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Abstract
This document presents the technical evaluation – version 1. It details the measurements procedures and the common aspects of the Technical Evaluation Key Performance Indicators that have been defined in D8.1. Based on the outcomes of the integration and testing activities, the Technical Evaluation Key Performance Indicators are refined for better suiting the context of the ICT4CART project.

Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
ADAS	Advanced Driver Assistance Systems
AMQP	Advanced Message Queuing Protocol
C-ITS	Cooperative Intelligent Transport Systems
CPM	Collective Perception Message
DEN	Decentralised Environmental Notification
DENM	Decentralised Environmental Notification Message
DOP	Dilution Of Precision
EPM	Environment Perception Model
ETSI	European Telecommunications Standards Institute
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HMI	Human-machine interface
HTTP	Hypertext Transfer Protocol
IAM	Identity and Access Management
ITS-G5	European implementation of WLANp based on IEEE 802.11p
MEC	Multi-access Edge Computing
NMEA	National Marine Electronics Association
NTP	Network Time Protocol
OBU	On-Board Unit
OEM	Original Equipment Manufacturer
RSU	Road-Side Unit
RTK	Real-Time Kinematic
SCN x.y	Scenario x.y
TE-KPI	Technical Evaluation Key Performance Indicator
VRU	Vulnerable Road User

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Executive Summary

The aim of the ICT4CART project is to design, implement and test a versatile ICT infrastructure in real-life conditions, which will enable the transition towards higher levels of automation. It focuses on four high-value use cases: Smart Parking & IoT services, dynamic adaptation of vehicle automation level based on infrastructure information, intersection crossing (urban) & lane merging (highway), and cross-border Interoperability.

These use cases are serving one of the project's main targets, which is to show that the proposed and implemented ICT infrastructure architecture is flexible, adaptable and can serve the needs of various automated driving use cases (safety, comfort, etc.) with different requirements, across test sites with different capabilities. The ICT4CART use cases can be global or local, can be associated with network slices or not, can use Edge Clouds/Computing or not, can use different radio technologies and can be used everywhere (roaming aspect). They also consider mechanisms for cyber-security, authentication, integrity protection and privacy. For this purpose, four test sites are involved in ICT4CART, namely in Austria, in Germany, in Italy and a cross-border site at the Austrian-Italian borders.

The main objective of WP8 is to evaluate the performance of the ICT4CART architecture through the proposed scenarios defined for each test site. This deliverable describes the basis on which the technical evaluation will be performed. Based on the outcomes of Task 8.1 "*Evaluation Methodology and Plan*", this deliverable refines the definition of Technical Evaluation Key Performance Indicators (TE-KPIs) considering the feedback received from the integration and testing activities of the different test sites. Furthermore, it introduces procedures for the measurements of each TE-KPI to achieve a consistent approach across the ICT4CART test sites. These procedures take also into account the need to evaluate the different components and solutions of the ICT4CART architecture that are tested in some scenarios or in some specific configurations.

In the introduction of this deliverable in Sect. 1, the purpose of this document is explained as well as the audience, that this deliverable targets, is described. In Sect. 2, common aspects of the measurements of the TE-KPI are detailed. Sect. 3 to Sect. 11 report for each TE-KPI the specific procedures and details for measurement. Lastly, Sect. 12 concludes the report.

1 Introduction

1.1 Purpose of the document

The purpose of this document is to lay the foundations for the technical evaluation of the ICT4CART architecture, of its components and of its solutions. The main objective of this deliverable is to define the approach that should be followed in all test sites of the ICT4CART project for the technical evaluation process. This objective includes the definition of measurement procedures that should be followed when collecting data during the testing activities. These procedures will allow to have a consistent approach for the evaluation in all the test sites. A fair comparison of different solutions will then be possible.

Furthermore, this deliverable aims to take into account the feedback received by the integration and testing activities. The feedback helped to refine the Technical Evaluation Key Performance Indicators (TE-KPIs) of interest in addition to determine the definition of the best measurement approaches to be considered in the different scenarios.

1.2 Targeted audience

This deliverable is addressed to any interested reader (i.e., PU dissemination level) who wishes to be informed of the technical evaluation of the ICT4CART project and, in particular, to the readers that want to be informed about the procedures of TE-KPI measurements that have been defined in the project and that will be used for collecting data for the technical evaluation.

2 Common aspects of TE-KPIs measurements

In this section, common aspects about TE-KPI measurements are introduced. These aspects concern the format of log files, the definition of the Points of Observation and of the units of measurement to be used, the possible approaches for latency measurements and the time synchronization methods. The aim is to provide reference procedures to guarantee consistency in the TE-KPIs measurements across the scenarios of the ICT4CART test sites.

2.1 Log files

Information to be logged for each TE-KPI is detailed in the following sections. The log files shall be in .csv format. They shall contain a row identifier for each information logged. The log files shall be uploaded using the tool and according to the procedures defined in Task 7.7 "*Data Collection and Aggregation*".

2.2 Units of measurement

Information to be logged is measured using the following units of measurement:

- Time is measured as the number of milliseconds from the 00:00:00 UTC on 1 January 1970 (Unix time);
- Size of C-ITS message is expressed in kilobytes;
- The geographical position of the vehicle is defined by the latitude and longitude pair expressed in decimal degrees.

Information to be logged specific to a given TE-KPI is defined in the section dedicated to the TE-KPI under consideration.

2.3 Points of Observation

The Point of Observation is the point at which a measurement of a TE-KPI is performed. It corresponds to a specific instant and location when a given action is performed (e.g., the transmission of a message, the information provided by a received message is processed, …). The definition of the Points of Observation of a TE-KPI is provided in each section related to that TE-KPI.

In case a TE-KPI involves the transmission of a message, the "*start Point of Observation*" is the location and the instant at which the measurement (typically time measurement) shall take place at the source, while the "*end Point of Observation*" is the location and the instant of the measurement at the destination.

