ETSI TR 103 579 V1.1.1 (2020-09)

TECHNICAL REPORT

Intelligent Transport Systems (ITS);
Pre-Standardization Study on
payment applications in Cooperative ITS using
V2I communication

Reference

DTR/ITS-00187

Keywords

application layer, charging, ITS

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Intelligent Transport Systems (ITS).

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Executive summary

The present document provides a pre-standardization study for the deployment of C-ITS for charging and tolling operation. The proposed changes and adaptations to the C-ITS protocols would allow local road charging and payment applications to benefit from the deployment of C-ITS, with a minimal impact on existing standards.

The document starts with a general description of the existing payment applications in the transport domain. The main driving application is the European road tolling system which is presently implemented using the CEN DSRC standards. The present document describes the typical tolling zone geometry in this system and gives more details on its implementations such as the toll plaza with or without barriers and the free flow systems where electronic equipment is mounted on gantries in order not to force the traffic to slow down and/or inhibit lane changes. The road tolling technology can also be used for other payment applications including the management of parking space, energy charging and the access to city centres or ferries. Further use cases are envisaged including the payment at drive-through locations.

In a second step, the document proposes an architecture to perform the tolling transaction, leveraging the C-ITS technologies. In an existing DSRC system, the transaction equipment is deployed in every lane. In the proposed solution, a single R-ITS-S is able to operate the entire toll station, executing the payment transaction and communicating with the C-ITS enabled vehicles passing the tolling area. As the C-ITS technologies cover a larger area than the DSRC system, two major challenges need to be solved by this architecture:

- reliable geolocation of the connected vehicles when passing the toll area in the different lanes;
- security of the wireless communication and payment information during the transaction process.

The reliable geolocation of the vehicles in the tolling gate lanes is obtained at the R-ITS-S by applying corrections to the position broadcasted by vehicles in the CAM. A secure exchange of information allows to execute the payment operation while the vehicle crosses the toll gate. With the proposed application, the customer does not provide any payment data until its application is able to authenticate the service provider.

A proof-of concept of the proposed application, combining the geolocation and the secure exchange of payment information has been implemented using the ITS-G5 technology. The present document describes the configuration of this test as well as the results obtained. An analysis of these results is provided. They show that the proposed method fulfils the requirement of an accuracy lower than one metre (indeed 0,3 metre was observed) to perform the ETC transaction and that in all the test runs, the lane used by the vehicle has been successfully identified. The security procedure used by the application has also been validated, in both cases when the provided vehicle identification is valid and invalid.

Finally, the present document proposes the required changes and adaptations of the C-ITS protocols for the support of the payment application. The adaptations are presented for each of the relevant protocol layers. Management entity, N&T and Access layers are not impacted, while new functions are introduced at the facilities and application level, as well as in the security entity. Performance considerations related to the impact on the C-ITS channel occupancy are computed, showing that only in peak hours the channel utilization would have to be carefully balanced.

1 Scope

The present document identifies potential requirements for the set of payment applications (including positioning and security requirements) and investigates possible updates and changes to the existing set of ETSI Cooperative ITS standards using V2I communication to support locally hosted payment applications including Electronic Fee Collection (EFC) and other general payment applications.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] Directive (EU) 2019/520 of the European Parliament and of the Council of 19 March 2019 on the interoperability of electronic road toll systems and facilitating cross-border exchange of information on the failure to pay road fees in the Union.

[i.2] Commission Implementing Regulation (EU) 2020/204 of 28 November 2019 on detailed obligations of European Electronic Toll Service providers, minimum content of the European Electronic Toll Service domain statement, electronic interfaces, requirements for interoperability constituents and repealing Decision 2009/750/EC.

[i.3] ISO 17573-2: "Electronic fee collection -- System architecture for vehicle related tolling -- Part 2: Terminology".

[i.4] CEN EN 15509: "Electronic fee collection - Interoperability application profile for DSRC".

[i.5] ISO 14906: "Electronic fee collection -- Application interface definition for dedicated short-range communication".

[i.6] ISO 15628: "Intelligent transport systems -- Dedicated short range communication (DSRC) -- DSRC application layer".

[i.7] CEN/TS 16986: "Electronic Fee Collection - Interoperable application profiles for information exchange between Service Provision and Toll Charging".

[i.8] ISO/TS 17575: "Electronic fee collection -- Application interface definition for autonomous systems".

[i.9] CEN/TS 16331:2012: "Electronic fee collection. Interoperable application profiles for autonomous systems".

[i.10] IEEE Std 1609.11-2010™: "IEEE Standard for Wireless Access in Vehicular Environments (WAVE) -- Over-the-Air Electronic Payment Data Exchange Protocol for Intelligent Transportation Systems (ITS)".

[i.11] ARIB STD T-75: "Dedicated Short-Range Communication System", Version 1.0, September 2001.

[i.12] ETSI ES 200 674-1: "Intelligent Transport Systems (ITS); Road Transport and Traffic Telematics (RTTT); Dedicated Short Range Communications (DSRC); Part 1: Technical characteristics and test methods for High Data Rate (HDR) data transmission equipment operating in the 5,8 GHz Industrial, Scientific and Medical (ISM) band".

[i.13] ETSI EN 302 890-1: "Intelligent Transport Systems (ITS); Facilities layer function; Part 1: Services Announcement (SA) specification".

[i.14] ETSI TS 103 097: "Intelligent Transport Systems (ITS); Security; Security header and certificate formats".

[i.15] Francesco Dionori et al: "Technology options for the European electronic toll service", EC study, April 2014.

[i.16] ETSI TR 103 300-1: "Intelligent Transport System (ITS); Vulnerable Road Users (VRU) awareness; Part 1: Use Cases definition; Release 2".

[i.17] Malalatiana Randriamasy: "Localization and secure transmissions for Vehicle to Infrastructure communication (V2I): Application to the electronic toll service using the ITS-G5 technology", PhD thesis, May 2019.

[i.18] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation), OJ 2016 L 119/1.

[i.19] Malalatiana Randriamasy, Adnane Cabani, Houcine Chafouk, Guy Fremont: "Reliable vehicle location in electronic toll collection service with cooperative intelligent transportation systems", PIMRC 2017.

[i.20] Malalatiana Randriamasy, Adnane Cabani, Houcine Chafouk, Guy Fremont: "Evaluation of methods to estimate vehicle location in Electronic Toll Collection Service with C-ITS", Intelligent Vehicles Symposium 2018: 748-753.

[i.21] "Geolocation Process to Perform the Electronic Toll Collection Using the ITS-G5 Technology". Malalatiana Randriamasy, Adnane Cabani, Houcine Chafouk, Guy Fremont: IEEE Trans. Vehicular Technology 68(9): 8570-8582 (2019).

[i.22] ISO/IEC 27001:2013: "Information technology -- Security techniques -- Information security management systems - Requirements".

[i.23] Malalatiana Randriamasy, Adnane Cabani, Houcine Chafouk, Guy Fremont: "Formally Validated of Novel Tolling Service With the ITS-G5", IEEE Access, vol. 7, pp. 41133-41144, March 2019.

[i.24] The AVISPA team. AVISPA v1.1 User Manual, June 2006. .

NOTE: Available at http://www.avispa-project.org/package/user-manual.pdf.

[i.25] ETSI EN 302 637-2: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

[i.26] Commission Delegated Regulation (EU) 2020/203 of 28 November 2019 on classification of vehicles, obligations of European Electronic Toll Service users, requirements for interoperability constituents and minimum eligibility criteria for notified bodies.

[i.27] ACEA Position Paper: "Access to vehicle data for third-party services", December 2016.

[i.28] CEN/TR 16690: Electronic Fee Collection - Guidelines for EFC applications based on in-vehicle ITS stations.

[i.29] CEN ISO/TS 17444-1: "Electronic fee collection -- Charging performance -- Part 1: Metrics".

[i.30] CAR 2 CAR Communication Consortium: "Basic System Profile", Document number RS-2037, Release 1.4.0, September 2019.

[i.31] ISO 17573-1: "Electronic fee collection -- Systems architecture for vehicle-related tolling -- Part 1: Reference model".

[i.32] ETSI TS 101 556-1: "Intelligent Transport Systems (ITS); Infrastructure to Vehicle Communication; Electric Vehicle Charging Spot Notification Specification".

[i.33] ETSI TS 101 556-3: "Intelligent Transport Systems (ITS); Infrastructure to Vehicle Communications; Part 3: Communications system for the planning and reservation of EV energy supply using wireless networks".

[i.34] ISO 12855:2015: "Electronic fee collection -- Information exchange between service provision and toll charging".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

charging: electronic fee collection payment process

DSRC: Dedicated Short-Range Communication used for tolling applications (as specified in ISO 15628 [i.6])

electronic fee collection: fee collection by electronic means (see ISO 17573-2 [i.3])

enforcement: measures or actions performed to achieve compliance with laws, regulations or rules (see ISO/TS ISO 17573-2 [i.3])

localization augmentation: information delivered to on-board equipment about the current geographical location or the identity of a charge object (see ISO/TS ISO 17573-2 [i.3])

EXAMPLE: This may happen for example when the satellite signals are insufficient for adequate positioning.

on-board equipment: all required equipment on-board a vehicle for performing required Electronic Fee Collection (EFC) functions and communication services (see ISO/TS ISO 17573-2 [i.3])

roadside equipment: fixed or movable equipment located along or on the road

NOTE: Derived from ISO/TS ISO 17573-2 [i.3], can be applied to both ETC and ITS.

toll: charge, tax, fee, or duty in connection to using a vehicle within a toll domain (see ISO 17573-2 [i.3])

toll charger: entity which levies toll for the use of vehicles in a toll domain (see ISO 17573-2 [i.3])

toll declaration: statement to declare the usage of a given toll service to a Toll Charger (see ISO 17573-2 [i.3])

toll domain: area or part of a road network where a certain toll regime is applied (see ISO 17573-2 [i.3])

toll regime: set of rules, including enforcement rules, governing the collection of tolls in a toll domain (see ISO 17573-2 [i.3])

toll service: service enabling users to pay toll (see ISO 17573-2 [i.3])

toll Service Provider: entity providing toll services in one or more toll domains (see ISO 17573-2 [i.3])

transport service: transport infrastructure related service which is offered to the user (see CEN EN 15509 [i.4])

3.2 Symbols

For the purposes of the present document, the following symbols apply:

a longitudinal acceleration

δ	steering wheel angle
θ	direction of the vehicle
v	speed
w	yaw rate
(x, y)	UTM coordinates

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AC-CR	ACcess CRedential
ACEA	Association des Constructeurs Européens d'Automobiles
ANPR	Automatic Number Plate Recognition
BO	Back Office
BST	Beacon Service Table
CA	Constant Acceleration
CAM	Cooperative Awareness Message
CAN	Controller Area Network
CCC	Compliance Check Communication
CEN	Comité Européen de Normalisation (European Committee for Standardisation)
CRL	Certificate Revocation List
CTRA	Constant Turn Rate and Acceleration
CTRV	Constant Turn Rate and Velocity
CV	Constant Velocity
C2C-CC	Car 2 Car Communication Consortium
DCC	Decentralized Congestion Control
DENM	Decentralized Environmental Notification Message
DSRC	Dedicated Short-Range Communications
EC	European Commission
ECC	Electronic Communications Committee
EDM	Enhanced Dynamic Model
EETS	European Electronic Tolling Service
EFC	Electronic Fee Collection
EGNOS	European Geostationary Navigation Overlay Service
ETC	Electronic Toll Collection
ETSI	European Telecommunications Standards Institute
FA	Facilities to Application
GDPR	General Data Protection Regulation
GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HDR	High Data Rate
HLPSL	High-Level Protocol Specification Language
HMI	Human-Machine Interface
HSM	Hardware Secure Module
IEEE	Institute of Electrical and Electronics Engineers
ISMS	Information Security Management System
ITS	Intelligent Transport Systems
LAC	Localisation Augmentation Communication
MEMS	MicroElectroMechanical System
MDR	Medium Data Rate
MLFF	Multi-Lane Free-Flow
MMI	Man-Machine Interface
OBE	On-Board Equipment
OBU	On-Board Unit (alternative for OBE)
OSI	Open Systems Interconnection
OTA	Over-The-Air
PAN	Personal Account Number
PKI	Public Key Infrastructure
PoC	Proof of Concept
PoTi	Position and Time

RF	Radio Frequency
R-ITS-S	Roadside ITS Station
RLAN	Radio Local Area Networks
RSE	Road Side Equipment
RSU	Road Side Unit (alternative for RSE)
RTI	Road information Systems
RTK	Real-Time Kinematic
RTTT	Road Transport & Traffic Telematics
RX	Receive
SAEM	Services Announcement Extended Message SCH Service Channel
TC	Toll Charger
TLS	Transport Layer Security
TSP	Toll Service Provider
TX	Transmit
UID	Unique IDentifier
UTM	Universal Transverse Mercator (coordinates)
V-ITS-S	Vehicle ITS Station
VRU	Vulnerable Road User
VST	Vehicle Service Table
WAVE	Wireless Access in Vehicular Environments
WG	Working Group

4 Payment use cases

4.1 Overview

In clause 4, a general description of the existing payment applications in the transport domain is given. The main driving application is the European road tolling system which is actually implemented using the CEN DSRC standard CEN EN 15509 [i.4]and the ETSI HDR DSRC standard ETSI ES 200 674-1 [i.12] based on the corresponding EC directive [i.1]and its Delegated Regulation [i.26] and Implementing Regulation [i.2]. This technology can also be used for other payment applications including the management of parking space and the access to city centres. Further use cases are envisaged including the payment at drive-through locations.

4.2 Electronic Toll Collection

4.2.1 Overview

Typical implementations of a tolling system are the following:

- Toll plaza systems with up to 40 parallel lanes (typically around 10 to 20 lanes in each traffic direction).
- Free-Flow tolling systems with a maximum of 6 parallel lanes (typically 3 to 4 lanes in each traffic direction).

Toll plaza systems are typical for tolling of motorways and are mostly located in large open areas with good GNSS reception. Free-flow tolling systems are more versatile and can be used both for motorway tolling even under complex infrastructural conditions such as tolling of narrow urban highways or inside tunnels, as well as for urban charging systems applied in environments with "urban canyons".

Other technology combinations are possible such as:

- GNSS based tolling, with enforcement based on DSRC (e.g. ETC used in Germany).
- Video tolling and enforcement based on license plate recognition.

For these two combinations, the operation is similar to free flow tolling: the OBUs are controlled by roadside equipment installed on gantries.

The traffic demand determines the configuration of the deployed tolling system. Table 1, derived from an EC study on European electronic toll service (EETS) [i.15] and road operator measurements, shows the capacity according to the tolling technology.

Table 1: Capacity depending on the tolling technology

Source	Capacity (vehicles / hour /lane)		
	ETC with barriers	**ETC reduced speed**	**Multilane free flow**
Villalonga (2010)	650-750	1 200	N/A
Dancso (2008)	500-600	1 000	3 000
SANEF measures	600	800	N/A

The ETC transaction takes place according to the sequence described in Table 1 titled "Overview of DSRC L7 and EFC functions" given in section 6.1.3 of CEN EN 15509 [i.4]. This table describes the DSRC-L7 services and EFC functions involved in the transaction. See also clause A.4 for related information.

NOTE: The OBU tag emits the beep after the SET_MMI message described in the table.

4.2.2 Plaza systems

4.2.2.0 General considerations

Three types of tolling systems in plazas need to be differentiated:

- automatic barrier (stop&go); generally, toll lanes are of different types: ETC, automatic machines, manual (toll collector);
- automatic ETC lane (reduced speed);
- non-stop ETC lanes.

Figure 1: Toll plaza with non-stop ETC lane (far left), stop&go ETC (centre lanes) and automatic lane (right)

Figure 2: Toll plaza with non-stop ETC lanes (left), stop&go ETC and automatic lanes (right)

4.2.2.1 Example of French System

In France, two types of ETC system with barriers exist: the stop-and-go mode, and the non-stop mode with reduced speed.

For the stop-and-go mode, when the driver crosses the toll gates, he has to stop until one beep from the OBU tag sounds shortly.

