# 3GPP SEAL as an Edge Application: The Ultimate Enabler of Flexible and Universal Communication between Vulnerable Road Users and Autonomous Vehicles

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***Abstract*—Enhancing communication between Vulnerable Road Users (VRUs) and Unmanned Automated Vehicles (UAVs) has significant potential to improve road safety. The need for this communication is due to the fact that VRUs will no longer be able to establish physical eye contact with UAVs, given the absence of a human driver behind the steering wheel. However, a challenge in the state-of-the-art technologies for Connected, Cooperative, and Automated Mobility (CCAM), i.e. ITS-G5 (IEEE 802.11p) and Cellular Vehicle-to-Everything (C-V2X), is the lack of a unified communication stack that connects all types of users. This is because the current generation of CCAM communication technologies requires dedicated hardware devices that cannot be easily installed on devices carried by VRUs (such as phones or wearables). This paper aims to address this challenge by providing a real-life, sophisticated solution that offers the CCAM communication stack as a Network-as-a-Service (NaaS) in the 5G and Beyond ecosystem. Integration is achieved by relying on the Service Enabler Architecture Layer (SEAL) principles standardised by the 3rd Generation Partnership Project (3GPP). These architectural principles are embedded in the design of Network-Aware Edge Applications (EdgeApps), which are the building blocks of vertical services in 5G and Beyond. This way, any device or user with the capability to connect to 5G will also be able to retrieve important CCAM services from the network by using EdgeApps. In addition, no dedicated CCAM hardware is needed. Furthermore, this paper provides key lessons learned from the challenges encountered in connecting VRUs and UAVs by integrating CCAM into the 5G and Beyond ecosystem. Moreover, we have conducted real-life experiments to evaluate the system-level latency characteristics of the proposed solution and compared them with those of ITS-G5 and C-V2X.**

***Index Terms*—5G and Beyond, CCAM, EdgeApp, 3GPP, SEAL, V2X, ITS-G5, C-V2X**

## I. INTRODUCTION AND MOTIVATION

Communication, whether it be through body language or vocalisation, is a universal characteristic found in all intelligent life forms [1]. For this reason, intelligent, fully autonomous vehicles, especially those at level 5, are of great interest [2]. Currently, the Society of Automotive Engineers (SAE) has outlined six stages of automation, ranging from level 0 to 5, as illustrated in Table 1 [2]. Vehicles with level 5 autonomy, which require no human intervention, are also known as Unmanned Automated Vehicles (UAVs) [2]. This introduces several potential risks, one of which is that Vulnerable Road Users (VRUs) can no longer make the driver aware by establishing physical eye contact with the UAVs [2].

In recent years, Connected, Cooperative, and Automated Mobility (CCAM) has emerged to facilitate communication between VRUs and Intelligent Transport Systems (ITSs) equipped vehicles. CCAM serves as an umbrella term that encompasses various communication protocols, enabling interaction between vehicles. CCAM currently spans technologies such as Intelligent Transport Systems - G5 (ITS-G5) and Cellular Vehicle-to-Everything (C-V2X), providing a foundation for Vehicle-to-Everything (V2X) communication. Standardised CCAM communication not only relies on embedded sensors for environmental perception but also facilitates bidirectional interaction with the environment [2]. The European Telecommunications Standards Institute (ETSI) plays a key role in standardising CCAM messages and ensuring interoperability across different communication technologies [2,3]. These types of V2X messages, including Cooperative Awareness Message (CAM), Decentralised Environmental Notification Message (DENM), In-Vehicle Information (IVI), and VRU Awareness Messages (VAMs) are not yet widely adopted, as most of the vehicles do not exchange messages due to a lack of dedicated hardware [2,4]. Facilitating flexible and universal message generation between VRUs and UAVs has the potential to break down the current communication barriers between various vehicles and other road users, creating a safer mobility environment [5].

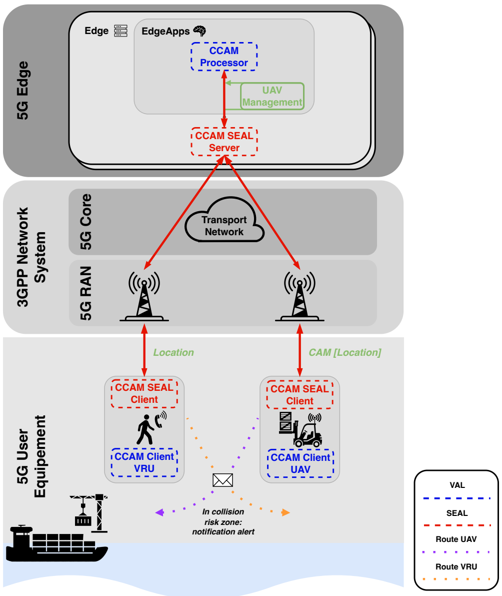

Fig. 1. CCAM communication between VRUs and UAVs enabled by the 5G and Beyond network via the SEAL-enhanced EdgeApps.