2.4 Procedures for latency measurements

In this subsection, several alternative methods are introduced for measuring the latency of the transmission of a C-ITS message from a source to a destination instance. These methods can be used by any of the TE-KPI that requires to perform latency measurements. The Points of Observation may vary from a TE-KPI to another (e.g., the latency can be referred to the application level or to the transport level), but the same latency measurement methods can be used.

The methods introduced in this section are not requiring the use of specific C-ITS messages. In the following sections, these methods are refined considering the TE-KPI, the specific scenarios under examination and the type of C-ITS message that is used. Indeed, some latency measurement methods should be preferred if a specific C-ITS message is transmitted.

A first method for measuring the latency is based on the presence of a field in the C-ITS message that can provide to the end Point of Observation the time instant at which the latency measurement begins. In this case, the logging of the information is only required at the end Point of Observation since the latency can be computed using the timestamp that is retrieved from the C-ITS message and the timestamp logged at the end Point of Observation.

Two different types of data elements related to time information are mainly defined for C-ITS messages. The first type is "*TimestampIts*". It provides the number of milliseconds since 2004-01-01T00:00:00.000Z [1]. This value can be translated in an absolute timestamp that can be used for the latency measurement. The second type of data element is "*generationDeltaTime*". This type does not provide an absolute time information, but it contains the current value of "*TimestampIts*" wrapped to 65 536 [2]. This information can be reconducted to an absolute timestamp by reversing the modulus operation. This operation must be done knowing approximately the absolute timestamp (i.e., within 65 536 ms from the instant in which the "*generationDeltaTime*" value is computed) to get a unique and correct solution. This means that the reverse operation shall be done in real-time when the C-ITS message is received. Otherwise, it is required to log together with the "*generationDeltaTime*" value also the absolute timestamp when the message received. In this way, the absolute timestamp can be retrieved from the "*generationDeltaTime*" value also offline.

Some C-ITS messages already have some fields in the body of the message that can be exploited to provide time information. In case that the C-ITS message under consideration has no field that can provide time information or if the field present cannot be used for the latency measurements in a specific scenario, an alternative solution is to modify the structure of the message to include a field providing time information. The "*ItsPduHeader*" field, which is a data frame present in all C-ITS messages, could be the most appropriate position in which a data element representing a timestamp field could be added. However, this means that the transmitted C-ITS message is not anymore compliant to the standard. Furthermore, this change increases the size of the C-ITS message increasing, even if slightly, the latency.

A second method to measure the latency can be based on logging a unique message identifier together with an absolute timestamp. The logging shall be performed both at the start and at the end Point of Observation. The timestamp logged at the start Point of Observation corresponds to the time instant at which the latency measurement begins, while at the end Point of Observation it shows when the latency measurement ends.

The C-ITS messages do not contain a field that provides a unique message identifier. A possible approach is to insert an additional field in the body of the C-ITS message. The "*ItsPduHeader*" field is also in this case the location where it is reputed more convenient to add the new field. This approach has the same drawbacks of the additional timestamp field. The alternative approach is to use an already existing field with a different scope from what expected by the relevant ETSI standards. The best candidate is the field "*stationID*" of the "*ItsPduHeader*" field. This field is of integer type and its maximum value is 4294967295. Furthermore, this field is not providing critical information, exploitable by the scenarios under consideration.

The latency measurement approaches that have been introduced so far are independent of the communication technology (i.e., ITS-G5 or 4G/5G) used to transmit the C-ITS messages. An alternative solution for the scenarios in which 4G/5G communication channel is used jointly with the Advanced Message Queuing Protocol (AMQP) is based on the possibility to insert additional properties to the header of AMQP messages. The initial timestamp or a unique message identifier can be added to the header of the AMQP message as additional property. At the end Point of Observation, the AMQP client can retrieve the information inserted for the latency measurements.

2.5 Time synchronization methods

The different Points of Observation involved in the measurement of a TE-KPI related to latency require to be synchronized to each other to guarantee the lowest time gap between local clocks. It is recommended that the clock synchronization is performed using Global Navigation Satellite System (GNSS) time sources. In the case a GNSS receiver is not available for a given Point of Observation, it is possible to use the Network Time Protocol (NTP) or equivalent implementations to achieve an accurate clock synchronization. In the configuration of the NTP protocol it is recommended that a NTP server with the lowest stratum available (i.e., stratum 1) is used in order to achieve clock gaps of only a few tens of milliseconds.

3 End-to-End Transport Latency (TE-KPI1)

3.1 Description

The end-to-end transport latency (TE-KPI1) measures the elapsed time from the time instant at which a C-ITS message is transmitted by the source point to the time instant at which the message is received by a destination point.

3.2 Communication paths to be evaluated

The TE-KPI1 can be measured for different cases related to the use of short-range (i.e., ITS-G5) and/or long-range (4G/5G) communication technologies in the message transmission.
The use of one or of a combination of the two different technologies is due to the hybrid communication approach that is defined in the ICT4CART project [3]. This approach guarantees that any C-ITS message can be received by any vehicle regardless of which communication interface it is equipped with.

We identify four different communication paths that can be evaluated in the context of the ICT4CART project. The four cases are introduced in the following parts of this sub-section.

3.2.1 Transport Latency from MEC Server to Vehicle (4G/5G)

The C-ITS messages are generated by an application that is running on the MEC server (e.g., the Collective Perception Service exploiting the information provided by the Environment Perception Model (EPM) fusion module) and they are received by the vehicle using 4G/5G communication technology. In this case, according to the hybrid communication architecture defined in the ICT4CART project, the application publishes the generated C-ITS messages to an AMQP Message Broker that is running on the MEC server, the vehicle subscribes to Message Broker to receive the messages exploiting the 4G/5G communication network.

The TE-KPI1 of this communication path will evaluate the latency introduced by the 4G/5G network and the latency introduced by the Message Broker.