For the non-stop mode with reduced speed (30 km/h, 50 km/h), the beep from the tag is emitted a few seconds earlier than the stop-and-go mode.

This is possible since there are two RSUs in the concerned lane. Indeed, the transaction occurs a few meters before the barrier with the first RSU, and the second RSU relays the communication if the communication with the first RSU was interrupted.

4.2.3 Free flow tolling systems

Infrastructure based multilane free flow systems use Road Side Equipment (RSE) configured with electronic equipment mounted on gantries in order to not force the traffic to slow down and/or inhibit lane changes. There are as many RSE as lanes on the road. The equipment has three functions (see also Annex A):

- localisation;
- charging via RF communication;
- enforcement using local cameras.

Localisation is important even in the case of a free flow tolling system as it enables the activation of cameras that record the license plate number if the transaction is not successful (back office processing).

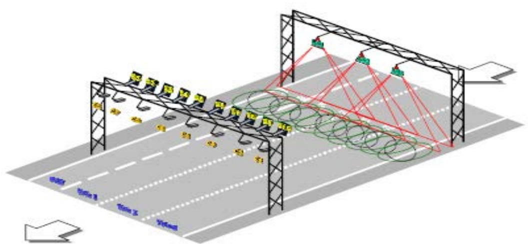

Figure 3: Free-flow situation

Figure 4: Typical free-flow installation with three lanes

Figure 5: Typical free-flow installation with four lanes

The typical tolling zone geometry of a free flow CEN DSRC tolling system (described in Annex A) is depicted in Figure 6 for a two-lane scenario. The "tolling zone" is the physical zone where the ETC is conducted with the OBU. The tolling zone should have an appropriate extension to ensure that all vehicles driving on the tolled road are charged, and that vehicles driving on other adjacent/nearby roads are not charged.

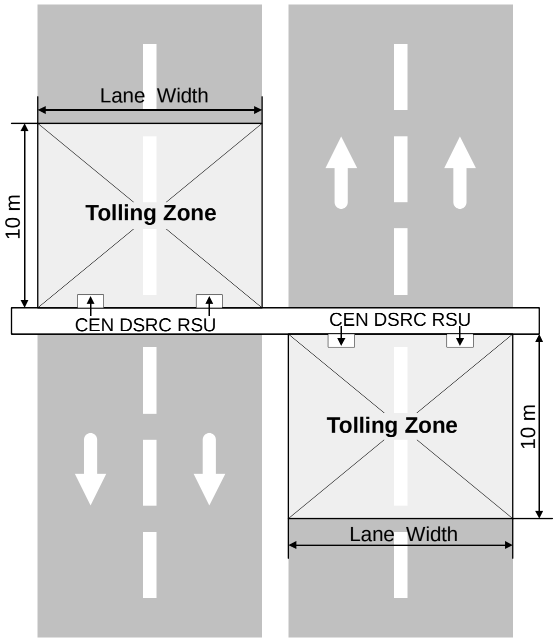

Figure 6: Typical tolling zone geometries for a two-lane free flow scenario

NOTE: To ensure the differentiation between the two directions, especially in the case of motorcycles, a minimum gap needs to be provisioned between the two tolling zones. However, in CEN DSRC, the system tracks the vehicles in one direction only and thus is able to determine in which direction the motorcycle is progressing.

4.3 Parking Fee application

In a parking configuration, there are typically 2 to 4 payment lanes equipped with automatic machines (normal payment) and potentially stop&go EFC. These lanes can usually support both payment methods. The lanes additionally include licence plate cameras for fraud enforcement. The licence plate numbers are being read at the parking entrance and stored in the back office with the parking ticket ID number. If the parking ticket does not match with the licence plate number of the vehicle at the exit, the transaction is not validated, and the barrier remains closed.

The following consideration apply when considering EFC for parking payment:

1) When entering a parking area - passing an EFC gate - the vehicle will always move very slowly, with or without a barrier.

2) If GNSS localization is used, the gates for entering and exiting should be under open sky, i.e. GNSS should be available in good quality. This is not naturally true for entrances to car parks and should be especially mentioned.

3) To determine the correct payment, the vehicle is captured twice with a time stamp and a unique vehicle ID (e.g. ticket ID and/or license plate):

   - first, when **entering** the parking area (Start of parking);

   - second, when **leaving** the parking area (End of parking). because only then it is clear which amount of money based on the time the vehicle spent in the parking needs to be charged.

4) The billing is based on the time spent between these two points in time (time-based pricing, different from the distance-based pricing of road tolling).

Security and privacy aspects are very important for such payment systems. For example, the use of license plate recognition might be sometimes problematic, for example in Germany, and the general recommendation today is not to rely on it.

The throughput of a toll parking lane with manual payment is typically about 160 to 180 vehicles/hour.

4.4 General payment application

Below is a non-exhaustive list of use cases involving vehicular payment applications. Some of these use cases were implemented in Italy and/or Portugal at the time the present document was prepared:

- Energy charging, whether it be electric charging (see ETSI TS 101 556-1 [i.32] and ETSI TS 101 556-3 [i.33]) or regular filling station delivering petrol is under investigation in some installations in Portugal. The RSE is located at one of the energy delivery parking places, which allows to authorise the delivery and prepare the payment charging once the energy delivery has completed.

- Dynamic recharging road section: this is a section of road able to supply electricity to electric vehicles. This future concept may encourage the massive adoption of electric vehicles by shifting part of the energy supply to road infrastructure. In that use case, the OBU presence is recorded both at the entrance and exit of the section, which allows to charge the energy delivered in the same manner as road tolling.

- Ferry: Tolling for using a ferry boat is already applied in the same manner as road tolling when the vehicle enters and leaves the ship. The OBU enables the classification of the vehicle and the application of the related fee (e.g. truck, van, passenger car).

- Drive-in commercial usage, for example at restaurants or chemistry is under investigation in some prototype installations. When road tolling is enabled, the amount of goods bought is charged directly to the holder's account.

Even though it is not a payment application, but rather used for regulation enforcement, the digital tachograph technology is based on similar mechanisms and on the same DSRC access technology.

4.5 Summary

Table 2 provides a summary of the main characteristics of the use cases presented above, including the needed positioning precision and transaction times. The positioning requirement is in a scale similar to the VRU positioning requirement, see ETSI TR 103 300-1 [i.16].

Table 2: Positioning and Transaction time requirements

Services		Description	Positioning precision with 99,9 % confidence	Time accuracy (milliseconds)	Maximum processing time
5,8 GHz DSRC road tolling	ETC with barrier	A barrier opens when a vehicle with an OBU enters the coverage of the RSU radiation pattern and a valid ETC transaction is performed	Less than the dimension of the vehicle in front of the barrier. i.e. better than ±1 m width and ±1 m length.	±500	100 milliseconds to start opening the barrier
	Multilane Free-flow payment	An ETC transaction is performed when a vehicle with an OBU passes a toll gantry	Less than the dimension of the passing vehicle. i.e. better than ±1 m width and ±1 m length.	±100	10 milliseconds to signal the correctness of the toll transaction.
	Multilane Free-flow enforcement	In an enforcement station a picture needs to be taken of the vehicle license plate when no OBU or no valid OBU is mounted in the vehicle. The picture is matched by the timestamp to the transaction and to classification data coming from other sensors.	Less than the dimension of the passing vehicle. i.e. better than ±1 m width and ±1 m length.	±10	10 milliseconds to signal the correctness of the toll transaction.
Parking application		The vehicle is stopped within the coverage of an RSU radiation pattern at an exit barrier to check for an OBU, Optionally, an RSU may also be positioned at the entrance. The barrier opens automatically after a valid EFC transaction is performed. Otherwise, a paper ticket is needed to open the exit barrier.	Less than the dimension of the vehicle in front of the barrier. i.e. better than ±1 m width and ±1 m length.	±1 000	Less than a second to start opening the barrier
General payment application		Like parking, but the OBU is checked only when exiting the payment area. Without OBU another means of payment is necessary to open the barrier.	Less than the dimension of the vehicle in front of the barrier. i.e. better than ±1 m width and ±1 m length.	±1 000	Less than a second to start opening the barrier

5 Proof of concept for road tolling with C-ITS protocols

5.1 Possible tolling evolution using C-ITS

5.1.1 General overview

The tolling payment application is among the prospective services which can benefit from C-ITS, as a new way to collect toll fees on highways for connected vehicles (see [i.15], section 3.5.9). This clause proposes an architecture and mechanisms to perform the tolling transaction leveraging the C-ITS technologies in the R-ITS-S of the Roadside Equipment (RSE) and the V-ITS-S of the On-Board Equipment (OBE) with features specified in ETSI C-ITS standards. Clause 5.2 describes a Proof of Concept (PoC) for this application [i.17].

The tolling system proposed in clause 5.1 is technology agnostic. It can be implemented using any access layer, as long as it is able to support the broadcast of C-ITS messages such as CAM and SAEM using the security mechanisms described in ETSI TS 103 097 [i.14], as well as the unicast of tolling messages directly between V-ITS and R-ITS-S. The access technology should also be capable to provide reliable communication (in terms of packets lost on the radio channel, delay and congestion management, while including unicast) between V-ITS-S and R-ITS-S over the tolling plaza area and possibly shared channels. The PoC described in clause 5.2 has been tested under real life conditions with the ITS-G5 access technology.

In existing ETC installations, an RSE is deployed in every lane. When the vehicle enters the coverage area of the CEN DSRC RSE, the CEN DSRC OBE answers to the request from the CEN DSRC RSE and exchanges the charging information with this RSE. Typical transaction performance of CEN DSRC systems is around 99,9 % of successful transactions over the total number of passages.

In the proposed solution, a single R-ITS-S is able to operate the entire toll station, performing the payment transaction and communicating with the C-ITS enabled vehicles passing the tolling area. This allows to reduce equipment costs through a decrease of the number of deployed equipment. In line of sight conditions, an ITS station (R-ITS-S or V-ITS-S) can communicate over up to one kilometre. This means in theory that a single R-ITS-S can handle the whole toll area. In practice, the system may need replication of the R-ITS-S for fault tolerance, to ensure scalability, and to increase performance. The proposed solution would also enhance the customer experience by combining the ETC application in the same equipment as other C-ITS applications. In the case of a closed tolled road (i.e. with an entrance and exit gate), the proposed solution behaves like the CEN DSRC deployment: the entrance gate is recorded in V-ITS-S and is provided with the payment information at the exit gate to enable the toll computation. This does not apply to the free flow tolling system which always behaves as an open tolled road. In existing DSRC ETC, the coverage area is very small, thus the transaction occurs in front of the lane barriers of the toll station and the OBU/vehicle localization accuracy is 100 % by design.

In contrast, the proposed R-ITS-S evaluates the car position when it arrives in front of the toll gate or passes the gantry in a free flow scenario. As the C-ITS technologies cover a larger area, two major challenges need to be solved by this architecture:

- reliable and accurate geolocation of the connected vehicles when passing the toll area in the different lanes;
- security of the wireless communication and payment information during the transaction process.

Figure 7 illustrates the placement of the R-ITS-S (noted as RSU) appointed to the tolling service on the tolling plaza. For the stop-and-go situation, the gate in each lane will open when the ETC transaction has been completed and validated (detection of the vehicle and ETC identification information).

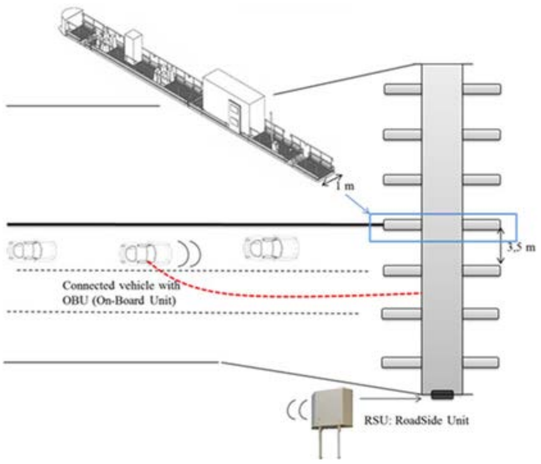

Figure 7: Possible ETC system using R-ITS-S equipment

The architecture and mechanisms described in clause 5.1 should be seen as an additional software brick that integrates with the infrastructure's electronic toll collection application. It leverages the benefit of using messages such as CAM from C-ITS-enabled vehicles passing the toll station and SAEM sent by the R-ITS-S. Using CAM also means paying particular attention to the process of retrieving, processing and storing the broadcasted data. Indeed, the use of the latter is subject to the regulations of the GDPR directive [i.18], e.g. personal data captured to perform the transaction procedure, as well as the vehicle location tracking in the tolling zone needs to be as short as possible and prior consent is obtained at subscription time (see clause 5.1.4, step 1).

ACEA Position Paper [i.27] includes the following statements:

- "***Privacy and data protection:*** *In accordance with EU and national data protection and privacy laws, personal data of vehicle users will be made available to service providers only with the consent of the vehicle user except where a legal requirement or a contract exists. Service providers shall use this data only for the purpose(s) for which the vehicle user gave his or her consent.*"

- "***Personalised services:*** *Example: 'Pay how you drive' insurance, electric vehicle infrastructure routing for charging (pay and charge). Except where a legal requirement or a contract exists, personal data will be made available to service providers only with the consent of the vehicle user. Service providers shall use this data only for the purpose(s) for which the vehicle user gave his or her consent.*"

Clause 5.1 introduces a new methodology used to address the challenges of reliable geolocation and security of the transaction process. Clause 5.2 presents the results obtained from a Proof of Concept under real life conditions using this methodology. Clause 5.3 summarises the proposed solution and its benefits.

5.1.2 Reliable and accurate geolocation

To improve accuracy and reliability in the context of a tolling application, it is proposed to use the tracking of the vehicle's trajectory to predict the lane where the vehicle will be located when crossing the toll gate. At a toll plaza, not all vehicles will go through the same toll gate. Indeed, some of them may even switch lane at the last minute (considering however the 20 meters concrete wall ahead of the barrier). Furthermore, for the infrastructure and the toll charger entity it is important to know exactly when each vehicle passes which toll gate to timely trigger the OPEN command to the barrier in the appropriate lane. The objective is to avoid queues at the plaza due to non-opening of barriers, but also loss of income due to false opening of barriers. The reliable geolocation is thus split into two algorithms:

- one for tracking the vehicle trajectory; and

- one for obtaining a sufficient position accuracy.

In free flow mode as well, knowing the location of a vehicle at a certain point of time allows to associate the vehicle with a valid toll transaction. In this mode, the effective positioning on one lane is also important to be able to activate the cameras that record the license plate number when the transaction was not successful and/or to associate the image data to the unsuccessful transaction. Some of the data processing and security checks can be done in the back office or in an edge computer system.

The process below is described with more details in conference papers [i.19], [i.20] and [i.21].

The presumed requirements for the proposed accurate localisation method are the following:

- E1: position accuracy less than 1 metre with 99,9 % confidence, to distinguish between 2 neighbouring vehicles (i.e. following one another or progressing in parallel). In the case of motorcycles, this accuracy is reduced to 0,3 metre;

- E2: fewer equipment to be deployed than with the current electronic toll system (1 master R-ITS-S and 1 backup R-ITS-S when no scalability concern);

- E3: tightly delimit the duration of the tracking to restrict it to the time necessary to perform the tolling transaction.

