Future Use Cases for Cooperative Intelligent Transport Systems based on Unmanned Aerial Vehicles

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Abstract

Cooperative ITS (C-ITS) focus on the exploitation of enhanced connectivity between vehicles (V2V) and between vehicles and the road infrastructure (V2I and I2V), enabling the provision of advanced drivers' assistance and traffic management services. C-ITS services can be functionally deployed through short-range, long-range or hybrid communication channels. The operational deployment of C-ITS based on short-range communication networks requires significant investments for installing Road-Side Units (RSUs) along transport infrastructure at acceptable intervals. A solution to this challenge is the utilization of properly equipped Unmanned Aerial Vehicles (UAVs) that may take the role of roadside intelligent infrastructure, easing the application of C-ITS operational scenarios and enabling additional ones. This paper proposes and analyzes several use cases for applying along highway networks UAV-enabled C-ITS services. The benefits of these services, encompass road safety, traffic and operational efficiency, as well as environmental performance.

Keywords: *Cooperative Intelligent Transport Systems, Unmanned Aerial Vehicles, Use Cases*

1. Introduction

The extended application of Information and Communication Technologies in the transport domain has led to the wide development of Intelligent Transport Systems (ITS). ITS constitute a multidisciplinary area of research that enable information exchange among various domain-specific actors, following collaborative models and creating benefits within the triptych of road safety, environment, and mobility. Cooperative ITS (C-ITS), which constitute a recent trend on the concurrent research on ITS, focus on the exploitation of enhanced connectivity between vehicles (V2V) and between vehicles and the road infrastructure (V2I and I2V) (Edwards & Zunder, 2018). Thereby, they enable the provision of advanced drivers' assistance and traffic management services, by engaging traffic managers, road users, fleet managers, and related services' providers.

The deployment of C-ITS services has been the main objective of several EU-funded R&D projects, in which both "Day 1" and "Day 1.5" C-ITS services have been deployed (Mitsakis et al., 2018). C-ITS services are based on the exchange of standardized messages. Standardization of provided messages along with the adoption of common architectures at a cross-border level enable interoperability across C-ITS applications (Kotsi et al., 2020). In Europe, the development of C-ITS standards and specifications is primarily under the responsibility of the European Telecommunications Standards Institute (ETSI) and the European Committee for Standardization (CEN) (Festag, 2015).

C-ITS services can be functionally deployed through short-range, long-range or hybrid communication channels. The operational deployment of C-ITS based on short-range communication networks (ETSI ITS G5) requires the mass installation of On-Board Units (OBUs) in vehicles and Road-Side Units (RSUs) along transport infrastructure. While the former is expected to be achieved through the progress observed in vehicle manufacturing domain or the utilization of aftermarket solutions by several vehicle fleets, the latter remains an open challenge. This becomes extremely relevant, when taking into account the significant required investments for covering extended road networks with the necessary equipment at intervals going up to hundreds of meters. Required investment encompass procurement, installation, operations/maintenance and security costs. A solution to this challenge is the utilization of properly equipped Unmanned Aerial Vehicles (UAVs) to substitute completely or to some extent the installation of RSUs at fixed locations. According to this approach, UAVs are turned into “floating” RSUs, enabling the deployment of cost-efficient V2I and I2V information exchange networks. The aim of this paper is to propose new C-ITS use cases based on the suggestions of C-ROADS (Damaris & Wolfgang, 2020), the European platform for C-ITS deployment, extended with the capabilities offered by UAVs.

The rest of this paper is organized as follows. Section 2 presents in brief the content of standardized messages utilized for the provision of C-ITS services that are in relevance with the proposed UAV-enabled use cases. The description of these use cases falls into the scope of Section 3, while Section 4 concludes.

2. C-ITS standardized messages

Cooperative Awareness Message (CAM) is a message created by the Cooperative Awareness (CA) service. CAMs are exchanged between connected vehicles and between connected vehicles and roadside infrastructure to create and maintain awareness of each other (Rondinone & Correa, 2019). Provided information, which is updated one to ten times per second, includes the presence, dynamics, and basic attributes of the originating C-ITS station (i.e., vehicle or roadside infrastructure).

Decentralized Environmental Notification Message (DENM) constitutes a warning message providing information about road hazard or traffic conditions deviating from those addressed as typical operational conditions. Provided information include the type of the event and its position. It is used to alert other road users about the occurrence of an unexpected event that may impact on road safety or traffic conditions (Rondinone & Correa, 2019).

