehicles, buildings, and trees), and high vehicle mobility.

The cooperative awareness level is evaluated in terms of the Neighbourhood Awareness Ratio (NAR) and Neighbourhood Interference Ratio (NIR). The neighbourhood awareness in an urban environment is above 90% for distances up to 100 m with a progressive decrease to 10% around 500 m. The interference levels from distant vehicles can be considerable; 10% interferes at 300 m but 50 % interferes at 100 m.