Tracking the vehicle trajectory

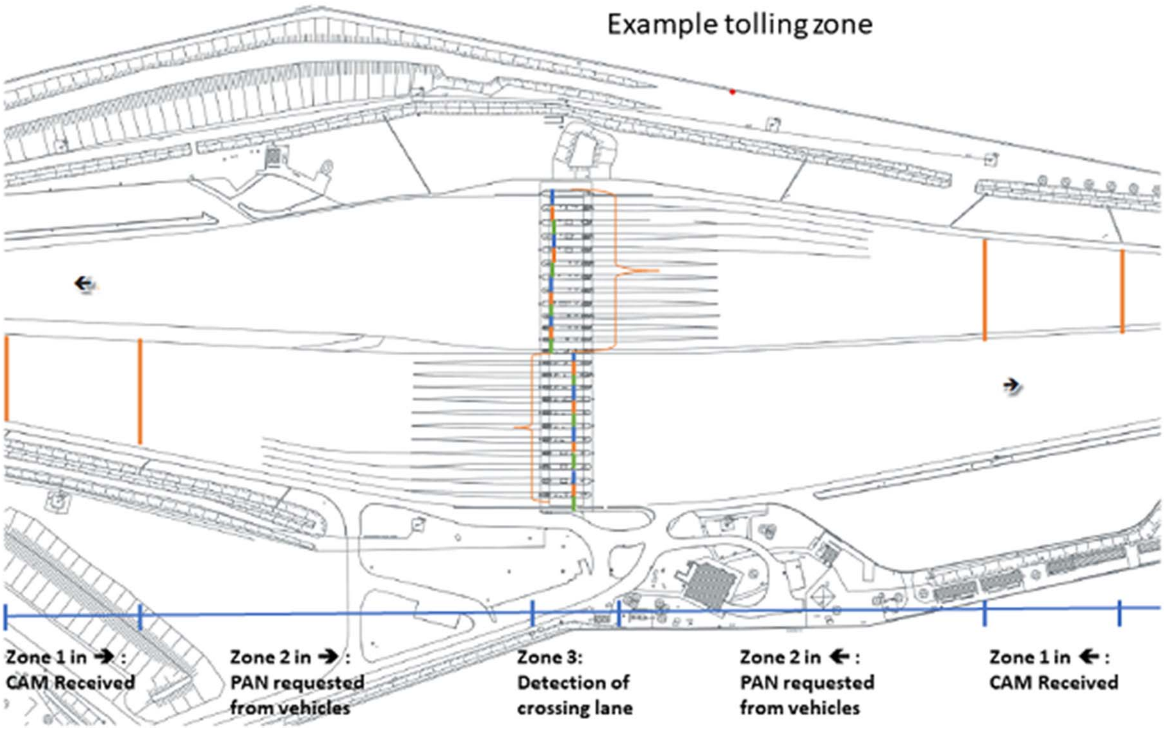

Figure 8: Zones used during vehicle geolocation

The tracking of the vehicle can be divided into three phases, which are delimited by well-defined zones. These zones are illustrated in Figure 8:

- The first zone starts at the point where the first CAM of the vehicle is received.
- The second zone is the limit zone where it is sure that the vehicle will cross the toll gate (paying zone). There may be an exit route between the first point and this limit. The communication between the vehicle and the infrastructure to perform the payment can be initiated while the R-ITS-S continues to track and corrects the position of the vehicle (see below) until it enters one of the toll lanes.
- The third zone is the tolling area where the transaction is completed.

Figure 9 illustrates this tracking process, which is implemented for all the three zones.

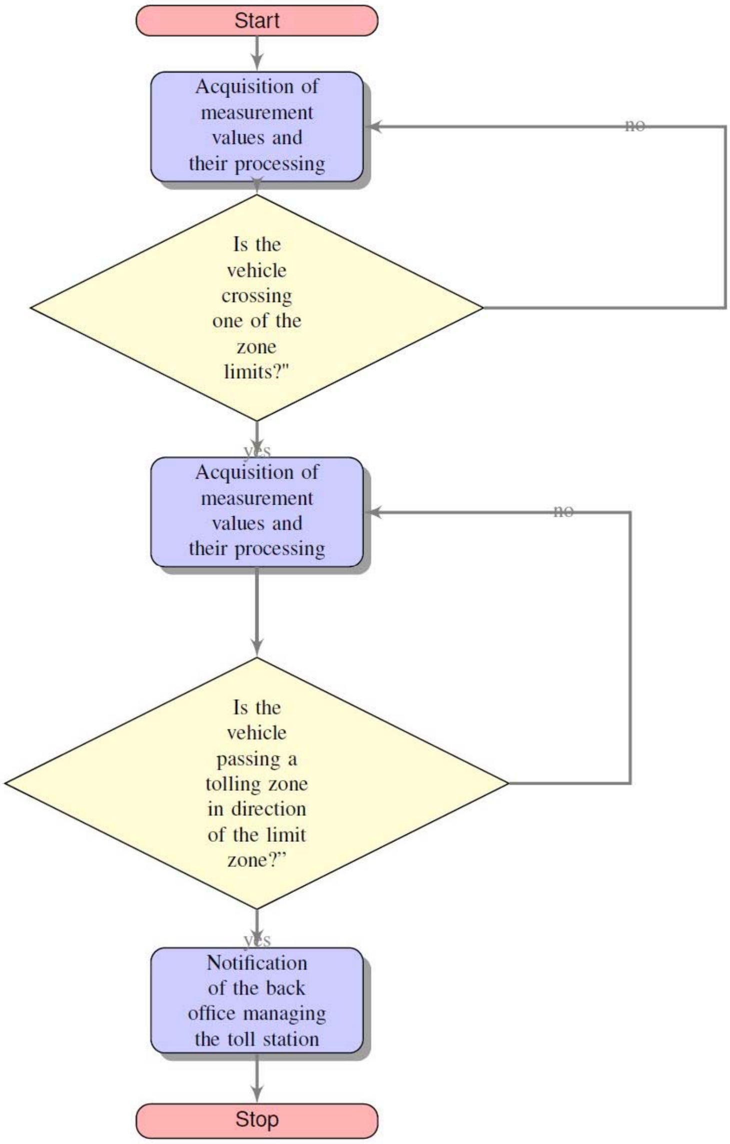

Figure 9: Geolocation stages

Obtaining a sufficient location accuracy

In this part, the proposed method to solve the geolocation challenge is described. This method for location accuracy benefits from the communications data received from the CAM. Furthermore, it uses the principle of Differential - GNSS mixed with Kalman Filtering and Extended Kalman filtering [i.21] applied to the position measurements received by the R-ITS-S from the vehicles to enhance this measurement at the R-ITS-S level.

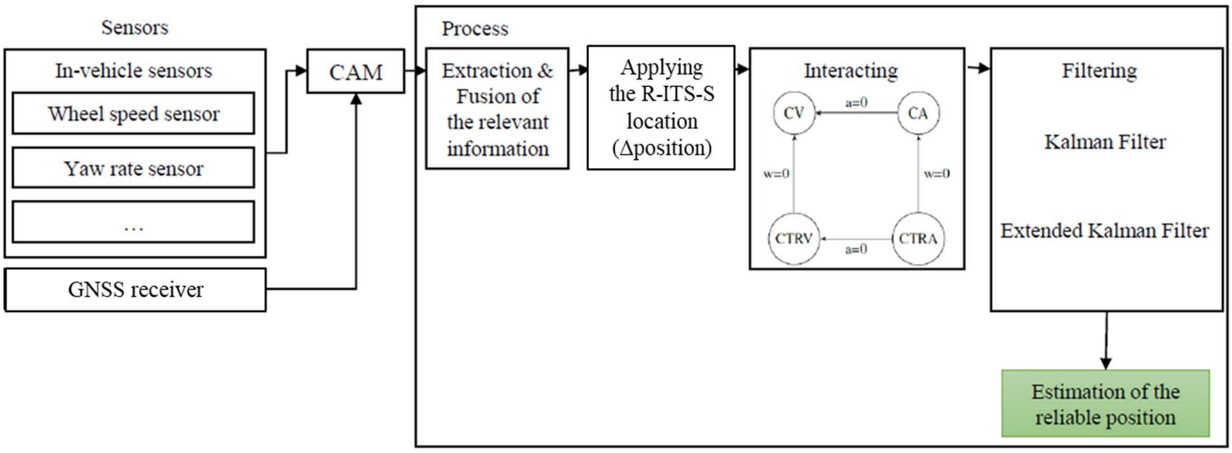

Figure 10: Global view of the geolocation method

The global view of the geolocation method is shown in Figure 10. Figure 11 summarizes this process starting from when the R-ITS-S receives the first CAM from the subscribed vehicles equipped with the payment application. This process is explained with further details in the next paragraphs.

Subscribed vehicles identify themselves by answering the SAEM broadcasted by the R-ITS-S while in Zone 1. This is detailed in clause 5.1.4, step 2.1. Vehicles that do not answer the SAEM are not tracked and are expected to pay by any other means.

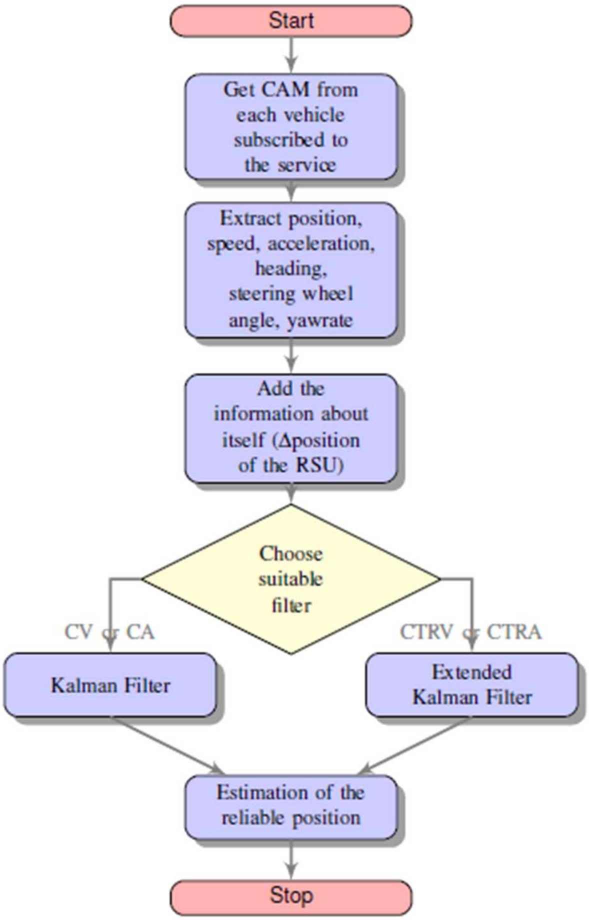

Figure 11: Loop process as long as the R-ITS-S (noted as RSU) receives CAM from the subscribed vehicles

Step 1: Get CAM from each subscribed vehicle and extract its data

Hence, this method benefits from the CAM messages received from each connected vehicle to improve its geolocation information. Improving the geolocation information is possible because data elements such as speed or steering wheel angle are captured by sensors other than the GNSS and can be used to improve the reference position measurement. This method allows to use only one R-ITS-S to detect all the enabled vehicles crossing the tollgates.

The CAM data elements used in this process are:

- reference position that gives the GNSS coordinates as provided by the V-ITS-S GNSS receiver: latitude and longitude. Both coordinates are converted into UTM coordinates (x, y);
- heading as provided by compass: it gives us the direction of the vehicle, θ;
- Speed as provided by the odometer, v;
- longitudinal acceleration as measured by MEMS, a;
- yaw rate as provided by the CAN Bus, w;
- steering wheel angle as provided by the CAN Bus, δ.

Since these data elements, besides the reference position, are used to perform a Kalman filtering, they are assumed to be measured independently from the reference position obtained through the GNSS. This is the case in original equipment vehicles, where these measurements are performed by components connected to the CAN bus. Under other conditions, the geolocation correction applied by the R-ITS-S through the Kalman filtering may be less efficient.

It should be noted that there is neither common practice nor obligation from the standards to use different sources of information to populate the CAM data elements. Additionally, the use of other sensor data than GNSS does only reduce the measurement uncertainty when at least its relative accuracy is in the same order or higher than the GNSS accuracy (see C2C-CC basic system profile [i.30]).

Step 2: Pre-treatment - correct with delta Position

In this approach, the differential of the position of the vehicle by means of the differential position by the R-ITS-S is computed. Indeed, the R-ITS-S has a static real position and a GNSS measurement. The gap, or delta position, between these 2 values is applied to the position of the vehicle. This approach assumes that all connected equipment close to the R-ITS-S has the same error of GNSS measurement as the R-ITS-S (inspired by the principle of Differential-GPS where the R-ITS-S plays the role of the base station).

This pre-treatment step is not needed if the vehicle indicates a high horizontal position accuracy in the CAM data, because the V-ITS-S already uses methods to enhance its GNSS position.

Step 3: Apply Filtering

The objective of this step is to improve the accuracy of the vehicle's trajectory by applying suitable filtering on the measured position values. To do this, the following Bayesian methods are used: Kalman filtering and Extended Kalman filtering [i.21].

Different models are applied according to the detected behaviour of the vehicle, using the value of the data elements obtained in the CAM messages: GNSS coordinates, speed, heading, acceleration, yaw rate, and steering wheel angle.

Indeed, when approaching the toll gate, vehicles can take any lane and arrive with any type of kinematics. Therefore, as the vehicle approaches the toll gate, it can be determined to be in one of the following four states for a period of 100 milliseconds based on the values of the CAM data element received by the R-ITS-S:

- CV [state (1)]: Constant Velocity ν in straight-line travel;
- CA [state (2)]: Constant Acceleration (or deceleration) a in straight-line travel;
- CTRV [state (3)]: Constant Turn Rate w and Velocity ν in curvature travel;
- CTRA [state (4)]: Constant Turn Rate w and Acceleration in curvature travel.

Figure 12 presents the Enhanced Dynamic Model (EDM) and the state transitions according to the value of the related data elements.

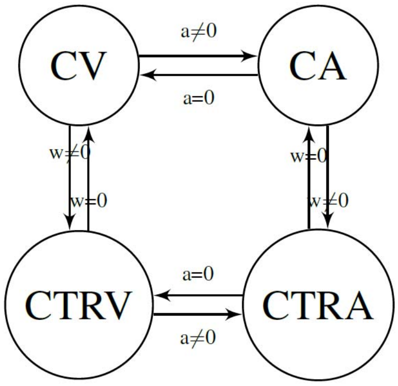

Figure 12: Transitions between vehicle motion state by setting one variable to zero

Each state is associated to a specific dynamic motion model. For states (1) and (2), Kalman filtering is applied to the system, and for states (3) and (4), the Extended Kalman filtering is used. The Kalman filtering is efficient for linear movements, and the Extended Kalman filtering is better suited to handle the non-linear movements in a curve. The different dynamic motion models and associated equations corresponding to each of the above states are further described in the referenced papers [i.20] and [i.21].

After applying the filter suitable to the corresponding state related to the kinematic of the vehicle, the expected result is to obtain a sufficient position accuracy (about 1 meter) that will permit the R-ITS-S to define exactly in which lane the vehicle is located.

5.1.3 Secure exchange of payment information

The design of the secure architecture of the toll payment service with the C-ITS technology complies with the recommendation of the standard ISO/IEC 27001 [i.22] enhanced with presumed requirements adapted to the context of payment with C-ITS equipment.

ISO/IEC 27001 [i.22] mainly recommends the compliance with the ISMS (Information security management system). i.e. the architecture applies the D.I.C.T. rules:

- Disponibility [D] or Availability;
- Integrity [I];
- Confidentiality [C];
- Traceability [T];

In addition to these rules, the following criteria are considered as important conditions to be fulfilled:

- Authentication;
- Non-repudiation;
- Managing the personal data.

The design of the security mechanism (see [i.17], [i.23]) ensures that only the provided service will be billed to the customers through the service provider. It permits to establish a mutual trust among them and to guarantee a positive user experience by proposing a method to perform the authentication of both the payment provider and the vehicle paying the toll. It secures the tolling transactions performed with the C-ITS equipment and the tolling server as a trusted party. It considers the privacy of the drivers' identities and is designed to prevent attacks.

Furthermore, the mechanism addresses the issue of payment over-the-air in the context of C-ITS. To perform the tolling transaction, a unicast (point-to-point) connection is used between the R-ITS-S of the infrastructure and the V-ITS-S in the vehicle, using IPv6 over one of the SCHs (Service Channel), the tolling transaction being considered as a service. The transaction can occur a few meters before the toll gate to avoid stopping the vehicle (in case of stop-and-go situation).

Indeed, critical exchanges take place between the R-ITS-S and the V-ITS-S. Therefore, these exchanges are executed through a secure C-ITS radio channel protected with the TLS (Transport Layer Security) protocol. In this case of wireless or OTA (over-the-air) communication, mutual authentication between each entity is required to ensure reliable communications.

