A proposal on a Connected Automated Mobility (CAM) communication system for (U)AVs

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The next generation of vehicular communications has the potential to interconnect Unmanned Automated Vehicles (UAVs), which are the level 5 autonomous vehicles, with its nearby surroundings including Vulnerable Road Users (VRUs), other UAVs, and roadside infrastructure. Given the increased interest in the demand of autonomous driving and Cooperative Connected and Automated Mobility (CCAM), the future UAVs will be safer through enabling communication between UAVs themselves and with their surroundings e.g., VRUs. Communication between UAVs and VRUs will be needed since VRUs will not be able to make a physical eye-contact with the UAVs since their is no physical driver anymore behind the steering wheel. In this way the VRUs can make themselves digitally aware in the UAV traffic and vice versa. Such that UAVs will not be isolated black boxes, i.e., operating and relying fully on their embedded sensors, to its surrounding UAVs and VRUs. This paper shows the current and future needs for autonomous vehicular communication between UAVs and VRUs. Therefore, we present the current trends in the vehicular communication domain and its research challenges. We propose a solution to enable communication between semi-autonomous vehicles, UAVs and their surrounding e.g., VRUs. In our paper, we provide also an early initial proposal to fuse the Vehicle-to-everything (V2X) communication with the embedded autonomous software in the autonomous vehicle.

Additional Key Words and Phrases: CCAM, autonomous driving, UAV, V2X, VRUs, communication, safety.

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1 INTRODUCTION

What all intelligent species have in common is a way of communicating with each other, e.g., by body language or some form of vocal communication. Communication not only makes the entire process of sharing information and knowledge easier but even more importantly communication is essential in the daily operation of modern cultures. As a result, the value of communication cannot be overstated. For those reasons intelligent fully autonomous vehicles especially from level 5. There are 6 levels of automation, ranging from 0 to 5 defined by Society of Automotive Engineer (SAE) as

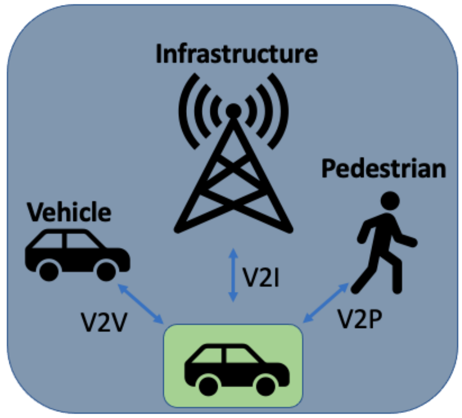


Fig. 1. Some examples of different types Vehicular communications.

Table 1. SAE levels of automation.

SAE level	Name
0	No Automation
1	Driver Assistance
2	Partial Automation
3	Conditional Automation
4	High Automation
5	Full Automation/UAV

shown in Table 1 [23]; these are vehicles without steering wheels or acceleration/braking pedals and thus, require no human attention, these are also called Unmanned Automated Vehicles (UAVs); of the near future should also be able to communicate with its surrounding UAVs and with its surroundings e.g., Vulnerable Road Users (VRUs), Roadside Units (RSUs), infrastructure, etc. Such that UAVs not only need to rely on their embedded sensor and communicate instead of being black boxes to its surroundings. This is why already present Advanced Driver-Assistance Systems (ADAS) are already increasing especially in semi-automated vehicles since they can already rely on some basic form of connectivity (e.g., traffic accidents warning messages, roadside construction warning messages, etc) as shown in Figure 1 [14]. This type of communication is widely known as Connected, Cooperative, and Automated Mobility (CCAM) Communication. Which is the overarching technology for example, for Intelligent Transport Systems (ITS) and Vehicle-to-Everything (V2X) technology.