In-Vehicle Information (IVI) message is an I2V message format (usually including free text) conveying information about infrastructure-based traffic services needed for the implementation of use cases focusing on road safety and traffic efficiency. It may also be utilized to transmit static or dynamic road sign information (Rondinone & Correa, 2019). The provision of dynamic road sign information may be addressed as a means of substituting Variable Message Signs (VMS) mounted on highway gantries.

Signal Phase and Timing Message (SPAT) is an I2V message primarily used to communicate the intersection status to vehicles approaching an intersection. SPAT message usually contains dynamic information about the state of a signalized intersection. It can contain the traffic light state, future state predictions, speed advice, queue state information and whether a priority request is active (Rondinone & Correa, 2019).

MAP is another I2V message used by the roadside infrastructure to convey many types of geographic road information. Currently, MAP is used to convey one or more intersection lane geometry information within a single message. The message content includes aspects, such as complex intersection descriptions, road segment descriptions, high speed curve outlines, and segments of roadway (Rondinone & Correa, 2019).

3. Proposed use cases

UAV-enabled use cases presented in this section rely on the suggestions of CROADS platform, taking into account the increased capabilities offered by the presence of a properly equipped UAV utilized to sense traffic environment through computer vision algorithms and exchanging information with vehicles and a traffic management authority. The actors that are assumed to be involved in these use cases include:

- a UAV in which a C-ITS roadside unit is installed;
- one or more vehicles in which C-ITS on board units are installed or a driver's smart device (e.g., smartphone) is utilized for information exchange purposes; and
- a traffic management authority (i.e., a Traffic Management Center) or backend system oriented to provide C-ITS services.

Communication between UAV and the traffic management authority is assumed to be based on long-range communication means (e.g., 4G LTE cellular network). On the other hand, communication between UAV and involved vehicles is assumed to be based on short-range communication means in line with ETSI-G5 standard, including the standardized messages presented in Section 2. All use cases are assumed to take place in a highway traffic environment.

3.1 Use case 1 – Stationary vehicle

The first use case involves the notification of vehicles moving along a highway segment concerning the existence of a stationary vehicle at the downstream direction. This use case includes two variations depending on the extent to which the UAV is by itself capable of recognizing the existence of a stationary vehicle or depending on whether the UAV is at that time located in the adjacent area. Involved actors are in this use case the following:

- Actor 1: UAV
- Actor 2: Connected vehicle approaching the event's location
- Actor 3: TMC or backend C-ITS service provision system
- Actor 4: Stationary vehicle (either connected or conventional)

According to the first variation and as it becomes evident from Figure 1, Actor 3 is aware of the existence of a stationary vehicle (Actor 4) along a highway segment from an external information source (e.g., from a CCTV camera monitoring traffic). To this end, Actor 3 requests Actor 1 to relocate to an area upstream of the event and transmit DENM messages to connected vehicles approaching the location of the event. In this variation, it is assumed that Actor 1 (UAV) plays the role of "floating" roadside unit (RSU).

According to the second variation and as it also becomes evident from Figure 1, Actor 1 (UAV) following a prespecified flight plan and monitoring a specific road segment, identifies the existence of a stationary vehicle making use of its installed equipment and computer vision algorithm. Subsequently, Actor 1 communicates this piece of information to Actor 3 and independently relocates to an area upstream of the event, in order to transmit DENM messages to connected vehicles approaching the event's location. In this variation, it is assumed that Actor 1 plays the role of an advanced traffic monitoring system, capable of automatically recognizing stationary vehicles, as well as of a "floating" RSU transmitting messages to vehicles passing through a road segment.