We will denote this communication path as “Case 1” during the Technical Evaluation of TE-KPI1.

3.2.2 Transport Latency from RSU to Vehicle (ITS-G5)

The C-ITS messages are generated by an application that is running on an RSU and they are broadcasted by the RSU using the ITS-G5 communication channel to all vehicles in its communication range.

The TE-KPI1 of this communication path will only evaluate the latency of the ITS-G5 transmission.

We will denote this communication path as “Case 2” during the Technical Evaluation of TE-KPI1.

3.2.3 Transport Latency from RSU via MEC Server to Vehicle (4G/5G)

The C-ITS messages are generated by an application running on the RSU that publishes the generated messages on a Message Broker that is located at the MEC server. The vehicle retrieves the messages from the Message Broker using the 4G/5G network. This approach is considered according to the hybrid communication architecture defined in the ICT4CART project.

In the context of the ICT4CART project, the communication between the RSU and the MEC server is performed using 4G/5G technology. However, in general, a wired communication between the RSU and MEC server can also be possible; it strictly depends on the deployment characteristics of the RSU and on the available physical infrastructure.

The TE-KPI1 of this communication path will evaluate the latency introduced by the 4G/5G network for the communication between the RSU and the MEC server, the latency introduced by the Message Broker, and the latency for the 4G/5G communication step between the Message Broker and the vehicle.

We will denote this communication path as “Case 3” during the Technical Evaluation of TE-KPI1.

3.2.4 Transport Latency from MEC Server via RSU to Vehicle (4G/5G + ITS-G5)

The C-ITS messages are generated by an application that is running on the MEC server and they are published on the Message Broker located at the MEC server. The RSU is subscribed to the Message Broker to retrieve the messages that are relevant to its ITS-G5 coverage area and to broadcast them to the vehicles using the ITS-G5 network interface.

The TE-KPI1 of this communication path will evaluate the latencies introduced by the Message Broker, by the 4G/5G network and by the ITS-G5 transmission.

We will denote this communication path as “Case 4” during the Technical Evaluation of TE-KPI1.

3.3 Points of Observation

The starting Point of Observation of this TE-KPI is strictly related to the communication path case that is under examination. It corresponds to the MEC server for cases 1 and 4, while it corresponds to the RSU for cases 2 and 3.

The end Point of Observation is always the vehicle.

Some intermediate Points of Observation may also be considered. In case 3, an intermediate timing can also be optionally measured at the MEC server. Likewise, an intermediate timing can be optionally measured at the RSU in measurement case 4.

This TE-KPI focuses on the transport latency, thus application-related processing time are not considered. This means that the start Point of Observation is when the message is ready to be sent and the end Point of Observation is when the message is received on the On-Board Unit before the decoding and message processing.

All four communication path cases will be measured in the scenario SCN 3.1a of the German test site. In the Italian test site, the cases described in Sections 3.2.1 and 3.2.2 will be measured in some scenarios among the following ones: SCNs 2.2, 2.3, 3.1b, 3.3. For the same scenarios, cases described in Sections 3.2.3 and 3.2.4 might also be measured.

3.4 Procedures for TE-KPI measurement

The end-to-end transport latency TE-KPI can be measured using any of the methods introduced in Sect. 2.2. According to the type of C-ITS messages that are transmitted, a different method can be selected.

3.5 Logging details

The log files and the logging procedures can be dependent to the method selected for the transport latency measurement.

Logging at the starting Point of Observation is required when the latency computation is based on an identifier present in the message. In this case the information to be logged are:

- Unique message identifier;
- Absolute timestamp of the C-ITS message transmission instant.

The information logged at the end Point of Observation is:

- Unique message identifier (optional, only if present in the C-ITS message);
- Absolute timestamp of the time instant at which the C-ITS message is received;
- Absolute timestamp retrieved from the C-ITS message providing the transmission time instant (mandatory if logging is not performed at the start Point of Observation);
- Size of the C-ITS message;
- Type of C-ITS message;
- Size of the C-ITS message;
- Communication path under consideration;
- Round-trip time of the Ping command towards the MEC server.

The logging of the round-trip time of the Ping command is optional, and it should be performed only when 4G/5G communication is used by the vehicle. The round-trip time can be measured with a different periodicity with respect to the C-ITS message transmission, but the measurements shall be done in the same time window interval when the message transport latency measurements are done. The round-trip time of the Ping command can indeed be used as benchmark value to evaluate the current 4G/5G network conditions.

3.6 Aim of TE-KPI1

TE-KPI1 aims to capture the latencies of the four different communication paths used for message transmission in the project. Using the results obtained from this TE-KPI measurements, it will be possible to compare the advantages and disadvantages of each communication path, e.g., with respect to latency and communication range.

The evaluation of this TE-KPI1 will then allow to validate the effectiveness of the hybrid communication approach introduced in the ICT4CART project or to identify possible drawbacks. For example, it will be possible to check if a given communication path of the hybrid approach can introduce too much latency impairing the usefulness of the information transmitted along that path.

4 End-to-End Application Latency (TE-KPI2)

4.1 Description

The end-to-end application latency (TE-KPI2) corresponds to the elapsed time interval between the instant at which the information, that is used by the application to generate the C-ITS message, is made available at the source point and the instant at which the information contained in the C-ITS message is processed by the application at the destination instance.

The evaluation of this TE-KPI is strictly dependent on which application is under consideration since the information processing can significantly vary from an application to another one. In this Section, we provide the details of this TE-KPI for each application that is considered in the ICT4CART project.

4.2 "Virtual mirror" application

The "Virtual mirror" application provides information about vehicles and Vulnerable Road Users (VRUs) to connected vehicles. It is based on the EPM building and fusion module, that processes data from sensors to build the representation of the environment, and on the Collective Perception Service, that is in charge to create the C-ITS message Collective Perception Message (CPM) based on the outcomes of the EPM building and fusion module.