However, two prominent challenges associated with CCAM communication pose significant limitations to achieving seamless and safe interactions between various VRUs and UAVs. The first challenge refers to the absence of a unified communication stack that ensures effective communication between all types of users (such as UAVs and VRUs), regardless of

TABLE I
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 |

their model. The second challenge is the dependency on a specific type of CCAM hardware that is present in the case of current CCAM technologies, i.e. ITS-G5 and C-V2X. These technologies operate on dedicated hardware that is designed specifically for vehicles, not for any other types of users, including VRUs. This design results in a significant barrier to equipping VRUs with these technologies, limiting their ability to enhance safety in traffic.

In this paper, we address these two challenges by proposing the following solution; running on a real-life 5G network that offers CCAM communication as a Network-as-a-Service (NaaS) in the 5G and Beyond ecosystem. This solution is illustrated in Fig. 1, and it establishes CCAM communications between VRUs and UAVs by integrating CCAM communication directly into the 5G and Beyond network. This integration is particularly pertinent given that one of the visions of 5G and Beyond networks is their ability to offer NaaS to various verticals (such as automotive, Transport & Logistics (T&L), etc.) directly from the network edge [6].

The integration is achieved by the principles of the Service Enabler Architecture Layer (SEAL), standardised by the 3rd Generation Partnership Project (3GPP). These architectural principles are incorporated into the development of Edge Network-aware Applications (EdgeApps), which are fully edge-based, and serve as the building blocks for vertical services in 5G and Beyond [7]. We applied the EdgeApps design principles as outlined in the VITAL-5G project[1] (EU H2020 ICT-41 project), which is a new generation of edge applications deployed at the edge of 5G and Beyond networks as advanced Virtual Network Functions (VNFs) [7,8].

EdgeApps allows us to specify the network, service, and hardware requirements via the EdgeApp blueprint [7]. These requirements are then interpreted by network controllers and orchestrators, facilitating adjustments and service deployments in accordance with the specifications provided in the EdgeApp blueprints [7]. These EdgeApps are then deployed on the 5G-enabled infrastructure at the edge, enabling the creation of complex 5G vertical services[2] by abstracting the underlying complexity of the 5G network [7]. This way, any device or user capable of connecting to 5G can access important CCAM services from the network through the use of EdgeApps enhanced with SEAL. Furthermore, this eliminates the need for dedicated CCAM hardware.

As shown in Fig. 1, the proposed CCAM EdgeApp, enhanced with SEAL, is fully edge-based, suitable for mission-critical operations, and characterised by low-latency requirements as defined through the EdgeApp blueprint utilising an Ultra-Reliable Low-Latency Communication (URLLC) slice. The paper aims to showcase an edge-based EdgeApp system that can support mission-critical operations and meet low-latency requirements.

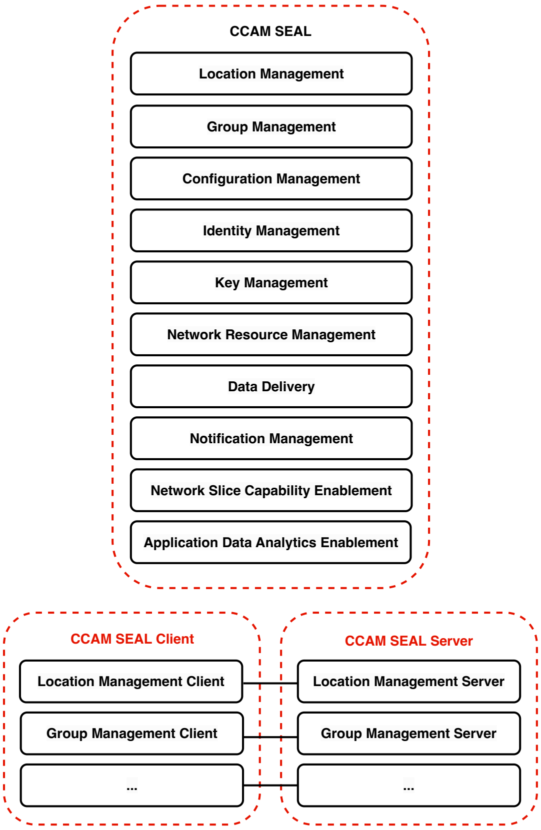

Fig. 2. Functional architecture of the SEAL framework.