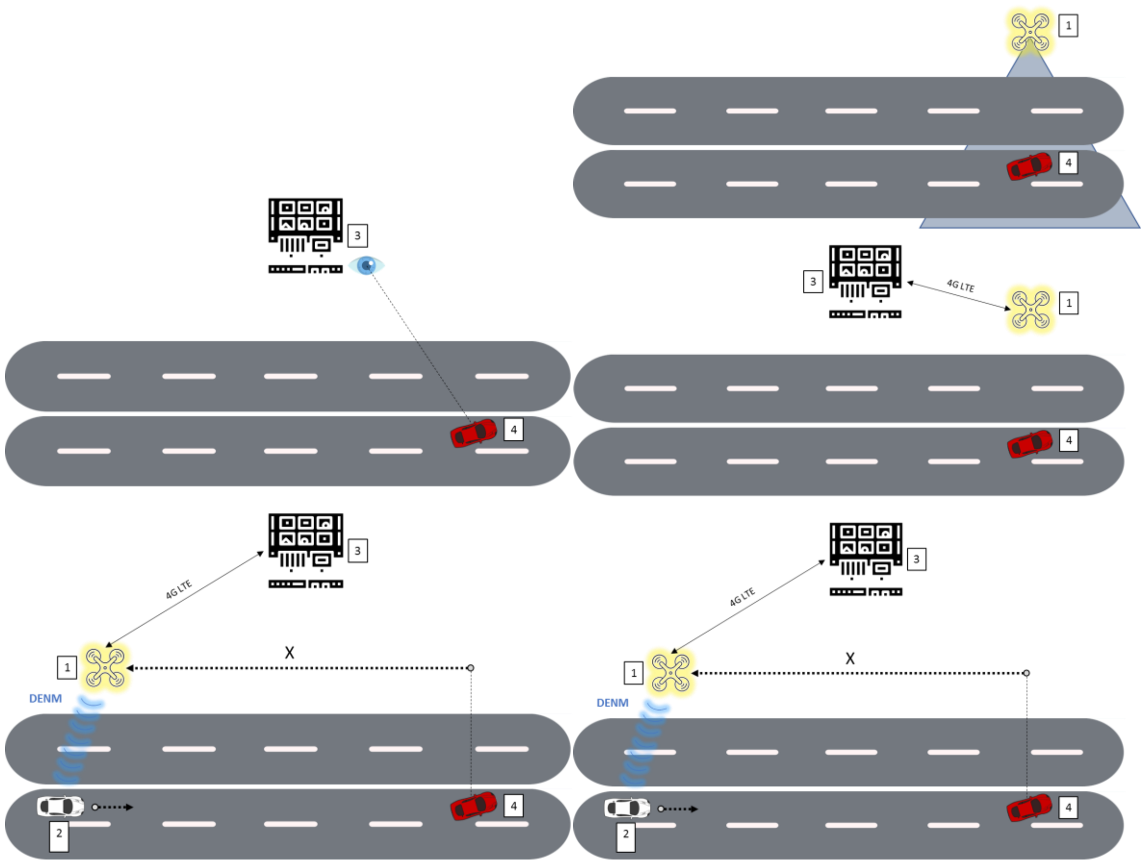

Figure 1: *Schematic representation of Use Case 1.*

3.2 Use case 2 – Traffic jam ahead

The second use case involves the notification of vehicles moving along a highway segment concerning the existence of traffic jam at the downstream direction. This use case includes two variations depending on the extent to which the UAV is by itself capable of recognizing the existence of traffic jam or depending on whether the UAV is located at that time in the adjacent area. Involved actors are in this use case the following:

- Actor 1: UAV
- Actor 2: Connected vehicle approaching the end of a queue
- Actor 3: TMC or backend C-ITS service provision system
- Actor 4: Vehicles (either connected or conventional) involved in a traffic jam

According to the first variation and as it becomes evident from Figure 2, Actor 3 is aware of the existence of traffic jam along a highway segment as well as of the end of the queue from an external information source (e.g., from a CCTV camera monitoring traffic or Floating Car Data provided by Actor 4). To this end, Actor 3 requests Actor 1 to relocate to an area upstream of the traffic jam and transmit DENM messages to connected vehicles approaching the end of the queue (Actor 2). In this variation, it is assumed that Actor 1 (UAV) plays the role of "floating" roadside unit (RSU).

According to the second variation and as it also becomes evident from Figure 2, Actor 1 (UAV) following a prespecified flight plan and monitoring a specific road segment, identifies the existence of a traffic jam making use of its installed equipment and computer vision algorithm. Subsequently, Actor 1 communicates this information to Actor 3 and independently relocates to an area upstream of the end of the queue, in order to transmit DENM messages to connected vehicles approaching the end of the queue. In this variation, it is assumed that Actor 1 plays both the role of an advanced traffic monitoring system, capable of automatically detecting traffic jams, and of a "floating" RSU.