One of the advantages of this type of standardized CCAM communication is that vehicles do not only need to rely on their embedded sensors and thus, their line-of-sight is virtually extended by relying on the information coming from sensors located in other CCAM entities (e.g., vehicles, roadside infrastructure ...). CCAM entities will support and understand the same standardized language (i.e., CCAM messages), thereby making it possible for VRUs to communicate to vehicles (from different vehicle manufacturers) and vice versa. One of the pioneering steps towards making this reality is made by the European Telecommunications Standards Institute (ETSI). ETSI has already standardized five types of these CCAM messages respectively: i) Cooperative Awareness Messages (CAMs) are messages exchanged by vehicles to be aware of their environment, a vehicle generates a new CAM message depending on its current position, speed, and direction, ii) Decentralized Environmental Notification Message (DENM) is a safety message that is triggered when the vehicle detects a relevant traffic event, iii) Infrastructure to Vehicle Information Message (IVIM) supports mandatory and physical road signs such as static or variable road signs, iv) Signal Phase And Timing Message (SPAT) is fully standardized in the SAE-J27353[1] and ISO 190914[2] standards for the moment SPAT messages are mostly envisioned to be used in intelligent transport systems in stop lights telling vehicles them which signals are green, yellow, or red and in a set of limited cases, the time left to cross an intersection for a specific approach, and v) MapData Message (MAP) that contains the topological definition of lanes within an intersection, of a road- segment they also define the links between the segments, type of lanes, and restrictions at lanes. Despite the numerous advances already done in CCAM communication with the standardization of the CCAM messages and use-cases, there are still plenty limitations to be overcome. One of the big research gaps and innovations gaps surrounding CCAM message communication is the missing of a blueprint/proof of concept of one innovative generic flexible deployable enabling CCAM communication system that can enable: i) an intelligent way the generation of CCAM messages in CCAM entities, ii) the distribution of the CCAM messages in the ITS-network, and iii) the processing of, intra and intervehicle communication, as well as the communication with the road network infrastructure or with VRUs. The main issues and challenges are, incomplete standardization of CCAM messages with potential lack of fields in CCAM messages [6, 8, 9]. The shortcomings of incomplete standards for how VRUs can become part and benefit of the CCAM environment (i.e., generating, distributing, and processing a CCAM message). The lack of a complete finished standardized CCAM message for VRUs [7]. The absence of research to generate real-time and real-life valid CCAM messages for vehicles and VRUs. The lack of guidance on processing the CCAM messages to ultimately find relations in the received CCAM messages [4]. The missing guidance on the needed technology infrastructures (in ITS-networks) for governance. All these issues limit the research potentials of CCAM message to expand the boundaries CCAM-related research e.g., researching the incorporation of the CCAM messages with UAVs and VRUs), allowing researchers to study and build more novel use cases that are currently infeasible and the use of the adoption by the industry.

In this paper we will survey the need of communication among UAVs, the demand for a generic flexible deployable enabling CCAM communication system, the absence to in cooperate VRUs.

The remainder of this paper is divided as follows: Section 2 is a brief overview of the current trends in the vehicular communication domain. We discuss in depth the proposed CCAM communication system and we discuss the need to fuse the proposed CCAM communication system with the autonomous software of the autonomous vehicle in Section 3. The conclusions is summarized in Section 4.