The proposed method for ensuring communication security to carry out the electronic toll service needs to be applied at all stages: installation of the toll application in the V-ITS-S, user's subscription to the service provider and mainly when passing the toll area (the consumption of the service).

It is important to secure the exchange of data at stake because it is sensitive and can be used for fraudulent purposes. Therefore, to solve the security issue for the electronic toll application using C-ITS technology, four main presumed security requirements have been identified:

- E1: Integrity of data exchanged - between equipment and at service level;
- E2: Non-exhaustion on all operations carried out for each entity involved in the transaction (non-repudiation of every action);
- E3: Confidentiality of sensitive data;
- E4: mutual authentication between all entities involved in the transaction (subscriber, V-ITS-S, R-ITS-S, Service Provider).

The presumed security requirements highlight the needs to authenticate all entities from the three main actors: R-ITS-S, V-ITS-S in the vehicle linked to a subscriber account and the security back office of the tolling server involved in the transactions.

The authentication is ensured by the use of public key certificates, signatures and verification of signatures processes during all exchanges. To ensure the security of communications between the ITS-S, a Public Key Infrastructure (PKI) was created following ETSI TS 103 097 [i.14] addressing the broadcast of CAM and DENM. Certificate usage combined with the signature process certifies the mutual authentication between the different entities: the V-ITS-S with the R-ITS-S, the payer with the service provider and the R-ITS-S with the tolling server. The certificates could be stored in the tolling application of the V-ITS-S, the R-ITS-S or in a secure module (HSM: Hardware Secure Module). In this case, they are stored in the tolling application package of each entity. The European Electronic Toll Service (EETS) specified in CEN EN 15509 [i.4] also foresees the subscribed vehicle license plate number to be entered in the on-board equipment, together with the security keys.

NOTE: As this is performed when the vehicle is subscribed to the service, there is no side effect of multiple users of the vehicle, e.g. second-hand vehicle or rental vehicle.

The encryption of the messages and the verification of the signatures ensure the confidentiality, the integrity and the non-repudiation of all exchanged information.

5.1.4 Data exchanges between the V-ITS-S and the R-ITS-S

Step 1: Service subscription

One of the requirements to use the service is that the payer entity should be subscribed with an ETC Service Provider. During the user subscription, the user defines which process will be used to connect to the toll application (e.g. login/password, fingerprint, etc.). When saving this information, the back office of the security part of the Toll Service Provider generates the certificate associated to the subscriber and the relative public key. At this step, the vehicle user also formally gives his consent to use, for the purpose of the payment application, the data that will be broadcasted in the CAM from his vehicle.

The R-ITS-S appointed to perform the service should be registered with the back office of the security part of the toll service provider as well. For the registration of the R-ITS-S, the Unique Identifier (UID) of the road operator and the toll station where the R-ITS-S will be installed should be provided.

The registration of the V-ITS-S occurs during the installation of the tolling application in the vehicle system. The vehicle registration number or/and the UID of the C-ITS equipment should be provided. The V-ITS-S then computes and stores the private key associated to the public key of the delivered certificate.

Step 2: Coming in and crossing the toll gate

Step 2.1: Authentication of the Payee entity by V-ITS-S

In this use case aimed to perform specific services, the SAEM (Service Announcement Message) message [i.13] has been used. The R-ITS-S appointed to the tolling service broadcasts a regular message to announce the tolling station and tolling service (Service Announcement Message [i.13], e.g. 1 message per second) signed with its private key according to [i.14].

While in the first zone described in clause 5.1.2, a V-ITS-S that can apply to the service authenticates the R-ITS-S with the public key of the R-ITS-S (already stored in the V-ITS-S). The V-ITS-S can extract the payee entity (which interacts through the R-ITS-S) information such as its IP address to later communicate with the R-ITS-S. This is illustrated in Figure 13.

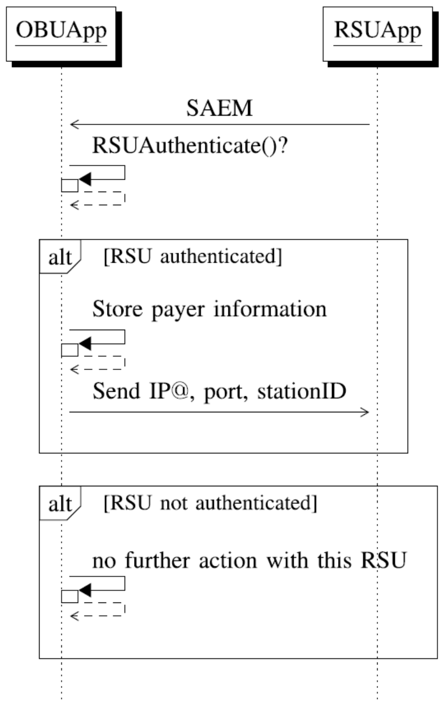

Figure 13: Authentication of the R-ITS-S (RSUApp) as a payee

Step 2.2: V-ITS-S Authentication

After the R-ITS-S authentication step, the V-ITS-S sends to the R-ITS-S a specific message that contains the V-ITS-S contact information and its public key certificate. The ITS-S ID retrieved from the CAM transmitted by the vehicle is sent together with this message, it allows to associate the vehicle and the transaction.

The R-ITS-S forwards this information to the Back Office of the security part of the service provider, which checks if this V-ITS-S information, ITS-S ID and certificate, is not blacklisted (i.e. associated with a revoked certificate) and responds either positively or negatively to the R-ITS-S. When positive, the response is signed by the private key of this security back office as a trusted party. The public key of the V-ITS-S, its Station ID and IP address are temporarily stored in the R-ITS-S. The R-ITS-S then sends an acceptance response to the V-ITS-S so that it can benefit from the service. The V-ITS-S decrypts the message and freezes its Station ID until the vehicle has finished crossing the tollgate. This is illustrated in Figure 14. It incurs a moderate risk of privacy as crossing the tollgate is usually achieved in a few seconds.

This solution tends to avoid changes in the BackOffice. Thus, what is referred to as BackOffice in Figure 14 onwards is actually done in a software located in the toll area and directly linked to the R-ITS-S.

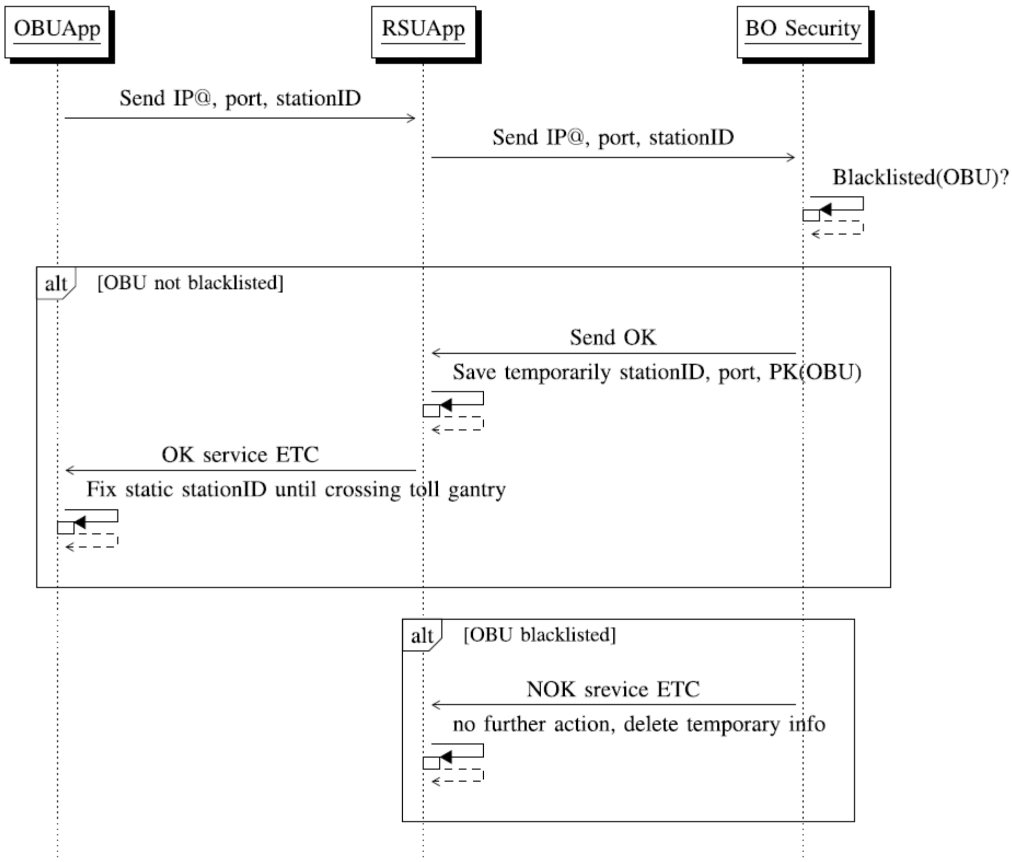

Figure 14: Authentication of the V-ITS-S (OBUApp) for eligibility to the service

Step 2.3: Authentication of the payer or service subscriber

When it enters the paying zone (or zone 2 as described in clause 5.1.2), the R-ITS-S requests from the V-ITS-S the identification of the account connected to the ETC service of the vehicle. The V-ITS-S replies to the R-ITS-S with a specific message that contains its payer information called PAN (Personal Account Number). This message should be signed with the V-ITS-S private key and encrypted with the symmetric session key. The borders of the area (paying zone) where the R-ITS-S can request the PAN in each direction are determined to ensure that the vehicle will pass the toll gantry.

The R-ITS-S forwards this content to the Back Office of the security part of the ETC service provider, which then checks if the PAN is valid, i.e. not present in the Certificate Revocation List (CRL). If valid, the Back Office of the security part of the service provider (or a local similar software, see note below) checks the subscriber information and sends a positive response to the R-ITS-S with a computed token signed with its private key, the public key of the payer, and potentially the car registration number. The R-ITS-S forwards the signed token to the V-ITS-S. The message should be encrypted with the session key.

If the signature is authenticated, the R-ITS-S waits until the vehicle has crossed a virtual position in front of the barrier, or under the toll gantry. At this time, the R-ITS-S sends an acknowledgement message to completely validate the transaction.

The use of a Token provided by the BO Security entity may imply a break of the system design inherent to ISO 14906 [i.5]. As mentioned before and in order to preserve the existing Backoffice architecture, this token exchange can be implemented locally at the toll plaza and not in the central system. This would mandate a real-time access to a recent copy of the subscriber's database, which is conceivable because the database has a longer update periodicity (e.g. daily or even weekly).

Figure 15 shows the process of subscriber's authentication and payment when crossing the toll gantry.

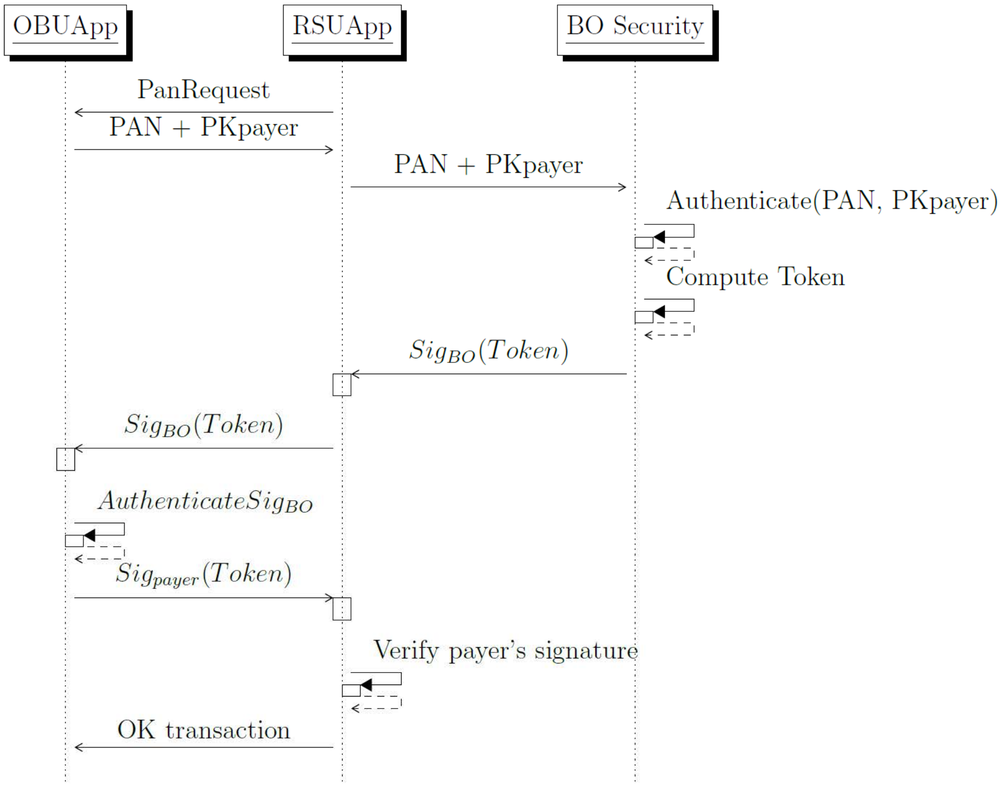

Figure 15: Subscriber's authentication for the ETC service

Step 2.4: Completion of the transaction

The achievement of the transaction triggers at the R-ITS-S a command to notify the central toll plaza server about the vehicle in the concerned lane. The central toll plaza server then sends a command to the concerned lane to perform the last checks (vehicle class, etc) and to open the barrier. The R-ITS-S also sends a notification to the V-ITS-S that the vehicle can pass.

Simultaneously, the Back Office of the ETC service provider books the transaction related to this payer. At this point, the R-ITS-S should stop the geolocation process of the vehicle, and the V-ITS-S can change its Station ID, as defined in ETSI TS 103 097 [i.14]. All data related to the tracking and the transaction is deleted in the R-ITS-S.

Step 3: Service resignation

When the subscriber wants to disconnect his/her account from the vehicle, the account with the key pair and associated certificate should be deleted from the vehicle.

5.1.5 Conclusion

With the proposed application, the customer does not provide any payment data until the application can authenticate the service provider. The security of this application is linked to the possession of certificates from all entities participating in the exchanges, the different authentication and encryption algorithms, as well as the secure channel used for each transaction fulfilling the security requirements set out in clause 5.1.3. The privacy is ensured by the formal consent provided by the user when subscribing to the service (see step 1 in clause 5.1.4) and the removal of all tracking and transaction traces in the R-ITS-S once the transaction has completed.

NOTE: Despite the enhanced geolocation obtained with the mechanism described in clause 5.1.2, it might happen that there is still a location error and the wrong barrier opens. In this case, the technological possibilities are numerous. Each road operator will deal with the problem in its own way, in a manner similar to a fraud case: post-regularisation for the vehicle that passed without paying, manual opening of the barrier for the vehicle that is wrongly located.

5.2 Proof of Concept under real life conditions and test results

5.2.1 Introduction

A proof-of concept of the proposed application, combining the geolocation and the secure exchange of payment information has been implemented [i.17]. As mentioned in clause 5.1.1, this PoC has been tested under real life conditions with the ITS-G5 access technology.

5.2.2 Test configuration

To carry out the proof of concept of the electronic toll service with C-ITS, the complete framework of the electronic toll application using the ITS-G5 technology has been developed, which is made of five application modules, as illustrated in Figure 16:

- Back Office Module:
  - Lane Server: application simulating the toll lane management server (opening and closing of the barriers).
  - BOApp: simulating the security management server: management of certificates related to the ITS stations and subscribers service.
- R-ITS-S Module (Infrastructure):
  - SmartTracker: Web application module that visualizes vehicle paths and manages the vehicle localization part by applying the appropriate filter.
  - RSUApp: Infrastructure-side electronic toll transaction secured application.
- V-ITS-S Module (Vehicle):
  - OBUApp: Vehicle-side electronic toll transaction application.

The tolling application is distributed between the V-ITS-S, the R-ITS-S, a mocked BO security module and a mocked lane server module. The solution was experimented in the Senlis toll plaza. It demonstrated that peer-to-peer communication for ETC is feasible using the ITS-G5 technology and that it performs well.

All communications between RSUApp and OBUApp, on the one hand, and between RSUApp and BOApp, on the other hand, are encrypted using the TLS protocol.