## II. VERTICAL APPLICATIONS IN 5G AND BEYOND

### A. *Service Enabler Architecture Layer (SEAL)*

The SEAL framework plays an important role in the future of the 5G and Beyond ecosystem. The 3GPP Release 16 serves as a foundational element to support the development and deployment of vertical applications. The SEAL framework, as a part of this release, focuses on providing common support services as a unified layer for vertical applications. Key entities such as Vertical Application Layer (VAL) Client, VAL Server, SEAL Client, and SEAL Server are integral components of this framework. Integration with the 3GPP Common API Framework (CAPIF), 3GPP Release 15, allows the VAL Server to function as an API Exposing Function (AEF), enabling deployment scenarios across Public Land Mobile Network (PLMN) and vertical application service provider domains [9]. The functional architecture of SEAL[3] encompasses essential features such as group management, location management, identity management, configuration management, key management, and network resource management, as shown in Fig. 2. Vertical services can leverage these capabilities from SEAL, resulting in a significant reduction in time and cost to market for both existing and future applications [10].

The SEAL functional model is structured into generic and specific SEAL service functional models that provide a comprehensive set of services to the vertical application layer.

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[1] VITAL-5G: https://www.vital5g.eu/

[2] A vertical service consists of multiple EdgeApps that work together to deliver a service from the edge of the 5G and Beyond network [7].

[3] 3GPP TS 23.434 V19.0.0 (2023-12): https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3587

These services encompass data delivery, notification management, network slice capability enablement, and application data analytics enablement. Each SEAL service offers Application Programming Interfaces (APIs)[4] on a service-based interface to its consumer entities, with vertical applications consuming these services in the form of APIs. The detailed specification of SEAL services, such as data delivery and enabling application data analytics, is provided in the 3GPP technical specifications[3].

However, it is important to highlight that while SEAL holds great promise for enhancing communication between UAVs and VRUs, it is not yet fully standardised. Therefore, in this paper we provide a proof of concept of our solution that enables the CCAM communication by incorporating SEAL into the EdgeApps middleware, making it a SEAL-enhanced EdgeApp. Fig. 2 illustrates the interlinked functional architecture that identifies the functions of the various components within the SEAL framework. In this way, the paper provides meaningful insights into how SEAL can potentially be further enhanced by addressing gaps to leverage it in CCAM communication via EdgeApps, subsection II-B provides the use case for our sophisticated solution with a proof of concept.

### B. *Use case*

As depicted in Fig. 1, a practical use case for vertical services, comprising EdgeApps enhanced with SEAL, is its implementation in a busy harbour environment. In our use case, this is demonstrated at a congested road intersection within the port environment (Fig. 3). A VRU equipped with a smartphone and connected via 5G and Beyond, along with a test vehicle equipped with a 5G modem, SEAL can potentially facilitate seamless communication between VRUs, and UAVs.

In the event of a potential collision between a VRU and a UAV, these SEAL-enhanced EdgeApps can intervene by requesting the UAV to stop completely, thereby avoiding a collision with the VRU. More specifically, the CCAM SEAL Clients, Fig. 1, continuously transmit location messages to maintain awareness of each other. These messages are transmitted over the 5G Radio Access Network (RAN) and then through the 5G Core network to reach the edge where EdgeApps are placed to process the data, as shown in Fig. 4. The VAL CCAM client serves as a lightweight application for sending CCAM messages on UAVs and VRUs. The VAL CCAM processor is designed to intelligently process CCAM messages, with the aim of improving environmental perception and facilitating optimal decision-making.

## III. EXPERIMENT

To validate and demonstrate the feasibility of our solution that offers CCAM communication as a real-life NaaS in the 5G and Beyond ecosystem. We focus on the following scenario: receiving a notification alert when a UAV and a VRU approach and enter each other's collision risk zones.