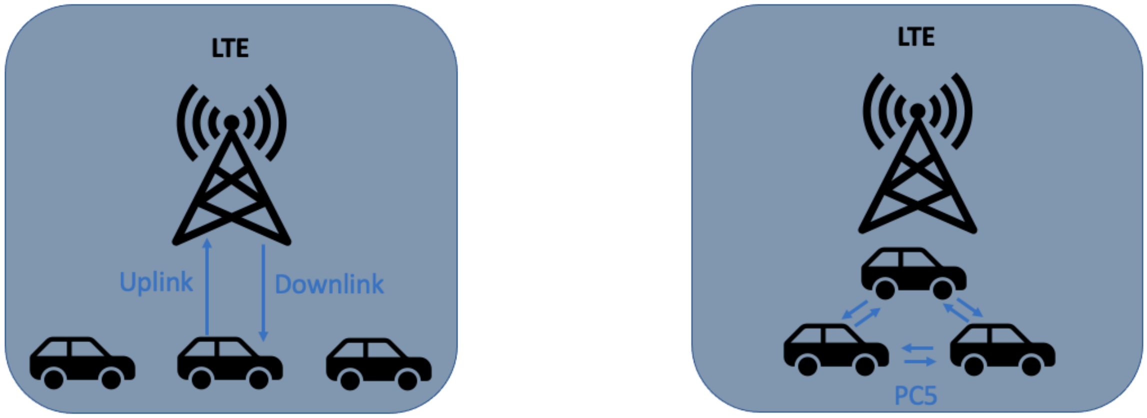
2 TRENDS IN THE VEHICULAR COMMUNICATION DOMAIN

Road facilities in Europe have seen a dramatic decrease over the years, i.e., from 2001 to 2018 facilities have decreased by 50%, through the implementation and widely adoption of the increasing safety features of vehicles (e.g., Airbags, Antilock Brakes, Electronic Stability Control, Adaptive Headlights, etc) [18]. Many industry experts believe that V2X technology will be a necessary technology to increase safety for semi-autonomous vehicles and especially for UAVs [1, 2, 14, 20].

2.1 Current major communication technologies

There are currently two main leading wireless technologies supporting the first generation V2X communication [17]. One is defined by the Third Generation Partnership Project (3GPP) in Release 14 and 15, and is named as Long-Term

[1] https://www.sae.org/standards/content/j2735set_202007/
[2] https://www.iso.org/standard/73781.html



(a) LTE-V2X Uu.

(b) LTE-V2X PC5.

Fig. 2. LTE-V2X communication interfaces

Evolution-V2X (LTE-V2X) [17]. This cellular-based technology can also be referred to as Cellular-V2X (C-V2X). LTE-V2X introduces two interfaces for radio access i.e., the direct interface PC5 as shown in Figure 2b, and the cellular interface Uu as shown in Figure 2a. The PC5 interface enables vehicles to communicate directly without the need of base stations. The Uu interface uses LTE's uplink and downlink to implement Vehicle-to-Vehicle (V2V) communication. The second current leading technology is IEEE 802.11p, it is a vehicular communication standard that makes use of the unlicensed 5.9-gigahertz (GHz) band which has been deployed for more than 20 years. In recent years the 5.9 GHz unlicensed band have emerged in: on one hand the Dedicated Short-Range Communications (DSRC) protocols developed in the USA and on the other hand the Intelligent Transportation System (ITS)-G5 protocol developed by ETSI. However, DSRC has barely been deployed in more than 20 years since adoption; because this spectrum has largely been unused; in 2020 the Federal Communications Commission (FCC) announced a reallocation of the 5.9 GHz bandwidth as a result, researchers and automakers in the USA may be foreced to switch to LTE-V2X[2, 5]. Furthermore, both IEEE 802.11p and LTE-V2X are not compatible with each other, which implies that vehicles are not able to interconnect with each other if they are equipped with communication units from different technologies [17]. This forms already a first challenge to the vision where all different (vendor crossing) UAVs can speak and understand the same language. Moreover, recent research performed by Charpentier et al, proofed that ITS-G5 (IEEE 802.11p) and LTE-V2X (3GPP) do not meet the requirements for UAVs [3]. Which reconfirms that ITS-G5 and LTE-V2X are designed for basic safety and traffic management use cases i.e., to support basic cooperative active traffic safety, traffic management, and telematics applications and thus not for advanced UAV communication [11, 16].