The TE-KPI2 for this application evaluates the time needed to process the sensors data and build the EPM, to generate and transmit the CPM at the source instance, and to receive and process the CPM at the destination instance.

This application will be tested in the SCN 3.1a of the German test site and in SCN 3.1b of the Italian test site.

In the German test site this TE-KPI will be measured using the long-range communication scheme (4G/5G) as the "Virtual mirror" application is executed on the MEC server.

In the Italian test site, the "Virtual mirror" application is running on the RSU and the ITS-G5 channel will be used to broadcast the generated CPMs. Evaluation of the "Virtual mirror" application on the MEC server exploiting the 4G/5G channels might also be done in the Italian test depending on the deployment that will be done in the Italian scenario.

4.2.1 Points of Observation

The start Point of Observation is on the MEC server or on the RSU, depending on the location where the "Virtual mirror" application is running, and it corresponds to the time instant at which the sensors provide data to the EPM building and fusion model. In detail, the sensors produce a timestamp, for each frame of data that they transmit, that indicates the capture time of the corresponding raw data. The timestamp of the latest sensor data, which is used in the EPM update by the EPM building fusion module, is the start time instant to be used for the end-to-end application latency measurement.

The end Point of Observation is in the vehicle after that the CPM has been processed and information has been provided to the destination application (e.g., the ADAS module or the HMI).

An intermediate Point of Observation can be optionally set after the EPM building and fusion model to evaluate the time needed to process the sensors' information and to build the representation of the environment.

4.2.2 Procedures for TE-KPI measurement

The end-to-end application latency TE-KPI can be measured using any of the methods introduced in Sect. 2.4. However, the CPM contains the field "*generationDeltaTime*" [4] that can be used to measure the latency, if it is set based on the timestamp of the last sensor data used. This approach may be the most viable for the measurement of TE-KPI2 for the "Virtual mirror" application. It is only needed to consider that the "*generationDeltaTime*" field is not an absolute timestamp and, as explained in Sect. 2.4, it is required to log the absolute timestamp retrievable from the field in real-time.

In case that logging at intermediate Points of Observation is performed, it is necessary to have a unique message identifier in each message to be able to correctly compute the time contributions of the different steps.

4.2.3 Logging details

The information to be logged at the end Point of Observation is the following:

- Unique message identifier (optional, only if present in the C-ITS message);
- Absolute timestamp when the CPM is processed by the destination application
- Absolute timestamp, providing the capture time of the latest sensor data, retrieved from the "*generationDeltaTime*" field of the CPM or using alternative latencies computation methods
- Size of the CPM
- Communication channel (ITS-G5, 4G/ 5G)
- Latitude and longitude of the vehicle position at the message reception (optional)

The optional logging at intermediate Point of Observation should include at least the unique message identifier and the absolute timestamp. The logging at the start Point of Observation is only required if the overall latency computation is based on the unique identifier approach introduced in Sect. 2.4.

4.2.4 Aim of TE-KPI2 for the "Virtual mirror" application

With TE-KPI2, it is possible to measure and evaluate the total application latency, i.e., the latency introduced from sensor data processing, EPM fusion, EPM prediction and EPM transmission (as CPM). The total application latency determines, together with the accuracy of the data, the quality of the CP service. High latencies can make data irrelevant to the receiving ITS station, hence the minimization of the total delay is necessary. However, some delays can also be mitigated using the EPM predictions.

4.3 "Traffic control center" application

This application is related to the generation of Decentralised Environmental Notification Messages (DENMs) to warn about events (e.g., accident or wrong way driving) that the road operator identifies based on data that receives as input.

In the ICT4CART project, the input data received by the "Traffic control center" application are generated by a test data generation application running in the road operator's network. The application is used to trigger the events and to generate the related required data. The "Traffic control center" application generates the DENMs based on the input data received. The DENMs are published on an AQMP Message Broker to make them available with 4G/5G connection and forwarded to the RSUs for broadcasting on the ITS-G5 communication channel. The vehicle can receive these messages after subscribing to the Message Broker or on the ITS-G5 interface if it is in the coverage area of an RSU.

The “Traffic control center” application will be tested in SCN 2.1 of the Austrian test site and SCN 4.1 of the cross-border test site.

4.3.1 Points of Observation

The start Point of Observation is at the backend server of the Traffic Control Center of the road operator. The initial timestamp is set equal to the time instant at which the backend server has available the input data of the event.

The end Point of Observation is at the vehicle side and the final timestamp corresponds to the instant at which the DENM information is processed on the vehicle at the application level.

Additional intermediate Points of Observation can be considered (e.g., when publishing on Message Broker, when message is broadcasted at the RSU) to identify the different contributions of the end-to-end application latency.

4.3.2 Procedures for TE-KPI measurement

Any of the approaches introduced in Sect. 2.2 can be used to measure this TE-KPI for the “Traffic control center” application.

The suggested method is to exploit the field “*detectionTime*” that is present in the body of the DENM. This field is of type *TimestampIts* and, as explained in in Sect. 2.2, it can be translated in an absolute timestamp. The “*detectionTime*” field provides the information about when the event has been detected that, in this case, corresponds to the initial timestamp when the backend server of the Traffic Control Center receives as input the data about the event.

If logging at intermediate Points of Observation is performed, a unique message identifier should exist in the message to let the possibility to compute the time needed in the different steps.

4.3.3 Logging details

The information to be logged at the end Point of Observation is the following:
- Unique message identifier (optional, only if present in the C-ITS message);
- Absolute timestamp when the DENM is processed by the destination application;
- Absolute timestamp retrieved from the “*detectionTime*” field of the DENM or using alternative latency computation methods;
- Size of the DENM;
- Communication channel (ITS-G5, 4G/5G);
- Latitude and longitude of the vehicle position at the message reception (optional).

The optional logging at intermediate Point of Observation should include at least the unique message identifier and the absolute timestamp. The logging at the start Point of Observation is only required if the overall latency computation is based on the unique identifier approach introduced in Sect. 2.4.