Figure 17 and Figure 18 show the configuration of the Senlis toll plaza, highlighting the R-ITS-S position. The R-ITS-S appointed for tolling characterizes the toll plaza by setting the following parameters:

- segments to delimit the zone to request the payment information (paying zone);
- segments to delimit each lane of the toll plaza.

A web application has also been developed to display in real time the geolocation tracking process performed by the R-ITS-S. The "SmartTracker" acquisition tool is an interactive web application whose main objective is to give the R-ITS-S operator an overview of the route taken by the connected vehicles in its coverage area. Its display is shown in Figure 17 and Figure 18.

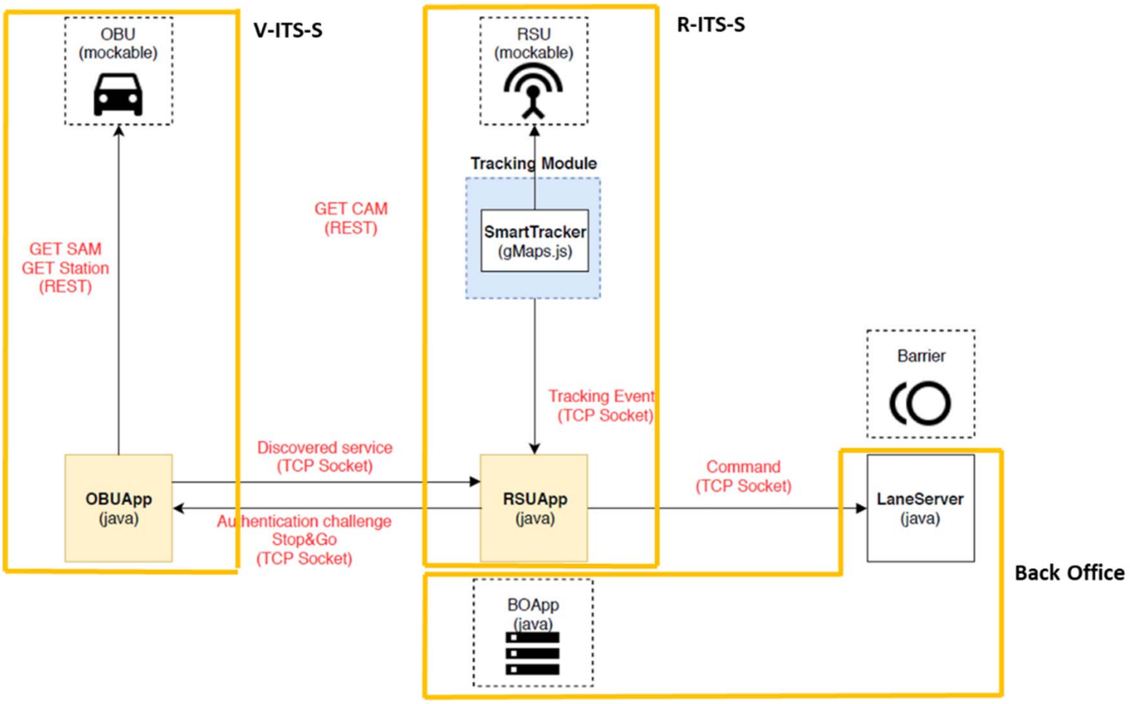

Figure 16: Architecture of the testing modules of the electronic toll application in C-ITS

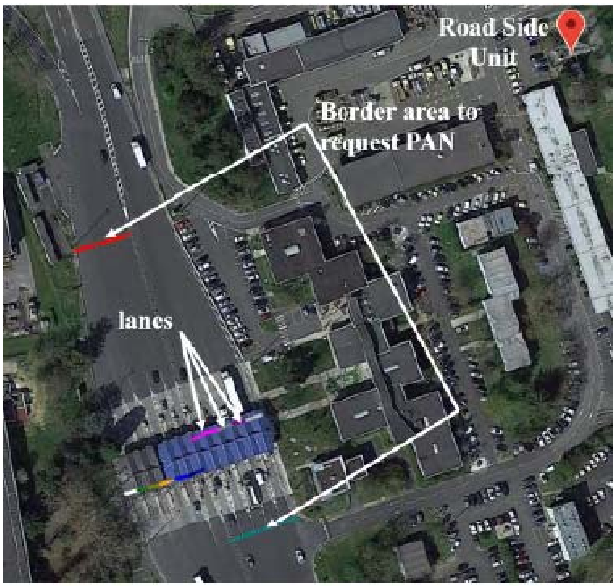

Figure 17: View of the setup of the Senlis toll plaza

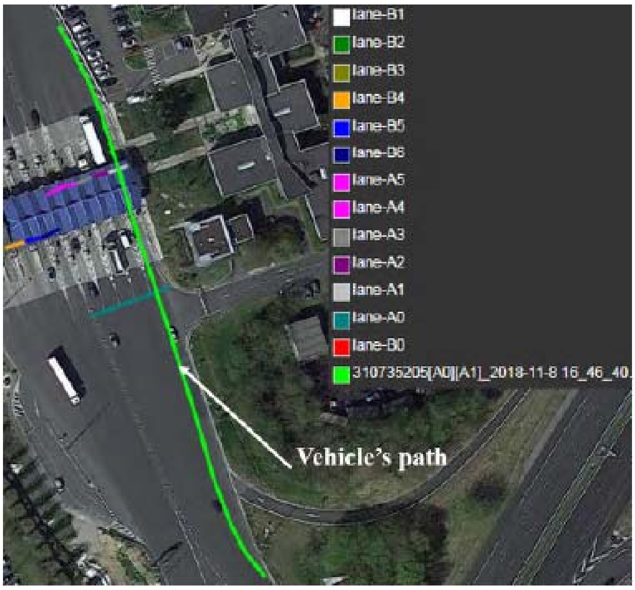

Figure 18: Configuration of the toll area

More than a hundred (100) passages of the Taissy and Senlis toll lanes were performed in real life conditions, using the devices illustrated in Figure 19, to test if the lanes actually used by the vehicle were consistent with the lanes detected by the SmartTracker. The PoC was also demonstrated at the On-road Vehicle Demo of IEEE IV symposium in Versailles in June 2019.

Figure 17 shows the setup in the Senlis toll plaza, with the R-ITS-S located on the upper right of the figure. Its antenna was mounted on a pre-existing pole at a height of 30 metres. In Versailles, the R-ITS-S was located on the side of the road used for the demonstration, at a height of 6 metres. This gave a good clearance to the communication. In both cases, the vehicle arrived at the toll gates with a speed of around 50 km/h.

The experimental setup for the verification of the proposed algorithm is presented in Figure 19. A combined antenna (GPS, GSM, ITS-G5) attached to the V-ITS-S and the reference GNSS antenna (noted GPS reference in Figure 19) were mounted on the roof of the testing vehicle. The reference GNSS antenna is connected to a separate GNSS receiver which provides real-time decimetre (10 cm / 4 inch) absolute accuracy positioning by coupling GPS and GLONASS reception for high-accuracy data collection, corrected with Real-Time Kinematic (RTK) solutions. This receiver is used as a reference to determine the measured positioning error. For more details on the reference GNSS receiver, see the reference paper [i.21]. The R-ITS-S is installed on a pylon and has a coverage of about one kilometre.

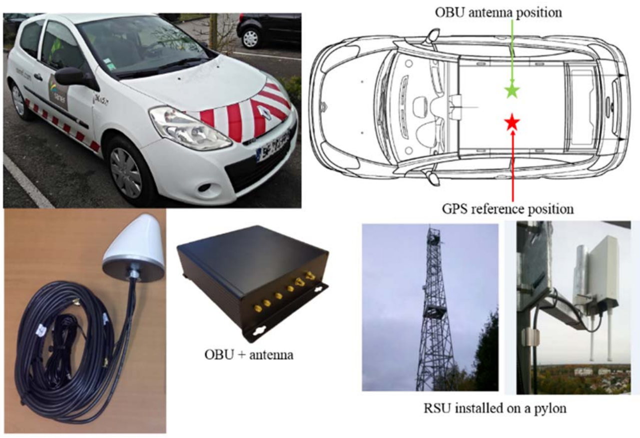

Figure 19: Experimental setup

5.2.3 Reliable geolocation results

Figure 20 shows the evolution of the geolocation deviation when comparing the output of the algorithms with the position obtained from the reference GPS receiver. It provides, at the R-ITS-S level, the GPS measurements from the V-ITS-S obtained from the CAM and the processed measurement results obtained at the R-ITS-S by applying the algorithms described in clause 5.1.2, including the EDM geolocation algorithm described in Figure 12. This graph has been plotted from a typical sample of measurements obtained during the more than one hundred experiments performed and evaluated. It can be noted that due to the open environment of the highway tolling plaza, the GPS measurements are already providing good results, which may not be the case in all situations described in clause 4.2.1.

The obtained results show that the measurement deviation improves over time as the vehicle passes through the toll plaza. This improvement over time is due to the larger number of measurements retrieved from the CAM as the vehicle passes the toll plaza. According to these results, the used method provides in this test a position deviation better than 30 centimetres when comparing the output of the algorithms with the reference position at a measurement time between 17 seconds and 25 seconds after the start of the trajectory tracking. This time interval corresponds to the time in the trajectory when the vehicle passes the toll gate. Thus, the algorithm in the R-ITS-S complies with the requirements for an enhanced geolocation of the vehicle.

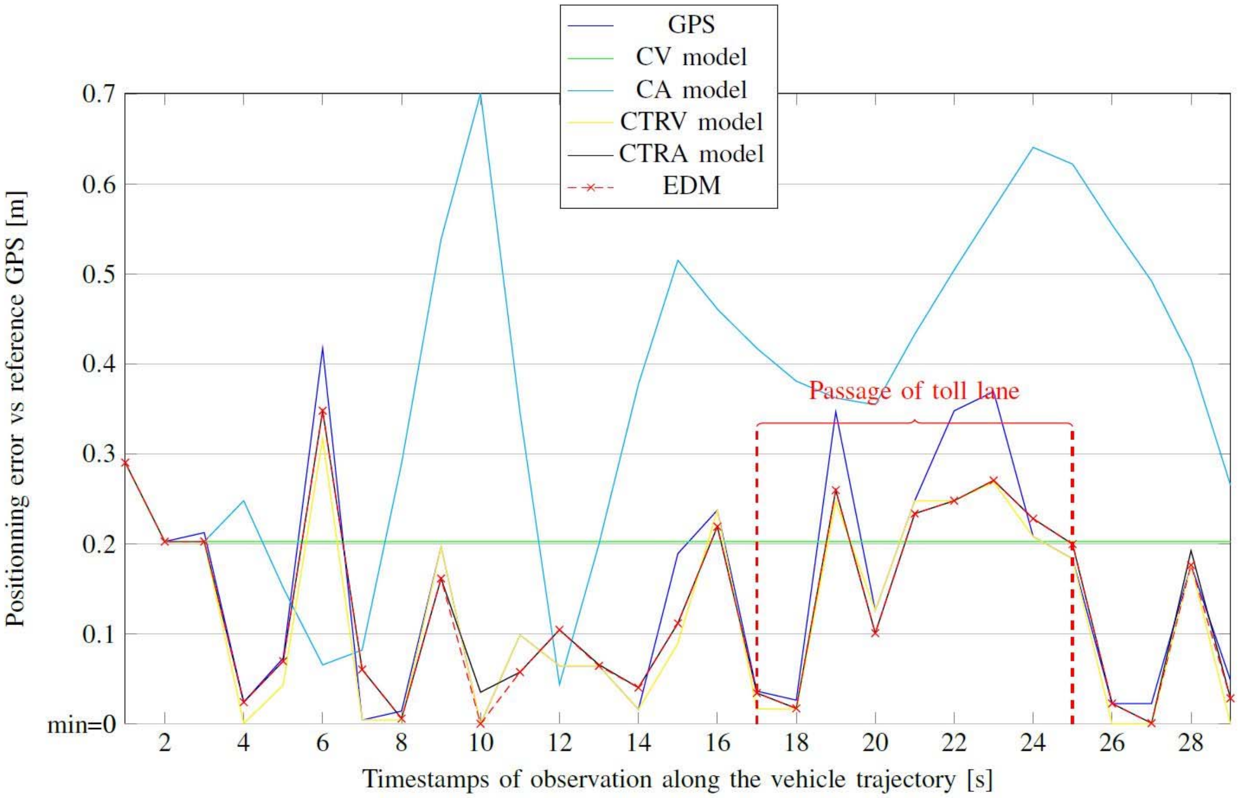

Figure 20: Evolution of the errors compared with the reference trajectory while passing the toll plaza

Figure 21 presents the activation of each state and associated dynamic motion models (CV, CA, CTRV, CTRA) according the process defined in clause 5.1.2.

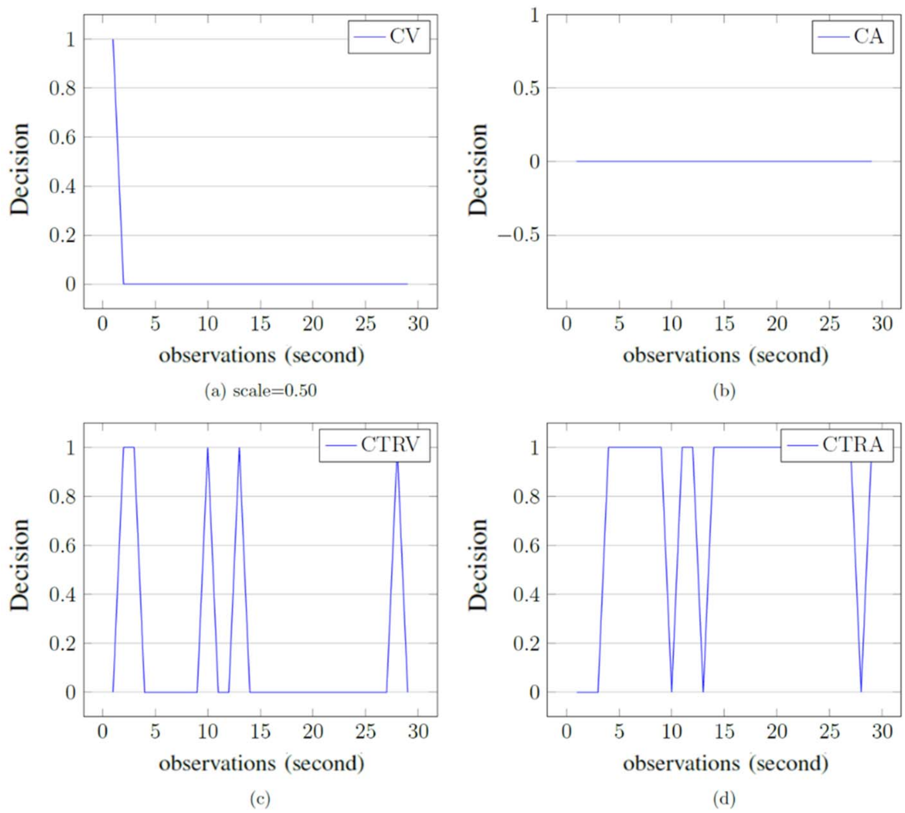

Figure 21: Activation of the different states and associated models for the Kalman filtering

When approaching the toll plaza, the vehicle is usually driven with constant deceleration before arriving in front of the barrier. In front of the toll barrier, the car is stopped, thus it is considered that the vehicle has a constant velocity. The driver's manoeuvres are noticed through deviations. This is due to the change of heading and steering wheel angle, influencing the yaw rate value, causing the algorithm to switch to the CTRV or the CTRA state.

5.2.4 Implementation of the secure exchange of payment information

The implemented solution has been illustrated in Figure 16.

All communication links are implemented, except for the secure communication between the V-ITS-S and the BO of the service provider as well as between the BO and the entity responsible for distributing the certificates: e.g. renew of certificates, etc. In this PoC, the certificates are directly integrated in the modules (OBUApp, RSUApp, BOApp).

The actual exchange sequences, including the implemented components, are presented in Figure 22. Figure 22 highlights the three phases of the exchange.