### A. *User equipment*

Fig. 3 illustrates the real-world test environment used to validate and execute our proof of concept of the proposed solution in the port of Antwerp-Bruges. The vehicle acting as the UAV, shown in Fig. 3, is a Smart Highway BMW. The C-V2X Smart Highway testbed is located in Antwerp, Belgium [5]. The vehicle is equipped with the Global Positioning System (GPS) Universal Serial Bus (USB) module and a 5G Standalone (SA) Peplink modem[6] (Fig. 3). The Peplink serves as a gateway connecting the vehicle to the edge part of the 5G SA network where the enhanced SEAL EdgeApps operate (Fig. 1). Through the GPS USB module, the location of the vehicle is continuously tracked and updated via the SEAL location management service. This SEAL location management is also used for the VRU location. The experiment is performed on the 5G SA Antwerp VITAL-5G pilot site created in the VITAL-5G project [7]. The Next-Generation Node B (gNodeB) used is depicted in Fig. 3, to which both the test vehicle and the VRU are connected.

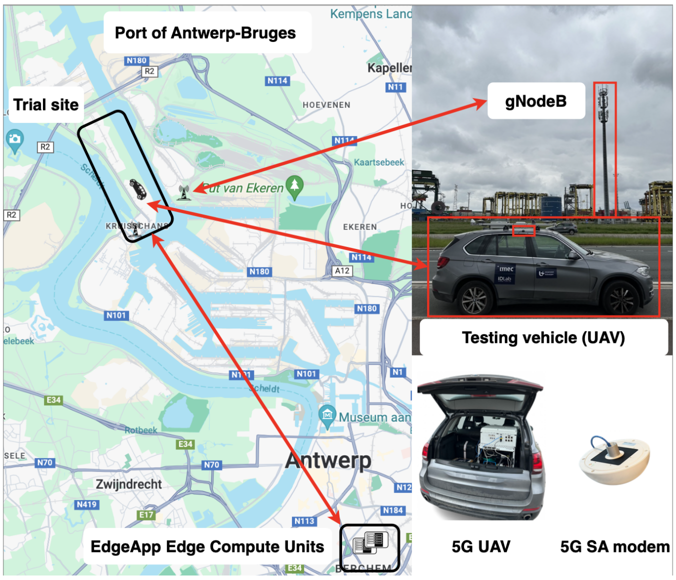

Fig. 3. Equipped test vehicle under 5G gNodeB in the VITAL-5G trial site at Antwerp-Bruges port.

### B. *Real-life proof of concept*

As mentioned earlier, the SEAL framework provides several functionalities that can be exploited: i) group management[7] categorises entities into VRUs and UAVs, including the UAV and VRU. This configuration is facilitated by existing APIs, ii) a location information event[8] (Fig. 2 and 4) is set up using another existing API allowing to subscribe to the location management server and receive updates on location changes from the UAV and VRU. The specified groups are added as subscribers to this event. Currently, the events available only track when locations enter or leave predefined zones. The 3GPP V2X Application Enabler (VAE) has a specific VRU zone management[9] which uses the location information event. However, continuous monitoring of location and movement is essential, especially in dynamically changing zones. Therefore, for the proof of concept, existing location reporting APIs[10] are used to continuously monitor their positions once subscribed. Once the UAV location is received as a CAM message, currently standardised across all CCAM equipped vehicles and in the near future UAV manufacturers, it is processed

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[4] 5G SEAL APIs: https://forge.3gpp.org/rep/all/5G_APIs

[5] Smart Highway testbed: https://www.uantwerpen.be/en/research-groups/idlab/infrastructure/smart-highway/

[6] Peplink: https://www.peplink.com/products/enterprise-mobility/max-hd1-dome-pro/

[7] SEAL Group Management: https://forge.3gpp.org/swagger/editor-versions/v3.18.0/?url=https://forge.3gpp.org/rep/all/5G_APIs/raw/REL-18/TS29549_SS_GroupManagement.yaml

[8] SEAL Events: https://forge.3gpp.org/swagger/editor-versions/v3.18.0/?url=https://forge.3gpp.org/rep/all/5G_APIs/raw/REL-18/TS29549_SS_Events.yaml

[9] VAE Server VRU Zone Management Service: https://forge.3gpp.org/swagger/editor-versions/v3.18.0/?url=https://forge.3gpp.org/rep/all/5G_APIs/raw/REL-18/TS29486_VAE_VRUZoneManagement.yaml

[10] SEAL Location Reporting: https://forge.3gpp.org/swagger/editor-versions/v3.18.0/?url=https://forge.3gpp.org/rep/all/5G_APIs/raw/REL-18/TS29549_SS_LocationReporting.yaml