2.2 Next generation communication technologies

In order to overcome these shortcoming, 3GPP has published in its Release 16 for the first time a V2X standard based on the 5G New Radio (5G NR) air interface and named it 5G-V2X or 5G vehicular communication [11]. In order to support advanced connected and automated driving use cases. However, 3GPP is currently standardizing 5G-V2X release 18. The 5G Automotive Association (5GAA) has concluded that 5G offers further options for V2X communication and is seen to be more future proof in the shift towards fully autonomous driving [24]. 5GAA concluded that the current present available C-V2X technology must need to evolve to meet the more demanding safety requirements of the future. Therefore, associations like 5GAA and leading research partners have acknowledged that 5G-V2X will be the leading technology for the advanced automated driving communication for UAVs, and that the present LTE-V2X and ITS-G5 technologies need to be considered for basic safety use cases and thus not for autonomous vehicles [2, 11, 20, 24]. One of the reasons 5G-V2X will be a game changer for vehicular communication is due to its, low latency, extreme throughput, enhanced reliability which are requirements for many aspects of autonomous driving and will allow UAVs to share real-time data [20]. State-of-the-art research is already looking at 6G as the next key enabler for vehicular networks as it paves the way to future ITS systems and V2X communication in 6G [21]. Since the next-generation AI empowered, 6G networks will be proposed for future evolution of network intelligence [21]. Therefore, aims the 6G vehicular network to highly dynamic and intelligent ITS systems, which enables the networks to change the environment to meet the demands of the application requirements [21].

2.3 Current vehicular messages

In order to let UAVs communicate with other UAVs of different automakers and with its surroundings like e.g., VRUs, as shown in Figure 1, they will need to exchange common agreed (standardized) messages that are independent from the transmitting technology. Therefore, in Europe, ETSI has already defined some of these messages e.g., CAMs, DENMs, VAMs, IVIs, SPATs, etc. Where the two most important messages surrounding safety are the CAM messages and the DENM messages. In the USA the WAVE protocol family of IEEE 1609 is used by the SAE J2735[3] and J3161/1 which has its own version for safety messages. For example, the safety message for pedestrians is defined in the USA as PSM and in Europe it is defined as VAM. The same is valid for the the safety message for vehicles, in the USA they define these messages as Basic Safety Messages (BSMs) and in Europe they define them as CAMs. Another very important challenge is that, research still has to explore how these safety messages can be used in UAVs, and not anymore as just warning messages for the human driver as in the first generation V2X communication, such that UAVs can take autonomous decisions based on these messages in collaboration with the on-board sensors of the UAV.

Due to the fact that different continents (e.g., Europe, USA) are standardising their own set of safety messages, the vision that all vehicles can communicate over the same standardized language, i.e., standardized messages, diminishes here. Another problem that arises with this, is the globalisation of UAV manufactures where it can not be that your UAV is dependent on the continent where it is been manufactured. Which will result in for example, that you can not buy a UAV that is been manufactured in the USA to use it in Europe since the vehicle can not communicate the standardized ETSI communication stack used in the European Union. Furthermore, this will slow down the adoption rate by UAV manufactures to adopt the next generation V2X communication technology. In order to overcome these challenges, research has also focused in the direction of external V2X On-Board Unit (OBU) equipment that can be installed flexibly in a traditional vehicle or UAV that already left the factory [15]. This will require specialized software that needs to run in these OBUs that is why we propose in chapter 3 the CCAM Communication System that can run in such OBUs for example.

2.4 Connecting UAVs with VRUs

If we know that by 2050, 70% of the population will be living in smart cities [4], it is then critical that VRUs (i.e., pedestrians, cyclists, motorcyclists, road workers, wheelchair users, scooters, etc) are also connected with the ITS-network, and vice