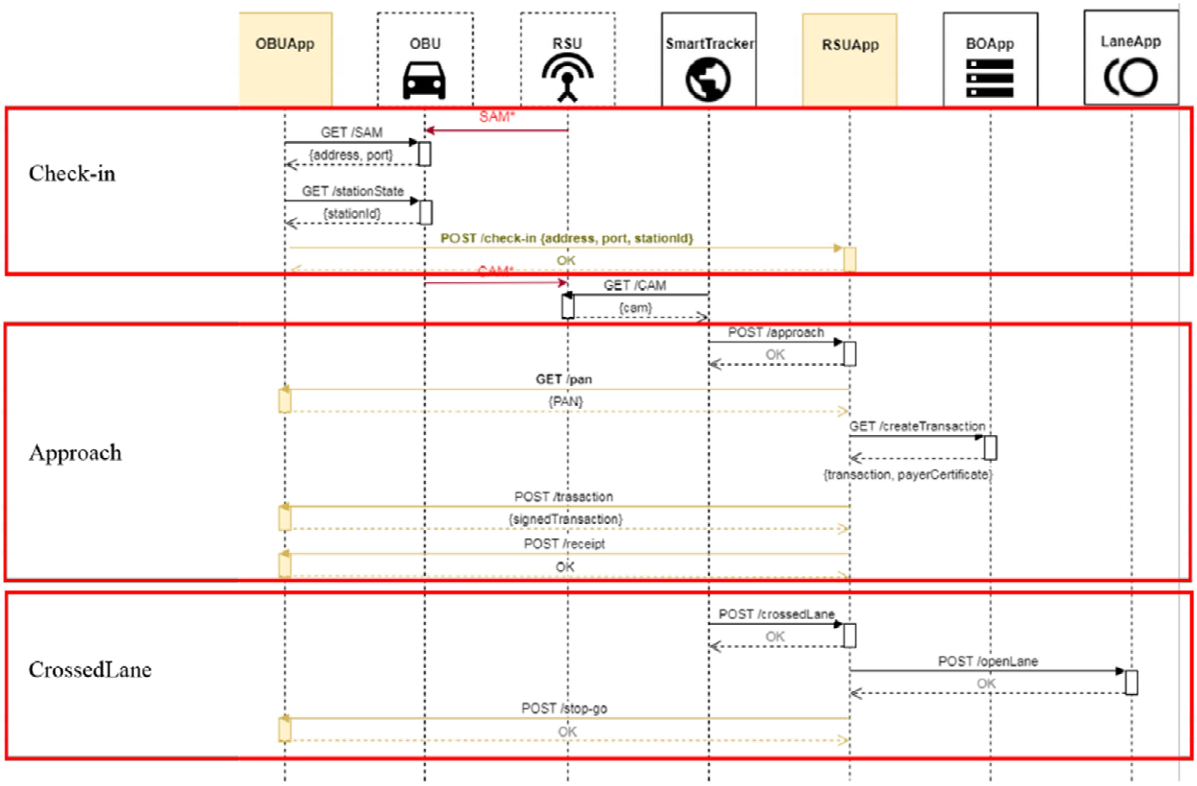

Figure 22: Toll passing scenario

The messages marked with (*) are periodically broadcasted messages, e.g.: SAEM (Service Announcement Extended Message) and CAM (Cooperative Awareness Message).

Before using the service (crossing the toll gate using the C-ITS technology):

- All the entities should have their own certificates.
- In the V-ITS-S, the OBUApp stores the public key certificate of all the R-ITS-S appointed for the tolling in the neighbourhood, as well as the BOApp public key certificate.
- In the BOSecurity, the BOApp manages all the payer's information i.e. all the public key certificates of the subscribers to the service, and the information about all R-ITS-S appointed for the tolling.
- In the R-ITS-S, the RSUApp stores the public key certificate of the BOApp.

When approaching and passing the toll area:

- After receiving the SAEM, the OBUApp authenticates the R-ITS-S that broadcasted the SAEM. This process is feasible through the stored public key certificate of the R-ITS-S.
- If the R-ITS-S is authenticated, then the OBUApp sends to this R-ITS-S its Station ID, IPv6 address, service port number. The station ID is sent to associate later the payment information and the tracked vehicle. After receiving this information, the R-ITS-S may track the vehicle until it fully passes the toll area.
- Close to the toll plaza (about 100 meters or less), the RSUApp requests the payment information, called PAN, to the OBUApp. The PAN is sent by the R-ITS-S to the BOApp, in charge of authenticating this payer information.
- When this step is achieved, the BOApp notifies the RSUApp which notifies the OBUApp. The RSUApp waits for the vehicle to cross the toll gate in one segment of lane. The RSUApp notifies the lane server to open the barrier in the suitable lane.

Generally, in the R-ITS-S, the RSUApp is responsible for:

- Tracking the connected vehicle until it crosses the toll barrier.
- Requesting, validating the tolling transaction of the connected vehicles with the support of the BO security.
- According to the vehicles' positions, the R-ITS-S requests the payment and sends the notification to the lane server to open the suitable barrier.

Figure 23, Figure 24 and Figure 25 show screen captures of the test, firstly in the case it runs successfully until the end, secondly in the case the subscriber is not authorised for the payment.

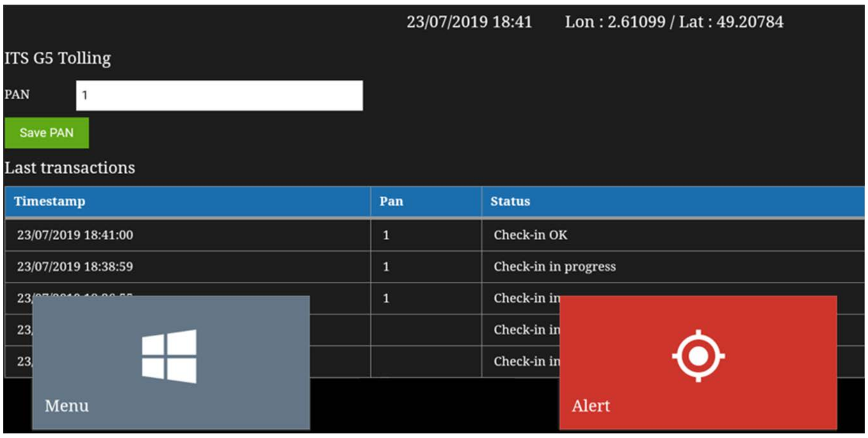

Figure 23: Screen capture of the initiation of the procedure (check-in phase)

Figure 24: Screen capture of the successful completion of the procedure

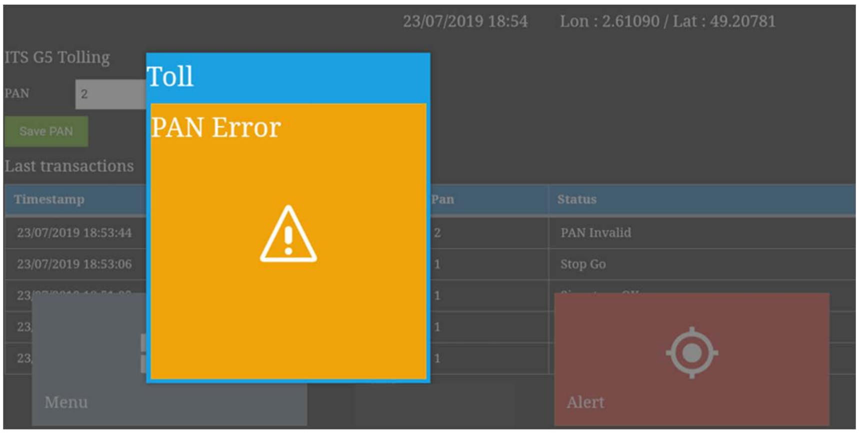

Figure 25: Screen capture of the unsuccessful completion of the procedure because the PAN is invalid

Evaluating the robustness of the approach is an important step to prove its effectiveness on preventing disruption to the normal operation. This mechanism has been formally verified using the HLPSL (High-Level Protocol Specification Language) [i.24].

5.2.5 Evaluation of the tests

Regarding the reliable geolocation, the results presented in clause 5.2.3 show that the proposed method fulfils the requirement of an accuracy lower than one metre with a confidence level at least 99,5 %, considering the number of obtained measurements, to perform the ETC transaction with the ITS-G5 technology. By applying the dynamic motion models described in clause 5.1.2, the real situation of the driving experiment is considered.

The tests conducted in Senlis as described in clause 5.2.2 (comprising more than a hundred experiments with a real V-ITS_S device) led to a result of 100 % of good detection recorded for the identification of the lane passed.

The benefit of using the algorithm is to ensure that the position of the vehicle is improved by taking into account both the GPS measurements and the kinematics of the vehicle using other vehicle specific parameters (speed, acceleration, steering, steering angle, etc.). In the case where the GPS measurements diverge (depending on the environment), the other parameters help to understand what the kinematic state of the vehicle is and choose the appropriate model to be applied to improve the position estimation.

Clause 5.2.4 has presented the implementation of a solution aiming to validate the security of a tolling transaction service. The approach recommends the authentication of all the entities involved in the process (subscriber, V-ITS-S, R-ITS-S, and trusted part of the toll service provider as server). The chosen cryptographic algorithms satisfy the requirements of authentication, integrity, non-repudiation and confidentiality of exchanges that have been identified to perform the tolling transaction.

For these initial tests, the exchanges to perform the vehicle tracking and the tolling service with ITS-G5 technology lasted between 10 to 15 seconds from the moment the vehicle had received the first SAEM notification message until the final toll gate crossing notification. This represents a lower transaction time than with other existing manual payment methods like cash or credit card, but it is much longer than a CEN DSRC ETC transaction, which typically needs about 35 milliseconds to be finished once the OBU and RSU communication has been established, because the value measured during the tests also involves the whole tracking time. But, as the vehicle is still moving normally during this period of time, there is no loss of time for the user and no impact on the traffic throughput. Accordingly, the ITS-G5 payment method is suited to provide a toll service without barriers for better traffic flow while ensuring the same performance in the processing of the toll payment.

It should be noted that the metallic canopy protecting the toll barriers has a minimal dimension. It is a general tendency to reduce or eliminate the canopies which were used to protect the staff from bad weather conditions but is not needed anymore with machines. Accordingly, the canopy does not constitute a visibility barrier between the V-ITS-S and the R-ITS-S and has no impact on the received signal (at least in ITS-G5) or on GNSS reception (sufficient clearance). This will be different in tunnels, where ordinary GNSS signals are shielded. But, in the vast majority of cases, toll gates are located before the tunnel entrance, not inside the tunnel. In cases when toll gates are in a tunnel, a beacon type signal can be envisioned at certain positions to provide location information. Note that the PoTi functionality in the Facilities layer also describes methods to enable location in this case: EGNOS, cellular triangulation, etc.

In the case of two-wheelers, the position accuracy needed is around 0,3 metres. The test results in clause 5.2.3 already demonstrate such an accuracy. In real life, this accuracy is needed to avoid fraud in the case of two motorcycles, one of which is not equipped, trying to pass a barrier in parallel at the same lane. In this very specific case, the vehicle class verification system at the end of the process (see step 2.4 in clause 5.1.4), typically an optical barrier, can detect this case and trigger the anti-fraud mechanisms.

Initial performance evaluation of the proposed architecture:

For a C-ITS tolling transaction, a set of information messages needs to be transferred between the V-ITS-S and the tolling R-ITS-S.

In particular, during the communication between the V-ITS-S and R-ITS-S to perform the service, the transaction message (with the PAN content, specified in ISO 14906 [i.5]and made of 18 digits) is transmitted just once. However, this information can be considered as important relative to the payer entity.

Accordingly, in order to identify the vehicle or the tolling charging card including the security not more than 200 Bytes would be sufficient for the communication from the vehicle to the R-ITS-S when providing the PAN. Even with repetition, this leads to a data volume of 0,4 KBytes per transaction.

With a capacity of 1 vehicle per second → 0,4 KBytes/s additional ITS traffic on the channel → single channel capacity is 6 Mbits/s so 750 KBytes/s. → additional traffic is only 0,05 % for one vehicle.

Based on the figures provided in Table 1, the maximum capacity of a tolling system would be 24 000 vehicles per hour (assuming 4x2 lanes in free flow, or 12x2 lanes in a large plaza with ETC reduced speed), which is around 7 vehicles per second.

With a capacity of 10 vehicles per second → 4 KBytes/s additional traffic → 0,5 % of overall capacity of a single channel.

5.3 Conclusion

The proposed solution improves the road users' mobility experience by adding another service to the vehicles connected with C-ITS communication. Additionally, it can reduce traffic jams on the toll areas compared to the transaction times required by manual payment such as cash, credit/debit card, etc. Further tests could show whether it can also be deployed in free-flow situation and for any configuration of urban tolling or access control.

The proposed architecture requires reasonable resources which will be suitable for vehicle-to-infrastructure (V2I) communications. This architecture suits the majority of tolling configuration in Europe, in this case the toll areas with barriers, but it can also be deployed for the free-flow tolling. The proposed method is adaptable to the standardized ETC architecture as described for example in IEEE 1609.11 [i.10] with the advantage that it benefits from the use of the C-ITS technology and the Facilities layer services. Furthermore, the concept foresees that a single R-ITS-S can perform the transaction exchanges with all the vehicles in the toll area.

Regarding the couple of tracking and security, the same communication architecture can be applied to other peer-to-peer services: e.g. tolling price by section, payment of parking fees on parking places or rest areas, payment of electric vehicles charging.

Another motivation for this study is also the improvement of the road safety of road operating agents. Indeed, to repair damages of the R-ITS-S appointed to toll transactions, the agents will not take dangerous risks to replace or to fix the issues because the equipment is installed on the road side. Hence, no lane closure is necessary for repair or maintenance of the radio infrastructure (for enforcement, still other types of sensors are needed for each lane).

It is important to note, as mentioned in step 2.3 of clause 5.1.4, that in order to preserve the existing Backoffice architecture, this secure exchange can be implemented locally at the toll plaza and not in the central system. This would only mandate a real-time access to a recent copy of the subscriber's database, which is conceivable because the database has a longer update periodicity (e.g. daily or even weekly).

6 Proposed adaptation for road payment applications

6.1 Overview

In this clause the proposed changes and adaptations of the C-ITS protocols for the support of payment application are depicted. The adaptations are presented for each of the relevant protocol layers.

C-ITS is well suited to be used in infrastructure-based road payment applications. This means that road payment applications could be installed in ITS-Stations configured as V-ITS-S (for OBE) or R-ITS-S (for RSE).

Figure 26 shows the functional entities related to road payment applications that would be involved in the ITS station architecture. New entities to be specified are highlighted in striped areas.

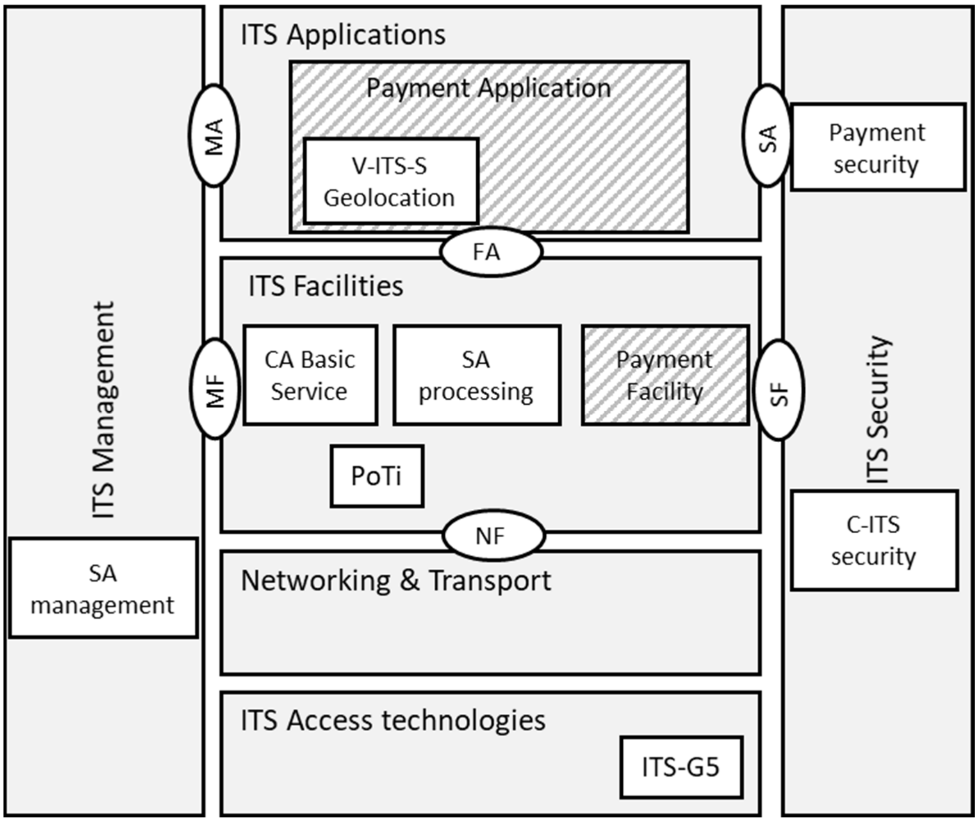

Figure 26: ITS-Station Architecture for payment applications

The road payment applications could use the service of a facility entity to support electronic payment applications. Details are described below.