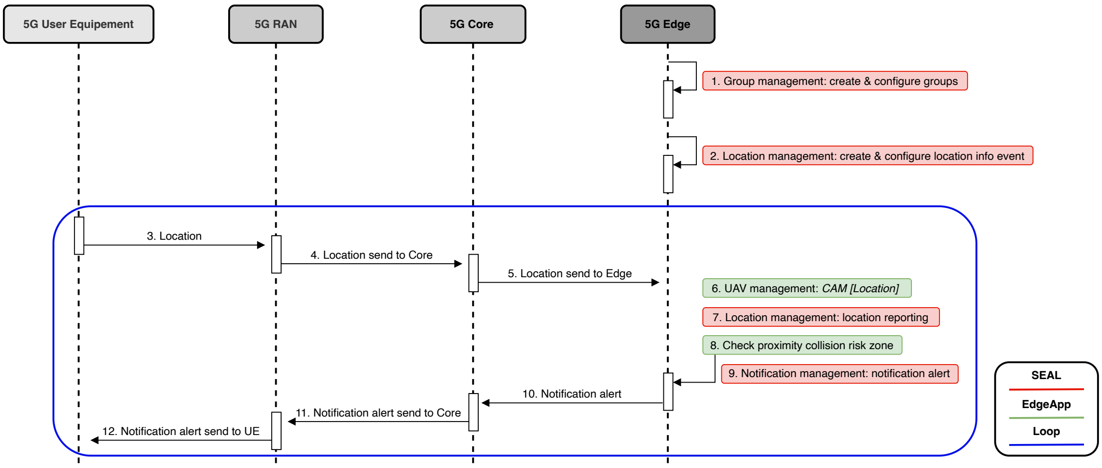

Fig. 4. Dataflow Path of the Proof of Concept Enhanced SEAL EdgeApp: Facilitating CCAM Communication between VRUs and UAVs through the 5G and Beyond ecoystem.

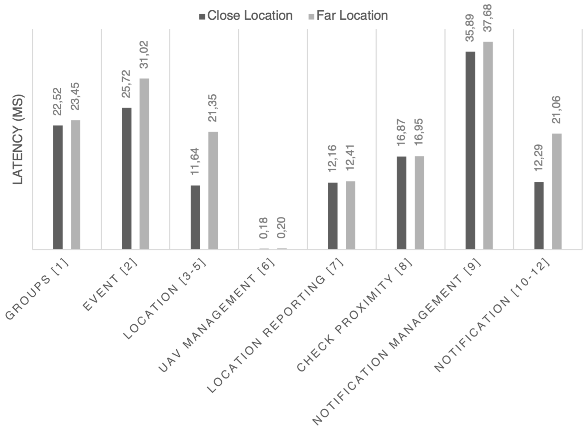

Fig. 5. Latency Results of SEAL-Enhanced EdgeApp Dataflow Paths of Fig. 4.

by new software blocks in the EdgeApp middleware that is called UAV management. The primary function is to extract pertinent information, resulting in a location report. This ensures compatibility between all CCAM-equipped vehicles, facilitating seamless integration and use of data.

In the proposed enhanced SEAL EdgeApp, the proximity collision risk zone, shown in Fig. 5, is then checked. The locations are compared at the Edge. These locations consist of longitude and latitude data obtained through existing SEAL location reporting APIs. When the locations intersect within each other's collision risk zones, an alert is triggered using the SEAL notification management block. This requires new SEAL notification APIs as they were not yet defined, despite frequent references. The 3GPP VAE APIs[11] utilise the SEAL APIs as well and do not provide any other additional functionality relevant to our specific use case. In our experiment, the UAV uses CAM messages, while the VRU publishes its real-time location through the SEAL client making it directly available towards the 5G and Beyond network. Consequently, we opted for the direct implementation of the SEAL APIs.

## IV. RESULTS

In this section, we validate the latency characteristics of all the different levels (5) of the proposed proof of concept SEAL-enhanced EdgeApp, as that latency requirements for CCAM communication is an important Key Performance Indicator (KPI) [2,3,11]. Therefore, we use as a baseline the work of Hakaka et al. [11] with their survey review on autonomous vehicles in 5G and Beyond networks. They specified that the total processing time of systems at the Edge must be within a latency of 100 ms [11].