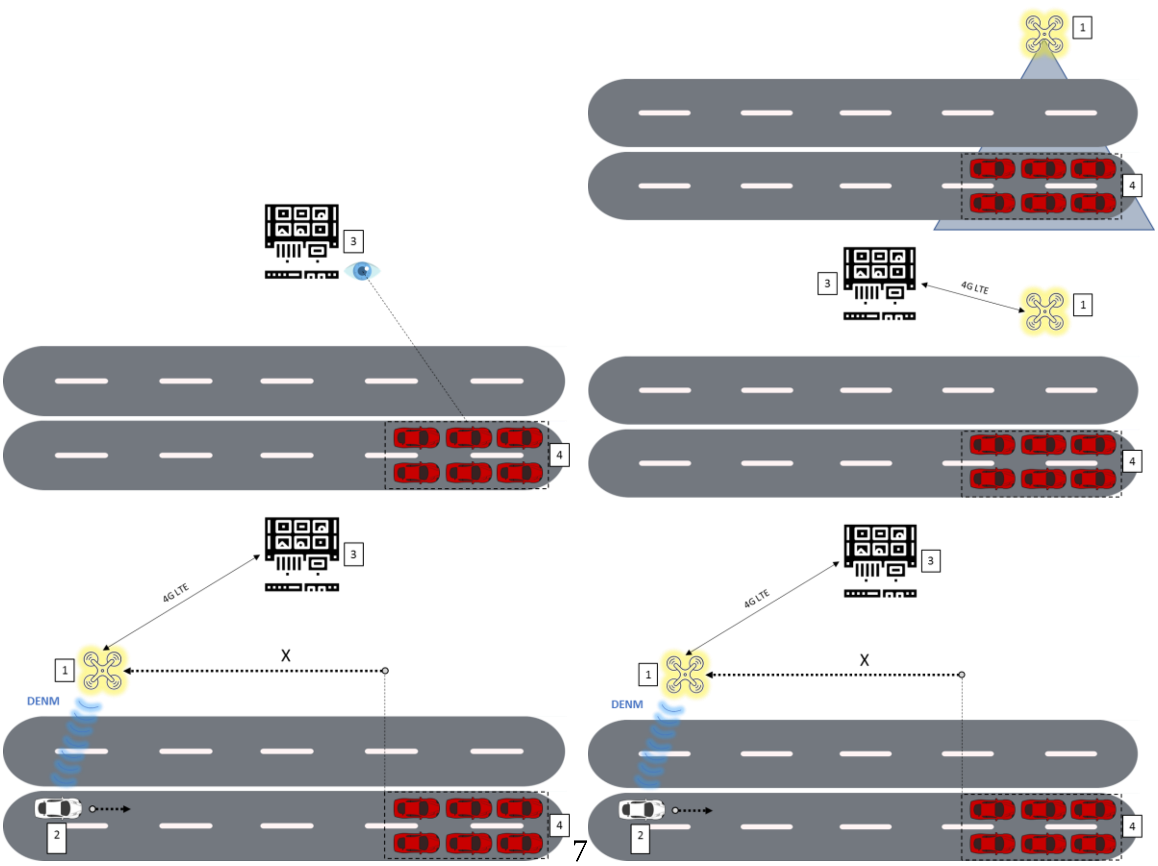

***Figure 2:** Schematic representation of Use Case 2.*

3.3 Use case 3 – Road works warning

The third use case involves the notification of vehicles moving along a highway segment concerning a lane closure resulting from the execution of road works in this location. Involved actors are in this use case the following:

- Actor 1: UAV
- Actor 2: Connected vehicle approaching road works' location
- Actor 3: TMC or backend C-ITS service provision system

As it becomes evident from Figure 3, Actor 3 is aware of the execution of road works along a specific highway segment from an external information source (e.g., the authorized department of local government authority). To this end, Actor 3 requests Actor 1 to relocate to an area upstream of the location in which the road works take place and transmit DENM messages to connected vehicles approaching road works' location (Actor 2). In the context of this use case, it assumed that that Actor 1 plays solely the role of a "floating" RSU.