[3]SAE J2735: https://bit.ly/3Papvw5
[4]Source: https://publicaties.vlaanderen.be/view-file/15725

versa and thus be able to communicate with UAVs to increase safety. In this way VRUs can make them self digitally aware to the UAV traffic, this is needed since VRUs can not anymore make physical eye-contact with the driver since it are UAVs and thus have no human driver to make eye-contact with. Research performed by 5GAA, showed that currently the smallest number of safety improvements has been done in the category for VRUs [18]. They also concluded that every single individual is a potential VRU which makes the total number of VRUs possible to exceed 7.7 billion people that will be in danger when they participate in UAV traffic if they can not make them self, digital, aware to the UAV traffic [18]. However, Europe has identified this present challenges and has acknowledged that connectivity and automation will offer a great potential to reduce errors and enhance protection of VRUs [10]. One of the challenges will be to let UAVs and VRUs communicate which each other. For example, UAVs their current safety messages they will send out are respectively in Europe CAMs and DENMS, and in the USA BSMs. The current safety message VRUs will send out are VRU Awareness Messages (VAMs) in Europe and Pedestrian Safety Messages (PSMs) in the USA. This forms already major research challenges to search for innovative solutions such that vehicles and VRUs will be able to communicate with each other and understand each other language thus, process the received messages and take actions on them. Not only that but current research is also challenged with how VRUs can become part of it, since VRUs will not be equipped with OBUs and thus not be equipped with advanced V2X radio technology hardware. However, the majority of today's VRUs are equipped with a modern smartphones, this can be seen as the connection point to let them communicate with UAVs and thus become part of the next generation ITS network. Since by then all smartphones will be equipped with 5G and by then 5G coverage will be rolled out. Recent research performed by 5GAA provided already initial answers to pending questions like, How does a smartphone detect a VRU situation?, How does the smartphone know where the VRU is heading? [18].

3 CCAM COMMUNICATION SYSTEM

All the topics briefly surveyed in the previous chapters prove that there are still a lot of (open) research challenges surrounding advanced vehicular communication. That is why we propose and see the need for a CCAM System to achieve safe and smart mobility when the world transitions to UAVs and thus, to the next generation of vehicular communication. That can be deployed on any generalized CCAM entity for example, on generic OBUs on e.g., passenger cars, busses, trucks, on generic RSU for roadside infrastructure or on generic VRUs e.g., smartphones and smart watches. This CCAM Communication System can enable: i) an intelligent way the generation of CCAM messages, ii) the distribution of the CCAM messages in the ITS-network, and iii) the processing of, intra and intervehicle communication, as well as the communication with the road network infrastructure or with VRUs. The proposed CCAM communication system as show in Figure 3 will enable V2X as a hole since the majority of research communication systems only include a specific vehicular communication type for example, V2V for the first generation V2X communication [20, 22]. Whereas the proposed CCAM communication system is meant for the next generation V2X including UAVs and VRUs.

3.1 CCAM message generator

One of the first steps towards improving ITS networks, such as smart cities and roads, is to generate messages that each participant in the traffic will be able to understand. Therefore, a state of the art analysis is needed of how all current and upcoming standardized CCAM messages need to work together in a single system. In order to be able to research a blueprint and develop a CCAM message generator that can run on any kind of CCAM entity. In order to do this, the system needs to know on which CCAM entity it is deployed. If it is in a passenger car, then it needs to read out the Controller Area Network (CAN)-bus of the vehicle in order to retrieve the appropriate data from the