4.3.4 Aim of TE-KPI2 for the “Traffic control center” application

The main target of the evaluation of the TE-KPI2 for the “Traffic control center” application is to verify if the information from the infrastructure can arrive to the vehicle in a sufficiently low amount of time. This evaluation can confirm or not the validity of this approach for warning in real-time connected vehicles about events.

4.4 “Identity and Access Management service” application

The Identity and Access Management (IAM) service is an application that provides to an OBU or RSU, upon request, Authorization Ticket certificates used to sign the C-ITS message as defined in ETSI standard [5].

In the ICT4CART project, the IAM service is running on the Airbus Test platform located on a cloud server, and its latency will be measured in the Italian test site with the LINKS’s OBU/RSU.

The interaction between the OBU/RSU and the IAM service is based on a HTTP connection and on the 4G/5G communication channel.

4.4.1 Points of Observation

The starting Point of Observation is at the cloud server where the IAM service is running. The initial timestamp is set equal to the instant at which the request for an Authorization Ticket certificate is received.

The end Point of Observation is defined at the OBU/RSU and the destination timestamp is set to the time instant at which the OBU/RSU receives the response from the IAM service.

4.4.2 Procedures for TE-KPI measurement

The measurement procedure of TE-KPI2 for the IAM service is based on the following steps:

- An Authorization Ticket certificate request is generated by an OBU/RSU;
- The request is sent to the IAM service;
- At reception of the request, the IAM service logs an absolute timestamp;
- The IAM service verifies and processes the request and it prepares the response;
- Just before sending the response, the IAM service logs an absolute timestamp;
- At reception of the response, the OBU/RSU logs the absolute timestamp.

A post-processing step is needed to match the logs collected at the start and at the end Points of Observation. As the communication among the entities involved is performed using 4G/5G channel and HTTP connection, it is expected that the message losses are rare and that they can be easily detected during the analysis of the logs.

4.4.3 Logging details

The information to be logged at the start Point of Observation is the following:

- Absolute timestamp of the instant at which the Authorization Ticket certificate request is received at the IAM service;

The information to be logged at the end Point of Observation is the following:

- Absolute timestamp of the instant at which the response from the IAM service is received;
- Size of the response;
- Latitude and longitude of the vehicle position at the message reception (optional);
- Round-trip time of the Ping command towards the IAM service server (optional).

The round-trip time can be measured when the OBU requests an Authorization Ticket to the IAM service. The round-trip time of the Ping command can provide an insight to what extent the measured latency depends on the underlying transport network.

4.4.4 Aim of TE-KPI2 for the "Identity and Access Management service" application

The aim for the TE-KPI2 evaluation of the IAM service is to quantify the latency that an OBU/RSU may experience in retrieving Authorization Ticket certificates. This latency may impact on the time needed to transmit C-ITS messages if the OBU/RSU is not retrieving in advance Authorization Ticket certificates.

5 Reliability (TE-KPI3)

In the ICT4CART deliverable D8.1, the TE-KPI3 was defined to measure the "Communication Reliability" of a given communication channel that consists of measuring the percentage of correctly received C-ITS messages that have been sent. The C-ITS messages shall be received within the time constraints identified by the related service.

In the process of detailing the TE-KPI procedures for the measurements in the different scenarios, the ICT4CART Partners identified the need to measure two different TE-KPIs concerning the reliability in the transmission of C-ITS messages. This need is due to the fact that some C-ITS messages (e.g., DENM) are transmitted with the same content. This message repetition is needed to ensure that new incoming vehicles, in the area where the messages are sent, can also receive the messages. It is then not important to receive all messages, but it is important to receive all messages having different content. For this reason, a new TE-KPI named "Information reliability" has been introduced.

In the following of this Section, the two TE-KPIs related to the reliability in message reception are introduced.

5.1 Communication Reliability (TE-KPI3a)

5.1.1 Description

This TE-KPI corresponds to the percentage of the C-ITS messages, that are correctly received by a vehicle's OBU, with respect to the total number of sent C-ITS messages in the communication channel under consideration.

The communication channels that are considered are ITS-G5 and 4G-LTE/5G depending on the scenario. Concerning the ITS-G5 case, the measurements of this TE-KPI is done only when the vehicle is in the expected communication range of the RSU.

The TE-KPI3a will be evaluated in the Italian test site in some scenarios among the following ones: SCN 2.2, SCN 2.3, SCN 3.1b and SCN 3.3.

5.1.2 Points of Observation

The start Point of Observation is where C-ITS messages are transmitted, thus at the RSU or at the MEC server.

The end Point of Observation is at the OBU of the vehicle.

5.1.3 Procedures for TE-KPI measurement

The measurement procedure of TE-KPI3a is based on the following steps:

- Each transmission of a C-ITS message is logged at the start Point of Observation;
- Each reception of a C-ITS message is logged at the end Point of Observation.

In a post-processing step, the total number of sent C-ITS messages is computed based on the log file of the start Point of Observation and, similarly, the total number of received C-ITS messages is computed based on the logs collected at the end Point of Observation. The percentage of messages received with respect to the messages that are sent can be computed based on the retrieved information.

The measurement will take place on an application level and the definition of time constraints depend on the actual application context and will be defined on a per Scenario base. The check of the time constraints requires to measure the latency of the reception of the C-ITS messages that can measured according to what introduced in Sect. 2.2.

5.1.4 Logging details

The information to be logged at the start Point of Observation is the following:

- Absolute timestamp of the C-ITS message transmission instant;
- Type of C-ITS message;
- Size of the C-ITS message;
- Communication channel used for the transmission.

The information to be logged at the end Point of Observation is the following:

- Absolute timestamp of the C-ITS message reception instant;
- Type of C-ITS message;
- Size of the C-ITS message;
- Communication channel used for the transmission;
- Latitude and longitude of the vehicle position at the message reception (optional).