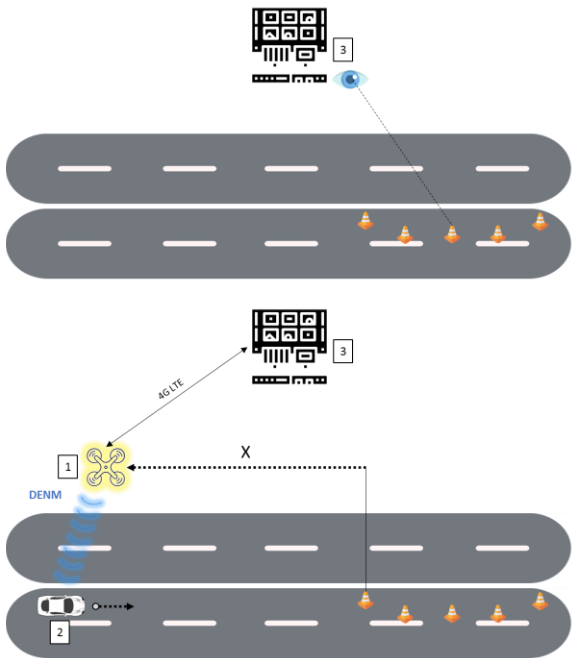

***Figure 3:** Schematic representation of Use Case 3.*

3.4 Use case 4 – In-vehicle signage

The fourth use case involves of the provision of information to vehicles passing through a highway segment. This use case includes two variations depending on whether provided information replicates or not a message broadcasted by a physical Variable Message Sign (VMS). In the context of the first variation (i.e., a physical VMS exists) involved actors include:

- Actor 1: UAV
- Actor 2: Connected vehicle
- Actor 3: TMC or backend C-ITS service provision system
- Actor 4: VMS

As it becomes evident from Figure 4, Actor 3 wishes to broadcast a message to drivers that are passing through a specific highway segment. To this end, Actor 3 exposes this message to a VMS (Actor 4) that is located within this segment. In addition, due to the increased importance of this message, Actor 3 wishes, if possible, to broadcast this message to drivers before their arrival in the vicinity of the VMS's location, in order to increase their reaction time. To this end, Actor 3 requests Actor 1 to relocate to an area upstream of Actor 4's location and transmit an IVI message to connected vehicles approaching this location (Actor 2). Transmitted message is shown on the vehicles' Human Machine Interface (HMI). In this variation, it is assumed that Actor 1 plays the role of a "floating" RSU that extends the spatial coverage of an existing VMS.

According to the second variation and as it also becomes evident from Figure 4, Actor 3 wishes to broadcast a message to drivers that are passing through a specific highway segment. In this case, it is assumed that there is no VMS installed in the highway segment. To this end, Actor 3 requests Actor 1 to be placed in an appropriate location and transmit an IVI message to Actor 2. In the context of this variation, it is again assumed that Actor 1 plays solely the role of a “floating” RSU.

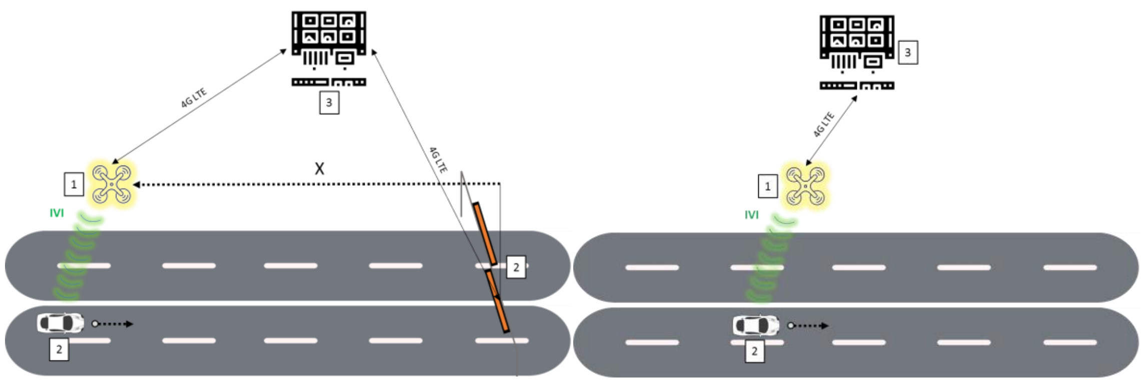

Figure 4: *Schematic representation of Use Case 4.*

3.5 Use case 5 – Green light optimal speed advisory

The fifth use cases involve the provision of green light optimal speed advisory (GLOSA) to connected vehicles approaching a signalized intersection. This use case involves the following actors:

- Actor 1: UAV
- Actor 2: Connected vehicle approaching a signalized intersection
- Actor 3: TMC or backend C-ITS service provision system

As it becomes evident from Figure 5, Actor 3 is aware in real-time of the existing traffic control plans that are applied in a signalized intersection (staging and phasing). Actor 3 is also aware of the geometry of this intersection. This information is transmitted to Actor 1, who is also requested by Actor 3 to broadcast SPAT and MAP to connected vehicles approaching the signalized intersection (Actor 2). Through, these messages GLOSA service is provided to the drivers. In the context of this use case, Actor 1 is assumed to play the role of a “floating” RSU.