6.2 Application Entity

6.2.1 Electronic Fee Collection

An interoperable application profile for EFC over C-ITS access technologies should be defined. Such an application profile would reference base standards and restricts the choice of base standard options to the extent necessary to maximise interoperability. Examples of such a profile are:

- CEN EN 15509 [i.4] for EFC over CEN DSRC.
- IEEE 1609.11 [i.10] for EFC over WAVE.

An interoperability application profile for EFC over C-ITS access technologies should specify by reference the applicable ETSI and CEN/ISO standards:

- The EFC service announcement including the BST.
- The EFC service response with the VST.
- The exchange of:
    - payment data according to ISO 14906 [i.5];
    - vehicle data according to ISO 14906 [i.5];
    - equipment data according to ISO 14906 [i.5];
    - receipt data according to ISO 14906 [i.5];
    - localisation data (optional).
- The use of the network and transport and access layers.
- Security mechanisms.

This application entity should be enhanced with the following feature proposed in clause 5:

- Reliable geolocation of the V-ITS-S crossing the tollgate, leveraging on the received CAM data elements, as described in clause 5.1.2.

NOTE: In the present document, the "V-ITS-S geolocation" function is part of the payment application, as it is mapped more specifically to the toll gate geography and the vehicle tracking during toll payment. It may happen that this function becomes useful for other types of applications, for example to locate vehicles in their parking slots. This function may thus be moved downwards to be included in the PoTi facility of the R-ITS-S in a future specification of the technology.

6.3 Facilities Layer

6.3.1 Electronic Fee Collection

A facility layer should be defined, which provides the application interface (FA interface) for DSRC-EFC defined in ISO 14906 [i.5] to EFC applications. This could be a common facility service for electronic payment applications. The facility layer for electronic payment applications should provide payment functions to payment applications by means of the DSRC Application Layer service primitives of ISO 15628 [i.6]including the following sub functions:

- Electronic payment transmission (TX) service of payment application data units:
    - message encoding;
    - transmission management.
- Electronic payment reception (RX) service of payment application data units:
    - message decoding;
    - reception management.
- Collection of specific CAM data elements to be provided to the payment application (in the R-ITS-S).

The electronic payment service should use the Service Announcement Service defined in ETSI EN 302 890-1 [i.13] to announce the EFC service by the RSE. There is no need for adaptations of this standard. The interoperability application profile should define how the SAEM transports the BST defined in ISO 14906 [i.5].

The electronic payment service should use the service of the Cooperative Awareness basic service defined in ETSI EN 302 637-2 [i.25] to provide the application with the data elements necessary to enhance the localization of the V-ITS-S at the R-ITS-S appointed to the tolling service. There is no need for adaptations of this standard. Other methods as defined in the POTI functionality may also be used to improve the localisation accuracy. In locations (e.g. tunnels) where the CAM cannot be received, it may be an option for the R-ITS-S to request its location directly from the vehicle during the payment transaction (rather than using the CAM information).

The electronic payment service should invoke the security entity services via the SF-SAP. The electronic payment service should deliver the EFC Application Protocol Data Units as payload to the Networking & Transport layer for dissemination via the NF-SAP.

6.4 Network and Transport Layer

6.4.1 Electronic Fee Collection

The Network and Transport Layer should support OBE to RSE unicast communication with low latency and overhead. IPv6 has been identified as a suitable network protocol for this operation. Adaptations of the IPv6 protocol are not needed, as its latency is sufficient for the tolling application requirement.

6.5 Access layer

6.5.1 Electronic Fee Collection

Multi-channel operations should be used to perform the EFC transaction on a non-safety service channel.

NOTE: In the case where localisation by RF (e.g. Angle of Arrival based localisation) is used, no further specification or standard is needed, since this localisation operates purely based on received RF signal characteristics. However, its accuracy may not be sufficient to accurately localize the vehicle in its lane in the case of a single R-ITS-S serving the whole toll plaza.

6.6 Management Entity

6.6.1 Electronic Fee Collection

The existing Service Announcement Service defined in ETSI EN 302 890-1 [i.13] should be used to announce the EFC service by the RSE. The interoperability application profile should define how the SAEM transports the BST defined in ISO 14906 [i.5].

Current DCC procedures are adequate to manage the EFC transaction, provided that appropriate priorities are assigned to the RSE.

The installation and configuration of EFC applications that are installed at the roadside ITS-S should be managed by the Toll Charger.

The installation and configuration of EFC applications that are installed at the vehicle ITS-S should be managed by the Toll Service Provider.

6.7 Security Entity

6.7.1 Electronic Fee Collection

The EFC service announcement should be secured as defined in ETSI EN 302 890-1 [i.13]and ETSI TS 103 097 [i.14].

The OBE to RSE transaction should be secured providing mutual authentication, confidentiality, integrity and non-repudiation.

When applicable, the interoperability application profile should define how to use ISO 14906 [i.5]and/or ETSI TS 103 097 [i.14] to achieve this.

Access to the data in the OBU should be protected using access control mechanisms. The interoperability application profile should define how to use ISO 14906 [i.5] to achieve this.

If needed, ISO 14906 [i.5] should be updated to include a security profile that provides the security requirements of the exchanged EFC data.

The security entity should be enhanced with the following feature proposed in clause 5:

- Payment security, including entities mutual authentication, integrity validation, confidentiality of the data, non-repudiation of the actions as described in clause 5.1.3.

6.8 Performance considerations

This clause provides considerations on required performance figures for the road charging application with C-ITS. Similar considerations would arise for other charging application. It can be assumed that the requirements for road charging are the most stringent in relation to transaction time, capacity, etc.

The required EFC system figures for DSRC according to CEN ISO/TS 17444-1 [i.29] are the following:

- 100 % correct (and hence 0% wrong) charges should incur when processing toll payment for a paying vehicle (CM-DTD-1 and CM-DTD-2).
- < 0,1 % false negatives, i.e. less than 0,1 % vehicles that are correctly paying should be blocked from passing thought the plaza, or should pass though the MLFF station with an enforcement record being created (CM-DTD-3).
- 0 % false positives, i.e. no vehicle that is not paying should be allowed to pass thought the plaza, or passed through the MLFF station without an enforcement record being created (CM-DTD-4).

The operational experience shows that the actual value performance obtained is around 99,9 %, considering that the OBU positioning on the windscreen and its battery condition may slightly alter this laboratory measurement for existing systems.

This in turn translates to the following technical figures:

- Required transaction accuracy in terms of successful communication without detected errors: 99,9 % correct transactions over total number of passages.
- Required transaction accuracy in terms of successful communication without undetected errors: 100 % correct transactions over total number of transactions.
- Required localization accuracy: ideally 100 % (as with CEN DSRC).
- The road tolling application may benefit from services and functions established in Cooperative ITS system, which would mutualise the following components: mainly CAM, SAEM and PoTi, plus N&T and access layer.
- The communication range needed for the application is about 400-500 meters as the vehicle is approaching the toll station. This could be covered by a single R-ITS-S, or to remain on the safe side, one R-ITS-S for each traffic direction, with a backup unit to guaranty continuity of service.
- A rough estimation allows to compute the number of vehicles to be handled per second/minutes/hour:
    - With 4 traffic lanes and 2000 vehicles/hour on each lane, it is necessary to handle 8 000 vehicles/hour; it makes 134 per minute or 2,2 per second (for each traffic direction).
    - Over a range of 500 meters on 4 traffic lanes, there can be a maximum of 100x4 vehicles = 400 vehicles to be tracked each second (in each direction).

- According to these values, the estimation of the ratio between the peak and average number of vehicles is:
    - Off peak hours capacity is not an issue.
    - Main issue might arise in peak hours.

7 Summary and conclusion

The possible inclusion of charging application into the set of applications for C-ITS has been investigated. The proposed changes and adaptations to the C-ITS protocols would allow local road charging and payment applications to benefit from the deployment of C-ITS, while keeping the impact on existing standards minimal.

The implementation of EFC applications on V-ITS-S and R-ITS-S brings both technical and operational challenges (see also CEN/TR 16690 [i.28]). Some of the solutions proposed in the CEN/TR 16690 [i.28] were analysed in the present document. However, other architectures proposed in the CEN/TR 16690 [i.28] could also be subject to further study.

Annex A: Existing Electronic Fee Collection systems and applications

A.1 Introduction

Road user charging, also known as road pricing or road tolling has existed since the early Middle Ages (in the Roman Empire). Road user charging can be performed using electronic fee collection. The geographic area where road tolls are applied is called the toll domain. The toll domain may encompass a road network, a specific section of road (e.g. a bridge, a tunnel or a ferry connection) or a specific area offering a service (e.g. a parking lot or access to a protected area in a city). The set of rules, including enforcement rules, governing the collection of tolls in a toll domain is called a toll regime. A toll regime can be of the following types:

- Section charging scheme:
  - road segment pricing: this toll is levied for driving on specific segments of roads;
  - closed network pricing: a fee is levied for driving on a road network and depends only on the points where the vehicle enters and leaves the network;
  - charging for road objects (e.g. tunnel, ferries, passes).
- Area charging scheme:
  - measured distance pricing: vehicles are charged for kilometres driven in a tolled zone;
  - vehicles are tolled for driving in a tolled zone, independent of the number of kilometres and the number of times they enter within a given time interval;
  - time-based pricing: vehicles are charged on the basis of time spent within a zone or on a network.
- Cordon charging scheme:
  - a fee is charged when a vehicle enters or leaves a tolled zone, or in both situations.

A.2 EFC system types

A.2.1 Infrastructure based EFC systems

Infrastructure based EFC systems use an access technology that enables localized communications between the OBU and the RSE. For this reason, they are also called EFC-DSRC systems. This technology supports the exchange of data between OBU and RSE and the localisation of the OBU. Typical examples of standardized EFC- DSRC technologies are the following:

- CEN MDR DSRC at 5.8 GHz according to CEN EN 15509 [i.4];
- ETSI HDR DSRC at 5.8 GHz according to ETSI ES 200 674-1 [i.12];
- ARIB DSRC at 5.8 GHz according ARIB STD-T75 [i.11];
- WAVE at 5.9 GHz according to IEEE 1609.11 [i.10].

Infrastructure based EFC systems are best suited to implement road segment-based toll regimes, or cordon pricing.

A.2.2 Autonomous EFC systems

Autonomous EFC systems operate without relying on dedicated road-side infrastructure and require an OBE that employs wide-area technologies such as Global Navigation Satellite Systems (GNSS) and Cellular Communications Networks (CN). These EFC systems are referred to by a variety of names. Besides the terms autonomous systems and GNSS/CN systems, also the terms GPS/GSM systems and wide-area charging systems are in use.

Autonomous systems use satellite positioning, often combined with additional sensor technologies such as gyroscopes, odometers and accelerometers, to localize the vehicle and to find its position on a map containing the charged geographic objects, such as charged roads or charged areas. From the charged objects, the vehicle characteristics, the time of day and other data that are relevant for describing road use, the tariff and ultimately the road usage fee are determined.

Some of the strengths of the autonomous approach to electronic fee collection are its flexibility, allowing the implementation of almost all conceivable charging principles, and its independence from local infrastructure, thereby predisposing this technology towards interoperability across charging systems and countries.

Autonomous systems are standardized in CEN ISO TS 17575 [i.8]and CEN/TS 16331 [i.9].

Autonomous EFC systems are best suited to implement area charging regimes, as well as road segment-based toll regimes in some cases.

A.3 EFC Architecture

A.3.1 EFC Role model and business architecture

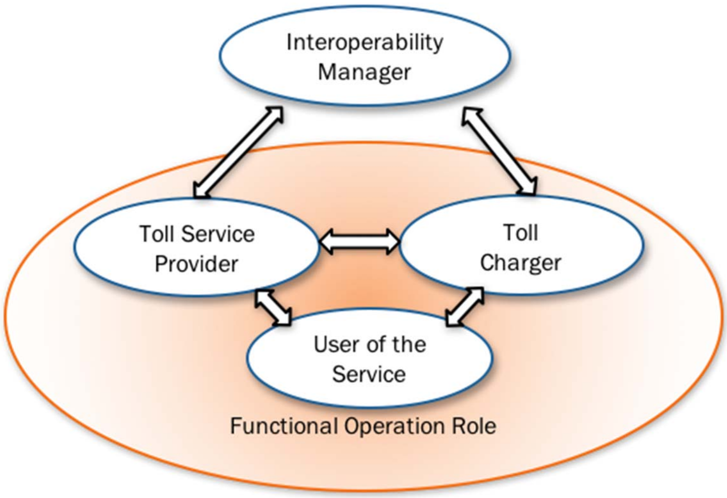

Figure A.1: Illustration of main roles in EFC (see also [i.31])

According to the well-established role model defined in ISO 17573-1 [i.31] and illustrated in Figure A.1:

- The Toll Charger levies toll for the use of vehicles in a toll domain. It defines the toll regime, operates the toll system and may provide transport services.
- The Toll Service Provider provides toll services in one or more toll domains. It is responsible for providing the basic artefacts, mechanisms, organization structures, and information transfer tools needed to run an EFC system.
- The User of the service is a customer of a toll service provider, i.e. one liable for toll, owner of the vehicle, fleet operator or driver depending on the context. It covers all aspects of using the toll system and, if applicable, of the transport service. Implementations of toll systems in various domains commonly refer to this role as, e.g. driver, user or customer.

- Interoperability Manager: A specific role is identified to manage a toll charging environment, i.e. defining and maintaining a set of rules that, taken together, defines the policy of a given regime or of the overall toll charging environment.

A.3.2 Technical Architecture

The complete technical architecture for both types of EFC systems is illustrated in Figure A.2.

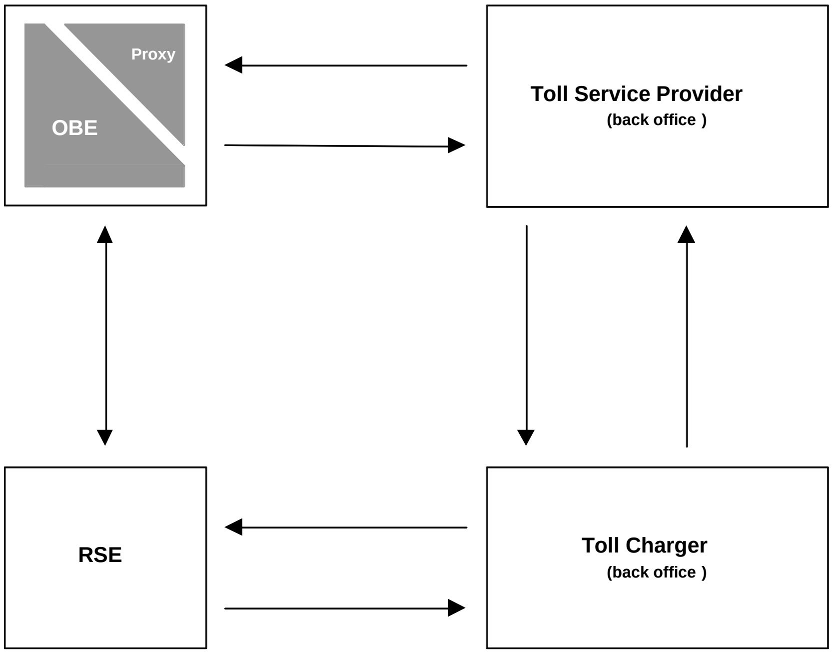

Figure A.2: Complete technical architecture (see also [i.34])

The following description details the technical architecture for both types of EFC systems, without covering aspects specific to payment settlement, exchange of enforcement data, exchange of quality assurance data, and the exchange of trust objects.