5.1.5 Aim of TE-KPI3a

The target of TE-KPI3a is to verify which could be the loss rate of C-ITS messages for a given communication channel. This aspect is important to understand the availability of information at the vehicle-side. This is specifically relevant to those C-ITS services that are transmitting new information in each C-ITS message that they send (e.g., Collective Perception Service). In the case of high loss rate, the usefulness of the support of the infrastructure to the connected vehicle is reduced and strategies to recover the lost messages should be considered (e.g., change communication channel in specific environmental context, increase message transmission frequency).

5.2 Information Reliability (TE-KPI3b)

5.2.1 Description

The newly introduced TE-KPI3b “Information reliability” evaluates the percentage of *different* C-ITS messages (i.e., messages providing different information in the payload) successfully delivered to the destination applications, within the time constraint required by the targeted service, with respect to the total number of *different* C-ITS messages transmitted by a specific C-ITS application.

As previously explained, this TE-KPI wants to measure if each different message is received at the vehicle-side and not how many of all messages sent, including the repetitions, are received. This TE-KPI has been thought in the specific for the DEN Basic Service which periodically repeats DENMs with the same information until the event of the DENM does not change and an update of the information provided is required.

The evaluation of this TE-KPI also considers both ITS-G5 and 4G/5G communication channels.

The TE-KPI3b will be evaluated for the SCN 2.1 of the Austrian test site, for the SCN 4.1 of the cross-border test site and in some scenarios among the following ones: of the Italian test site: SCN 2.2, SCN 2.3, SCN 3.1b and SCN 3.3.

5.2.2 Points of Observation

The start Point of Observation is where C-ITS messages are transmitted, thus at the RSU or at the MEC server.

The end Point of Observation is at the OBU of the vehicle.

Intermediate Points of Observation can be defined at interfaces between applications, and on the AMQP broker.

5.2.3 Procedures for TE-KPI measurement

The measurement procedure of TE-KPI3b is based on the following steps:

- Each transmission of a *different* C-ITS message is logged at the start Point of Observation;
- Each reception of a *different* C-ITS message is logged at the end Point of Observation;

The evaluation of this TE-KPI is based on the comparison between the number of *different* messages sent and received. These numbers can be retrieved analyzing the log files of the start and end Points of Observation in a post-processing step making possible to compute the percentage of *different* messages received with respect to the *different* sent messages.

The measurement will take place on the application level and the definition of time constraints depend on the actual application context and will be defined on a per Scenario base. The checking of the time constraints requires to measure the latency of the reception of the C-ITS messages that can measured.

5.2.4 Logging details

The information to be logged at the start Point of Observation is the following:

- Unique message identifier (optional, only if present in the C-ITS message);
- Absolute timestamp of the transmission instant of each *different* C-ITS message;
- Type of C-ITS message;
- Size of the C-ITS message;
- Communication channel used for the transmission.

The information to be logged at the end Point of Observation is the following:

- Unique message identifier (optional, only if present in the C-ITS message);
- Absolute timestamp of the reception instant of each *different* C-ITS message;
- Type of C-ITS message;
- Size of the C-ITS message;
- Communication channel used for the transmission;
- Latitude and longitude of the vehicle position at the message reception (optional).

5.2.5 Aim of TE-KPI3b

The aim of this TE-KPI is to understand if a message, which is created at the C-ITS application for a specific area and containing specific information, is received at the vehicle side at least once. The scope of TE-KPI3b is similar to the one of TE-KPI3a: to understand if the support provided by the infrastructure is effective or the message loss can reduce the effectiveness, and, in this case, strategies for loss mitigation should be introduced.

6 Position Accuracy (TE-KPI4)

6.1 Description

This TE-KPI deals with the position accuracy that a GNSS receiver can achieve while exploiting Real-Time Kinematic (RTK) positioning services. The evaluation is based on the quantification of the deviation between the ground truth (i.e., the actual position on earth) and the position retrieved by the RTK GNSS receiver.

The TE-KPI4 will be evaluated for the SCN 3.4 of the German test site and in some scenarios among the following ones of the Italian test site: SCN 2.2, SCN 2.3, SCN 3.1b and SCN 3.3.

6.2 Point of Observation

A single Point of Observation is present for this TE-KPI and it is the vehicle where the RTK GNSS receiver is installed.

6.3 Procedures for TE-KPI measurement

The ground truth and the position retrieved by the RTK GNSS receiver are measured and compared. The ground truth shall be a well-known position and it can correspond to:

- a geodetical reference point in case of static measurements (i.e., the vehicle is still);
- a GNSS professional receiver for dynamic measurements (i.e., the vehicle is moving), the GNSS professional receiver shall be much better performant with respect to the RTK GNSS receiver under testing.

The ground truth method should be noted for each test measurement session. Technical characteristics of the GNSS professional receiver used for providing the ground truth shall be noted.

This TE-KPI may be measured in scenarios that present very different conditions. Some of them are intrinsic to the scenario's location. For example, there could be locations with either clear sky view or with limited satellite visibility (i.e., rural or urban environments). Other conditions are instead time-varying, such as the weather conditions or the number of satellites in view. Since all these aspects have an impact on the accuracy of the position measurements, it is necessary to note them down.

For each test measurement session, a textual description of the condition in which measurements are performed should be provided. The scenario conditions should specify at least the type of environment (e.g., open-sky, urban, mountains) and the weather conditions (e.g., sunny, cloudy, light rain, heavy rain).

Other measurements' aspects such as the degree of precision of the measurements, the frequency of measurements, the time window for the measurements, the type of antenna shall be noted for each test measurement session.