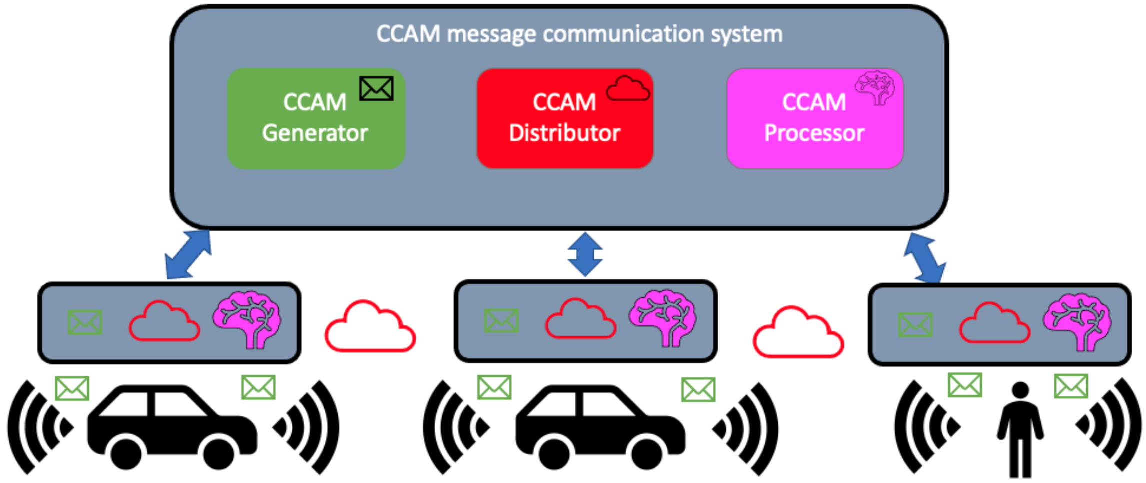


Fig. 3. CCAM communication between vehicle and VRU with the innovative flexible CCAM communication system

embedded in-vehicle sensors, to construct the CCAM messages with the correct data. This leads to another research challenge that needs to be solved and that is to design and create a generic software component that can read out any CAN-bus network of a vehicle. If this is possible, we can deploy this system on any regular UAV (by deploying it on its OBU for example) and then all UAVs in the smart city will construct valid CCAM messages. That is not all, if the system is deployed on VRUs equipment, it needs to be able to construct valid CCAM messages since VRUs do not have a CAN-bus this leads to the research challenges like for example, how the VRUs need to obtain the needed data to include in their CCAM message, where to run this software component directly on the smartphone of the VRUs or in the edge, cloud, etc.

3.2 CCAM message Distributor

The second logical step is to distribute the real-life CCAM messages generated by vehicles and VRUs (CCAM message generator) in the ITS network (i.e., the smart city, smart highways, etc). The focus of this CCAM message Distributor is primarily driven by the research and development, how to define the CCAM Distributor architecture and its requirements. Such that the CCAM Distributor can distribute messages from vehicles and VRUs. Research questions like, How to define, how VRUs need to send and receive these CCAM messages in their devices? In order to define which kind of technologies do VRUs need to use to transmit their CCAM messages. Since VRUs will not support the conventional first generation V2X technologies (i.e., ITS-G5 IEEE 802.11p or LTE-V2X 3GPP). This leads to another logical question that also needs to be researched and addressed i.e., "Can VRUs directly use the open already available public 4G or eventually the 5G, 6G networks to transmit their CCAM messages?" All recent and future smartphones will support 5G and currently already support 4G. One of the main innovations of 5G here is the latency aspect, the time needed to deliver the CCAM messages, will be much lower compared to 4G and thus, making it possible to process the CCAM messages sooner on the receiving CCAM entity. Furthermore recent research points to the fact that UAVs will make use of 5G-V2X, which will be a form of 5G, thus making it potentially easier to communicate with VRUs since they will potentially also making use of 5G [24].

3.3 CCAM message processor

A pending research question also acknowledged by 5GAA and academia is to find innovative ways to process the received CCAM messages [4, 12, 18, 24]. Since the current research challenges are for example, what can UAVs or VRUs do with the received CCAM message? As each received CCAM message needs to be decoded before processing, the question is: "Can there be a flexible generic CCAM message decoder that can be deployed on any generic CCAM device?". By enabling such a flexible and generic decoder, a portable decoding system can decode any kind of CCAM message and can run on any kind of CCAM entity/device (e.g., passenger car, trucks, pedestrian, cyclists). In order to make it then finally possible to research a portable framework that will enable to process/monitor all received CCAM messages specific for each CCAM entity through custom future researched state-of-the-art algorithms. In the current state-of-the-art one of the major missing pieces is how you can process these messages in an intelligent and efficient way to eventually find relations and thus predict what may happen. The aforementioned challenge will be enabled by the CCAM message processor such that research can be performed on state of the art (AI) algorithms for each individual CCAM entity. Furthermore, an existing solution such as the CAM Application Framework (CAMAF) exists for the processing of CAM messages [4].