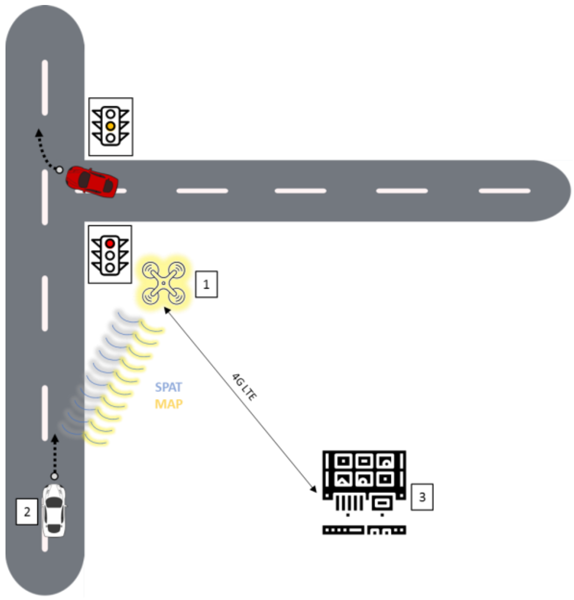

Figure 5: *Schematic representation of Use Case 5.*

3.5 Use case 6 – Probe vehicle data

The sixth use case involves the collection of probe vehicle data from vehicles passing through a highway segment. This use case involves the following actors:

- Actor 1: UAV
- Actor 2: Connected vehicles
- Actor 3: TMC or backend C-ITS service provision system

As it becomes evident from Figure 6, Actor 1 (UAV) following a prespecified flight plan in the vicinity of a highway collects CAM messages that are transmitted by connected vehicles, passing through the adjacent highway segments (Actor 2). Such messages provide information, updated at a certain frequency, regarding the position, direction, and speed of each vehicle. Subsequently, Actor 1 transmits collected information to Actor 3 and receives feedback regarding the location that should be placed depending on prevailing traffic conditions. In the context of this use case, it is assumed that Actor 1 plays the role of "floating" RSU supporting traffic management services.

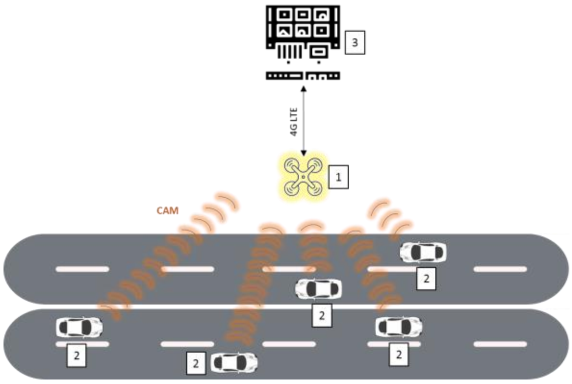

***Figure 6:** Schematic representation of Use Case 6.*

4. Conclusions

This paper presents six C-ITS use cases enabled by the involvement of a UAV in the relevant information and traffic sensing ecosystem. Provided use cases are oriented to enhance: a) road safety by providing drivers of connected vehicles with notifications regarding specific road hazards or generic information enabling the adaptation of their driving behavior (Use cases 1, 2, 3, and 4), b) traffic efficiency by enabling traffic management services (Use cases 6), c) environmental performance by reducing the number of vehicle stops at signalized intersections (Use case 5). Apart from these benefits and building upon the limited required investments for equipping a swarm of drones with the necessary technological means to enable the realization of the proposed use cases (compared to installing RSUs at fixed locations and at acceptable intervals), it is expected that the benefit/cost ratio of provided C-ITS services will increase. Finally, taking into account advancements in the field of Artificial Intelligence, it is expected that automation both concerning the vehicle side and the drone side will unlock additional use cases and operational C-ITS scenarios or increase the effectiveness of those suggested. However, there are several challenges that need to be overcome for achieving a successful operational deployment the proposed UAV-enabled C-ITS services. These challenges include the adaptation of the achievements in this field in the peculiarities of UAVs acting as floating RSUs (e.g., the identification by a moving object of users that shall receive a targeted message is not an easy exercise), as well as the resolution of potential (cyber)security and liability issues.

5. References-Bibliography

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