6.4 Logging details

The information to be logged is the following:

- Latitude and longitude of the ground truth;
- Latitude and longitude of the RTK GNSS receiver;
- Type of fix as for NMEA standard (i.e., 0 - fix not available, 1 - GPS fix, 2 - Differential GPS fix, 3 - PPS fix, 4 - Real Time Kinematic, 5 - Float RTK, 6 - estimated / dead reckoning), optional;

- Geometric Dilution Of Precision (GDOP), optional;
- Horizontal Dilution Of Precision (HDOP), optional;
- Vertical Dilution Of Precision (VDOP), optional;
- Positional Dilution Of Precision (PDOP), optional;
- Number of satellites in view, optional;
- Signal-To-Noise Ratio (dB), optional.

6.5 Aim of TE-KPI4

The objective of TE-KPI4 is to evaluate which position accuracy can achieve a GNSS receiver with RTK corrections. The evaluation will be performed taking also into account the performance of a commercial off-the-shelf GNSS RTK receiver. The result of the evaluation will indicate if the infrastructure support provided by means of RTK corrections can let the vehicle have a more accurate position.

7 Application-Level Handover Success Rate (TE-KPI5)

7.1 Description

The “Application-Level Handover Success Rate” TE-KPI evaluates the ratio of successfully completed *application-level handovers* of an AMQP client running on a OBU from an AMQP Message Broker instance to another AMQP Message Broker instance.

The TE-KPI5 will be evaluated for the SCN 4.1 of the cross-border test site.

7.2 Points of Observation

The main Point of Observation is at the vehicle on the OBU. An optional Point of Observation is at the AMQP Message Broker.

7.3 Procedures for TE-KPI measurement

The AMQP client on the vehicle’s OBU logs the events of handover between two AMQP Message Brokers. In detail, when a handover is triggered since the vehicle is moving in an area served by a different AMQP Message Broker, the AMQP client logs the connection request to the new AMQP Message Broker and, upon receival of the response or of timeout, it logs the successful or unsuccessful connection result. The analysis and post-processing of this log file allows to compute the success rate of AMQP Message Broker handovers.

The logging of connection requests and respective responses may be performed also at AMQP Message Broker side.

7.4 Logging details

The information to be logged by the AMQP client on the vehicle’s OBU is the following:
- Connection attempt and relative response
- Absolute timestamp (optional)
- Information about the Message Broker to which the connection request is sent

The information to be optionally logged on the AMQP Message Broker is the following:
- Connection requests received and relative responses with client identifier information
- Absolute timestamp (optional)

7.5 Aim of TE-KPI5

The scope of the TE-KPI5 evaluation is to identify possible issues when a connected vehicle changes the AMQP broker to which is currently connected to. This evaluation will confirm the goodness of the approach based on AMQP brokers for receiving C-ITS messages at the vehicle-side using the 4G/5G communication channel in a cross-border scenario.

8 Mobility interruption time (TE-KPI6)

8.1 Description

The TE-KPI6 “Mobility interruption time” measures the time duration in which an application client fails to exchange packets with an application server due to the unavailability of the mobile network. Only the 4G/5G communication channel is used for the measurements of this TE-KPI.

This TE-KPI has been defined specifically for the scenario SCN 4.1 of the cross-border test site since a change of the radio communication infrastructure provider is expected at national borders. Indeed, mobile networks infrastructure is typically provided by different operators at the two sides of a border.

8.2 Point of Observation

A single Point of Observation is present for this TE-KPI and it is the vehicle’s OBU.

8.3 Procedures for TE-KPI measurement

The availability or unavailability of the communication channel should be checked at the application layer of the involved OBU. An ad-hoc program can execute Ping commands towards a server, and it can understand if the network is available or not by checking the replies to the Ping commands. The suggestion is to use the server hosting the AMQP Message Broker as reference.

The procedure to measure the mobility interruption time can be based on the following steps:

- The ad-hoc program on the OBU performs periodically Ping commands towards the server;
- An absolute timestamp associated to the last Ping command whose reply is successful is stored in memory;
- In case the server does not reply to a Ping command:
    - the ad-hoc program logs the absolute timestamp of the last successful Ping command executed; this timestamp corresponds to the last known instant at which the network was available;
    - the ad-hoc program keeps trying to perform Ping commands and it logs the timestamp of the first Ping command that is again successful, this timestamp corresponds to the instant at which the network becomes available again.

The frequency of the Ping commands should be equal or less than 1 Hz. For each test measurement session, the physical characteristics of the scenario (e.g., tunnel) shall be noted.

8.4 Logging details

The information to be logged is the following:

- Absolute timestamp corresponding to the instant at which the communication channel becomes unavailable;
- Absolute timestamp corresponding to the instant at which the communication channel is again available.

8.5 Aim of TE-KPI6

The scope of TE-KPI6 is to evaluate the frequency and the duration of mobile network unavailability in a cross-border scenario. This unavailability can impact the effectiveness of the support that connected vehicles can receive from the infrastructure.

9 Takeover/Vehicle level handover time gained (TE-KPI7)

9.1 Description

This TE-KPI measures the advance in time that can be achieved for the vehicle handover where the support from the ICT4CART infrastructure exists with respect to the case in which the ICT4CART infrastructure is not available.

The TE-KPI7 will be evaluated in SCN 2.1 of the Austrian test site and in the SCN 4.1 of the cross-border test site.

9.2 Point of Observations

The vehicle is the only Point of Observation for this TE-KPI.

9.3 Procedures for TE-KPI measurement

The event (e.g., accident), for which the vehicle handover has to be performed, is simulated at a well localized position on the route of the vehicle.

In case there is the support of the ICT4CART infrastructure, the vehicle receives a DENM that provides all the information about the event (e.g., type of event, position). The vehicle is then aware of the event before reaching the actual position of the event, so that it can prepare for the safe handover to the driver.

The vehicle shall log an absolute timestamp at the instant at which the DENM is received. The following conditions have been set for measuring this TE-KPI. The vehicle receives the information using the 4G/5G communication channel subscribing to the Message Broker and filtering the messages to be received for a restricted geographical area using the quadTree approach as introduced in the specifications of the C-ROADS Platform [6]. In the specific case, the vehicle registers for 2 quadTree tiles with a zoom level equal to 14, which corresponds approximately to a 3.4 km horizon.