The output of the CCAM message processor can then be fused together with the embedded autonomous software running in the automated vehicle such that the automated vehicle make safer decisions based on his sensors and its communication. Therefore, we envision that there will be a software bridge needed that can fuse the output of the CCAM processor (V2X communication) with the autonomous software in the vehicle.

4 DISCUSSION AND CONCLUSION

As we have seen, the next generation V2X communications have the potential to connect UAVs with its surroundings for example, with other UAVs and VRUs. As government standards for the next generation V2X communications improve, manufactures will be more equipped to deploy V2X communication an rely on them for safety purposes [19]. Although current research explores possible solutions for vehicular communication, there are still many areas of potential yet to be addressed to turn this vision into a reality. For example, the lack of standardized messages, guidance on communication technologies, intelligent communication systems, and etc. One of the major research challenges will be to connect VRUs with the next generation ITS network in order to let them communicate with its surrounding UAVs . This implies that the messages the VRUs and UAVs exchange with each other can be processed on both sides for an intelligent action. Furthermore, UAVs need to be able to fuse their next generation V2X communication with their autonomous software to determine the safest decisions in traffic. Therefore in this paper, we presented briefly the current and upcoming trends in the vehicular communication domain. We presented an overview the current and upcoming CCAM messages and their transmitting technology. In order to propose a flexible deployable generic CCAM Communication system that address the present research challenges surrounding UAV communication. We end with an overview of how the proposed technologies need to be incooperate to create the vision of communicating autonomous vehicles with each other and VRUs.

As future work, we intend to research and develop the proposed CCAM communication system that is composed out of a CCAM message generator, CCAM message distributor, and CCAM processor as shown in Figure 3. These three blocks (i.e., CCAM generator, CCAM distributor, and CCAM processor) are fundamentally needed and depended on each other. We plan to research and develop these three blocks in three steps each step corresponding with one block of the CCAM system. Furthermore we will develop, implement and validate this CCAM communication system on the

Smart Highway testbed [13]. The first step is to research and develop is the CCAM message generator. This flexible component will address missing pieces in the CCAM communication state-of-the-art surrounding the generation of CCAM messages these are: i) potential missing fields in upcoming standardized CCAM messages for VRUs and standardized CCAM messages for vehicles, ii) how VRUs need to include the needed data in their CCAM messages, and iii) how real UAVs need to generate real CCAM messages with the connection of the CAN-bus of the UAV. The second key enabling sub-component is the CCAM message distributor. The major research gaps that this component will address and try to solve are: i) the lack of a standardized system on how CCAM messages from VRUs and UAVs can be exchanged with each other (i.e., VRUs do not have yet a complete standardized CCAM message), and ii) the lack of technologies the VRUs need to use in order to transmit theirs, and receive CCAM messages from the others CCAM entities (i.e., UAVs, VRUs, ...). The final key enabling sub-component is the CCAM message processor. One of the major current issues this component will address and what it will enable is how CCAM entities can make in an intelligent way use of the received CCAM messages. This component will make it possible to run any kind of intelligent algorithm to process the CCAM messages. This will be enabled by the CCAM messaging processor since this guarantees that every CCAM entity understands and processes the CCAM messages such that research can be performed on future custom researched (AI) algorithms, which will make them achieve an improved and extended perception of the environment. To eventually making it possible to perform research on how to fuse the vehicular communication with the embedded autonomous software in the UAV with the CCAM processor. This is a pre-requisite for making safer optimal decisions that affect not only VRUs but all participants in the traffic.

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