Infrastructure based EFC Systems (see Figure A.3) use the following elements:

- OBE: the OBE supports the following functions:
  - Localisation: the OBE supports localisation by RF means.
  - Charging & Enforcement: the OBE hosts an EFC application which provides a local interface for charging and enforcement purposes. This interface provides different kinds of application data on the demand to the RSE incl. the necessary security functions to secure this data. It also provides the RSE the possibility to write data to the OBE, i.e. the OBE functions as a data carrier (e.g. for entry and exit receipts).
- RSE: the RSE executes the following functions:
  - Localisation: the RSE localises the OBE inside the tolling zone.
  - Charging: the RSE collects charging data from the OBE in order to produce a passage report to be consumed by the Toll Charger Back Office.
  - Enforcement: the RSE collects images of the vehicle/licence plates in case of incorrect payment to produce an enforcement report to be consumed by the Toll Charger Back Office and/or opens or closes a barrier.

- Toll Charger (TC) back office: the TC back office executes the following functions:
  - The Toll Charger back office calculates the billing details from the charging data collected by its own RSE.
  - The Toll Charger back office receives the exception lists of the TSP and possibly manages exception lists of the Toll Charger. Exception list will be distributed to the RSE of the TC for immediate identification and enforcement of vehicles and users on the exception lists.
- Toll Service Provider (TSP): the TSP back office executes the following functions:
  - The Toll Service Provider back office uses billing details received from the Toll Chargers to calculate the invoices to the users. It implements the Customer Relationship Management, billing and invoicing processes of Service Users for EFC. Payment (collection of the fee) is handled between Toll Service Provider and Service User. The Toll Service Provider guarantees the payment to the Toll Charger.
  - The TSP back office manages exception lists of OBEs and its users which are no longer valid for collecting charging data (e.g. the user blacklist). This list is distributed to the Toll Chargers.
  - The TSP back office, either remotely or through a service point equipment uses an interface to load personalisation data, OBE parameters and software to the OBE (EFC application data). This service point equipment will receive and store the required data from and in the service provider back office.

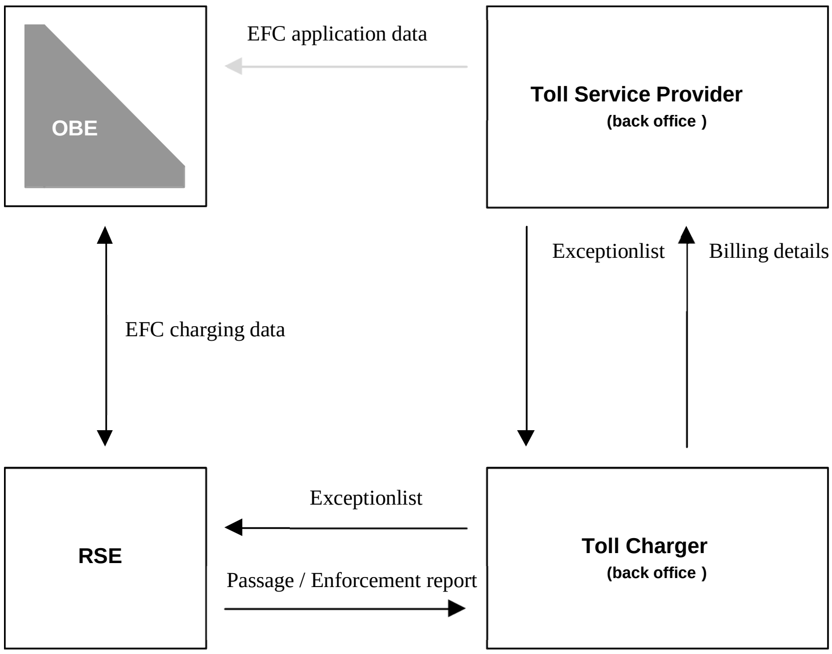

Figure A.3: Technical architecture for infrastructure-based EFC systems (see also [i.34])

Infrastructure based systems do use localised communications for charging purposes and are hence further considered in the present document.

Autonomous Systems (see Figure A.4) use the following elements:

- OBE + proxy: the OBE executes the following functions:
  - Localisation:
    - The OBE uses its sensors to localise itself within the toll domain.
    - The OBE hosts a Localisation Augmentation Communication (LAC) application which provides a local interface for localisation support purposes to the RSE.
  - Charging: the OBE generates charging data based on EFC context data, on its own or with the help of a central proxy and sends those data to the TSP back-office.

    - Enforcement: the OBE hosts a Compliance Check Communication (CCC) application which provides a local interface enforcement purpose.

- RSE: the RSE executes the following functions:
    - Localisation:
        - The RSE localises the OBE inside the enforcement zone.
        - The RSE supports vehicle localization by transmitting RSE localization augmentation data (LAC application) to the OBE.
    - Enforcement: the RSE performs vehicle and OBE (i.e. user) Compliance Checks (CCC).

- Toll Charger back office: the TC back office executes the following functions:
    - The Toll Charger back office calculates the billing details from the toll declarations received from the service provider back office.
    - The TC back office manages and distributes the EFC context data to the Toll Service Providers.
    - The TC back office receives the exception lists of the TSP and possibly manages exception lists of the Toll Charger. Exception list will be distributed to the RSE of the TC for immediate identification and enforcement of vehicles and users on the exception lists.

- Toll Service Provider: the TSP back office executes the following functions:
    - The Toll Service Provider back office is responsible for managing and deploying the OBE parameters including the EFC context data to the Front End.
    - The Toll Service Provider back office uses the billing details received from the Toll Chargers to calculate the invoices to the users. It implements the Customer Relationship Management, billing and invoicing processes of Service Users for EFC. Payment (collection of the fee) is handled between Toll Service Provider and Service User. The Toll Service Provider guarantees the payment to the Toll Charger. The back-office routes charge data generated by the Front End summarized as toll declarations to the Toll Charger back-office.
    - The TSP back office manages exception lists of OBEs and its users which are no longer valid for collecting charging data (e.g. the user black list). This list is distributed to the Toll Chargers.
    - The TSP back-office, either remotely or through a service point equipment uses an interface to load personalisation data, OBE parameters and software to the OBE. This service point equipment will receive and store the required data from and in the service provider back office.

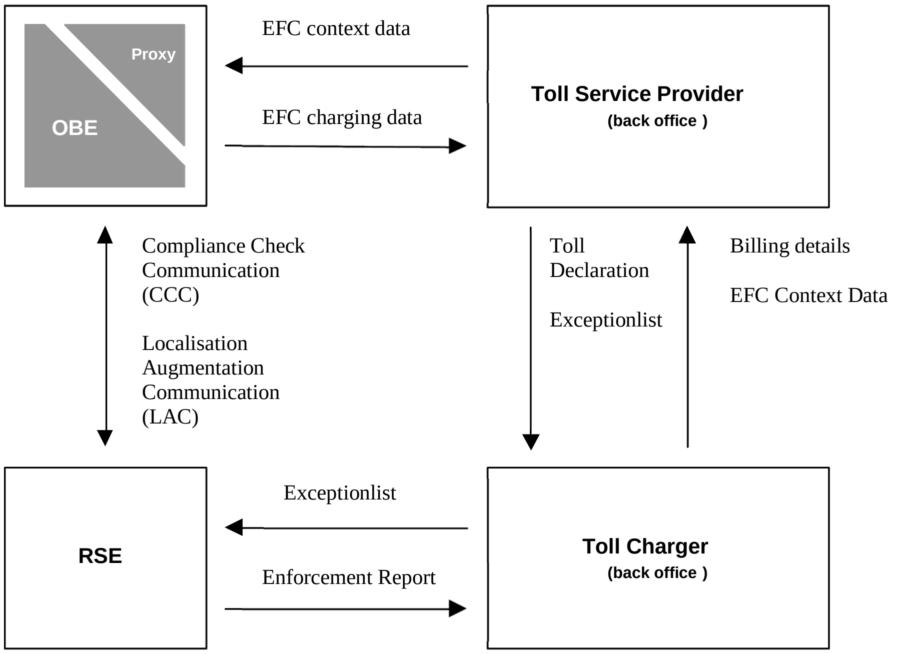

Figure A.4: Technical architecture for Autonomous EFC systems (see also [i.34])

Autonomous systems do not use localised communications for charging purposes and are hence not further considered in the present document.

A.4 Regulations and Standards

A.4.1 Overview

Interoperability of EFC systems in Europe is a legal obligation for Toll Chargers operating an EFC system (see also EC Study on the European electronic toll service [i.15]): Toll Charger are mandated to accept OBE of specific Toll Service Providers that fulfil the requirement of the legislation (called EETS Providers). Therefore, every EFC DSRC system in Europe is obliged to use one or more of the allowed technologies, and comply with the standards referenced by the legislation.

European legislation in the field of EFC comprises:

- The Directive (EU) 2019/520 [i.1] that defines the interoperability of electronic road toll systems in Europe.
- The Commission Delegated Regulation (EU) 2020/203 EETS [i.26] on classification of vehicles, obligations of European Electronic Toll Service users, requirements for interoperability constituents and minimum eligibility criteria for notified bodies.
- The Commission Implementing Regulation (EU) 2020/204 [i.2], that defines the European Electronic Toll Service in terms of its technical elements, among which the technologies to be used in Europe for EFC, namely 5,8 GHz DSRC (incl. both MDR and HDR DSRC), GSM, GPS.

NOTE: The current European legislation does not consider ITS-G5 as an EFC technology (see [i.15]).

Standardization in the domain of EFC is going on since the 90ies and lies within the scope of the joint working group CEN TC 78 WG 1 / ISO TC 204 WG5. The standards produced are referenced by the EU legislation. The complete and actual status of standardization can be consulted here: http://www.tc278.eu/efc.

A.4.2 Standards for Infrastructure based EFC

Some selected standards which are relevant for interoperability of infrastructure-based EFC systems in the context of EETS are the following (see Figure A.5):

- CEN EN 15509 [i.4]: this standard defines an interoperable application profile for EFC over CEN DSRC-based on ISO 14906 [i.5] and the CEN DSRC communication standards.
- ISO 14906 [i.5]: this standard specifies the application interface for EFC-DSRC systems, i.e. the interface between the EFC application process interface and the DSRC application layer. It is technology agnostic in that it assumes the presence of an OSI stack of a localized access technology featuring a DSRC application layer.
- ETSI ES 200 674-1 [i.12], alternative to both CEN EN 15509 [i.4] and ISO 14906 [i.5] in specific contexts.
- CEN/TS 16986 [i.7]: this specification defines that data exchanges between TC and TSP back office, including the format of the billing details and exception lists.

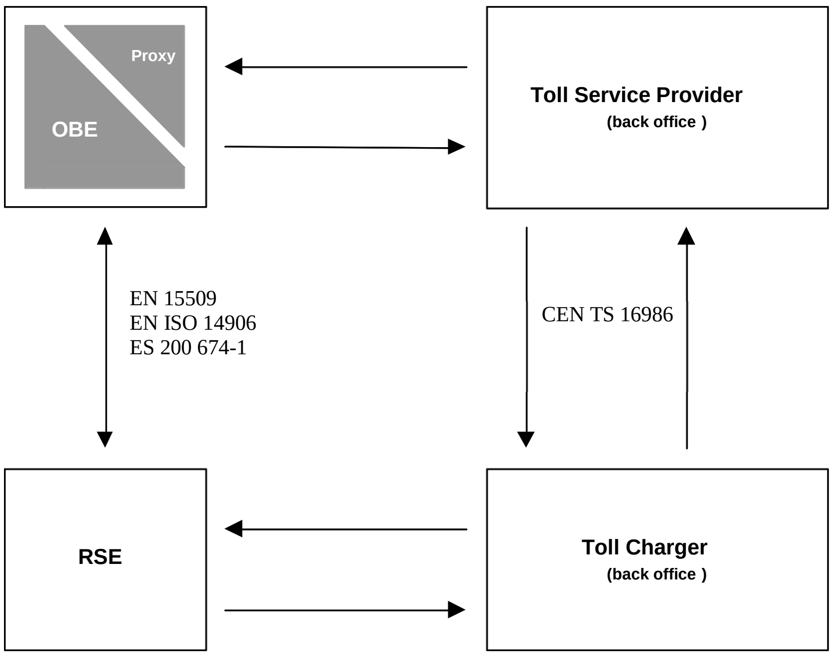

Figure A.5: Standards for infrastructure-based EFC (see also [i.34])

A.4.3 EFC charging transaction example

NOTE: Although the cited standards only offer sets of Protocol Data Units, so that each toll charger is able to implement their own tolling transactions, a typical transaction schema is commonly understood, and is described in what follows, based on an informative Annex of ISO 14906 [i.5].

The transactional model of ISO 14906 [i.5] defines two minimum phases for an EFC transaction:

- Initialisation phase: this is the phase where the service announcement is carried out by the RSE and responded to by the OBE. The RSE's EFC application is informed that there is an OBE with a specified EFC contract available.
- Transaction phase: this is the phase in which the RSE's EFC application uses the facility layer to carry out the EFC transaction. The transaction is carried out as a sequence of EFC functions (see clause 7 of ISO 14906 [i.5]). invoked by the RSE. These functions address data elements called EFC attributes (see clause 7 of ISO 14906 [i.5]).

A typical implementation on an abstract semantic level is shown in Table A.1 below (see ISO 14906 [i.5] for details).

Table A.1: Typical EFC charging transaction

Phase	RSE	Direction	OBE
Initialisation	*Announcement of EFC service*	→	
		←	*Announcement response about which EFC contract is supported*
Presentation	*Request for reading out of: - payment data - vehicle data - receipt data (of previous transactions) - Equipment data*	→	
		←	*Response with the requested data*
Receipt	*Request for writing of: - receipt data (of current transaction) - Equipment data Request to send HMI indication to driver*	→	
		←	*Response of correct writing to OBE's memory Response of execution of HMI signal*
Tracking and closing	*Optional localisation message*	→	
		←	*Response to optional localisation message*
	Closing notice to the OBE	→	

A.4.4 Localization in infrastructure-based EFC

Localisation of the OBE is performed by RF means and is outside the scope of the standards. It is for example based on shaping of the communication zone, on the evaluation of the Received Signal Strength Indicator and/or the Angle of Arrival of the signal.

A.4.5 Enforcement in infrastructure-based EFC

The enforcement of toll regulations and the punishment of toll violators is essential to obtain compliance of users with the toll regime. On the other hand, enforcement cannot be subject to false positives, which would lead to an unjustified punishment of road users.

Enforcement of toll violators, i.e. of vehicles/drivers not paying or paying the incorrect amount is based on:

- Charging data read out from the OBU during the EFC transaction.
- Images of the vehicle and licence plate and optional Automatic Number Plate Recognition (ANPR) readings.

Enforcement processes are subject to local regulations and practices.

Annex B: Bibliography

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Annex C:
Change History

Date	Version	Information about changes
January 2018	0.0.1	Creation of document
January 2020	0.0.6	Update as a stable draft for ITS WG1 #50
February 2020	0.0.8	Update of the stable draft for ITS WG1 drafting session on 17/02/2020
March 2020	0.0.9	Update of the stable draft integrating the comments received during the drafting session and answers to comments received from Kapsch
March 2020	0.0.9b	Revision due to late comments received from Kapsch after the draft was uploaded
April 2020	0.0.12	Update of the stable draft for ITS WG1 drafting session on 28/04/2020
May 2020	0.1.1	Revised after ITS WG1 drafting session on 28/04/2020 and uploaded as final draft for ITS WG1#52

History

Document history		
V1.1.1	September 2020	Publication