At the instant of DENM reception, no immediate reaction might be performed by the system since the event can be in a long distance. Furthermore, the reactions of the vehicle to an event are very specific to each OEM and the provided vehicle feature. The DENM instant reception is considered as the first instant at which the vehicle becomes aware of the event, and it can start performing any handover action if programmed to do so.

The vehicle has instead to rely only on its on-board sensors to identify the event if no support from the ICT4CART infrastructure is provided. Considering the case of a straight route, a fixed distance of 250 m is assumed to be the detection range according to the state-of-art Long Range Radar used for industrial standard detection [7]. The vehicle shall then log an absolute timestamp when its position is 250 m from the simulated event's position. Actual vehicle sensors are not used for this TE-KPI measurement to be able to compare industrial standards instead of any OEM or vehicle specific solutions.

The measurement of TE-KPI7 can rely on these two different timestamps. The difference between the two timestamps represents the time gained by the vehicle to start performing the handover.

9.4 Logging details

The information to be logged is the following:

- The absolute timestamp of the first received DENM notifying the vehicle about the event;
- The absolute timestamp when the vehicle is at 250 m from the event.

9.5 Aim of TE-KPI7

TE-KPI7 estimates the time gap between: (i) the first arrival of the event information for the vehicle equipped with the ICT4CART communication system (i.e., “DENM instant reception”), and (ii) the time in which the non-equipped vehicle could be aware of the event (i.e., “when the vehicle is at 250 m from the event”).

This estimated time-gap corresponds to the additional amount of time gained by the vehicle equipped with the ICT4CART communication system, with respect to a non-equipped one, and that could be potentially exploitable by the vehicle for anticipating the driver involvement and preparing the handover.

The analysis of TE-KPI7 aims at estimating and evaluating the time-gap in real traffic conditions and in presence of different types of event notifications (i.e., information related to a new speed limit and an accident), to see how the context could affect the amount such a time.

The time gained by the equipped vehicle is expected to be always enough to let the driver anticipate the handover maneuver, if needed, in a quite consistent way, thus improving the driver and road safety. TE-KPI7 is helpful to study how the additional time available for equipped vehicles could be exploited for improving the way in which the handover operation is reported/asked to the driver.

10 Map Matching successful ratio (TE-KPI8)

This TE-KPI measures the ratio of the number of successfully matched points over the number of matched points measured at the map matching frequency.

The TE-KPI8 has been introduced in the ICT4CART deliverable D8.1, but it is not expected to be measured anymore in any ICT4CART scenario. For this reason, this TE-KPI is not detailed in this document, and it will not be used for the Technical Evaluation.

11 Driver comfort (TE-KPI9)

11.1 Description

The TE-KPI9 concerns the evaluation of the driver comfort when having or not having the support of the ICT4CART infrastructure. The driver comfort is assumed to be mainly related to the speed profile and the acceleration/deceleration profile. For instance, an overall constant speed characterized by lower acceleration/deceleration instances compared to a benchmark profile, which is obtained without using the ICT4CART infrastructure, means a higher driver comfort.

11.2 Point of Observation

The vehicle is the only Point of Observation for this TE-KPI.

11.3 Procedures for TE-KPI measurement

The vehicle shall log all the parameters that characterize the driver comfort for a given task/maneuver. These parameters have to be logged in two conditions: when the vehicle is exploiting the information from the ICT4CART infrastructure and when such an information is not available. Then, the comparison of the parameters' values for the two operating conditions provides the meaning of the measurement for this TE-KPI.

It is worth noticing that for each measurement session, the description of the support provided by the ICT4CART infrastructure shall be noted to better understand the impact of the ICT4CART infrastructure.

11.4 Logging details

The information to be logged is the following:
- Task/maneuver performed
- ICT4CART infrastructure support (yes/no)
- Speed
- Acceleration
- Deceleration
- Absolute timestamp of the task/maneuver start
- Absolute timestamp of the task/maneuver end

11.5 Aim of TE-KPI9

TE-KPI9 estimates the driver comfort, through several parameters related to the speed and acceleration profile, in two operating conditions: (i) when the vehicle is equipped with the ICT4CART communication system; and (ii) when the vehicle is not equipped with such system. The comparison of the estimated measures aims at evaluating the impact of the use of communication-based information for improving the driver comfort.

The driver comfort is expected to increase for vehicles equipped with the ICT4CART communication system. In other terms, less variability and outlier measures are expected in both speed and acceleration profiles when the vehicle is equipped with the ICT4CART communication system.
The reason beyond this is that equipped vehicles can exploit the use of communication-based information to preventively optimize, with respect to non-equipped vehicles, the speed profile according to the early acquired information about, e.g., other vehicles, road events, and road

prescriptions.

The analysis of TE-KPI9 aims at estimating and comparing the driver comfort, in the two operating conditions, by considering real traffic conditions and different locations (e.g., urban and motorway areas), different road events (e.g., presence of pedestrians, of vehicles, traffic signs) and scenarios (e.g., the ones related to the project use-cases). This aims at helping the identification of relevant aspects that could characterize and influence the driver comfort for vehicles that use of communication-based information.

12 Conclusions

This deliverable defines all the aspects needed to perform a high-quality technical evaluation. It refines the TE-KPIs of interest that were originally introduced in D8.1. The TE-KPIs have been detailed together with the related measurement procedures to be followed to achieve a consistent evaluation across the ICT4CART test sites. This activity has been carried out considering the feedback of the on-going integration and testing activities from the different test sites.

The work illustrated in this document is preparatory for the next deliverable D8.3 "*Technical evaluation – Final Version*", in which the evaluation of data collected from the different test sites will be presented and the value of the different components and solutions of the ICT4CART project will be calculated.

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