Fig. 5 shows the obtained latency characteristics at each level of the SEAL-enhanced EdgeApp, where the numbers in brackets correspond to the numbers of the dataflow paths as depicted in Fig. 4. For instance, as illustrated in Fig. 5, 'Location (3-5)' refers to steps 3 to 5 in the dataflow depicted in Fig. 4. This designation represents the cumulative latency, extending from VRU/UAV to the 5G Edge employing an URLLC slice, necessary to obtain the location of both the UAV and VRU via the SEAL location management service. Similar to 'Notification (10-12)' (Fig. 5) this is the total time from the 5G Edge to the VRU or the UAV leveraging an URLLC slice to deliver the notification message to improve the road safety.

### A. *Latency results of the SEAL-enhanced EdgeApp*

We conduct preliminary validation rounds focusing on the latency characteristics of the SEAL-enhanced EdgeApp operating at the Edge of a real-world 5G SA network (Fig. 3). However, the challenging conditions in the port environment, including the presence of vessels, bridges, cranes, trucks, and variable weather conditions, can interfere with the signals and negatively impact the obtained latency results. Nevertheless, this is a realistic scenario that reflects real-life conditions, particularly in port environments.

Initial latency tests are performed under two distinct scenarios: i) placing the UAV and VRU in close proximity to the gNodeB, approximately 100 meters away (Fig. 3), ii) positions them at a greater distance from the gNodeB, approximately 3000 meters. Each position, i.e. close and far, accumulates about 3000 latency data points. Examining Fig. 4 and 5, it is observed that the average computation time at the Edge for the loop in the SEAL-enhanced EdgeApp, i.e. steps 6, 7, 8, and 9 (Fig. 5) for the close and far location is 64.9 ms and 67.24 ms. If we compare this with the baseline latency of 100 ms provided by Hakaka et al. [11], our system, in

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[11] VAE (V2X Application Enabler): https://forge.3gpp.org/rep/all/5G_APIs

its operating state, meets the latency requirements. However, when we compare this to the overall end-to-end latency of our proposed system, i.e, from dataflow points 1 to 12 (Fig. 5), we obtain for the close location an end-to-end latency of 137.07 ms and for the far location, it is 164.12 ms. In this case, our system does not meet the baseline 100 ms latency requirement. Nonetheless, it is important to note that the computational capabilities at the 5G Edge are sufficient enough. In our case, the SEAL enhanced EdgeApp operates on a virtual machine deployed in an OpenStack environment, equipped with a 1-core CPU and 4GB of RAM. Future research should aim to determine the most optimal requirements for these EdgeApps.

### *B. Comparison of notification message delivery latency with ITS-G5 and C-V2X*

Specifically, the latency for the notification messages, which are sent to the UAV to alert it of the VRU when a potential collision may occur, corresponds to dataflow points 10 to 12 (Fig. 5). This latency is 12.29 ms for the scenario with the close location and 21.06 ms for the scenario with the far location. The latency for transmitting the CAM message from the UAV to the Enhanced SEAL EdgeApp is 11.64 ms for the close location and 21.35 ms for the far location.

When comparing these obtained results with our prior work [3], one of the findings is that the latency of a CAM message in very short range is significantly better for ITS-G5 compared to C-V2X. In particular, transmission of a CAM message over ITS-G5 takes on average 4.45 ms for a close location, compared to 22.79 ms for C-V2X. Upon comparing these results with the latency values depicted in Fig. 5 for dataflow points 3 to 5 and 10 to 12 (Fig. 4), several findings emerge. While ITS-G5 maintains the lowest possible latency, the most significant difference is observed between C-V2X, which has a latency of 22.79 ms, and the latency of 11.64 ms achieved by our system. This represents a 48.89% decrease in latency compared to C-V2X. One of the reasons for this improvement is that C-V2X operates on 4G, whereas our SEAL EdgeApp operates on 5G SA (Fig. 1).

## V. GAPS IN SEAL

There remain some gaps in the SEAL framework to make the proposed vision a reality. The assumed advancements include UAVs transmitting CAM messages via APIs to the edge, which will require further development and validation of specific UAV communication APIs. As mentioned earlier, the SEAL documentation[12] is incomplete, often referring to sections or APIs that are not yet developed. In particular, the notification management feature is completely missing from the APIs documentation[13]. Furthermore, there is an inconsistency in the naming of variables within the 3GPP documentation. For instance, in the location reports provided by the SEAL framework, the altitude data is specified not under the geographic location block but in the shape block, among others. Moreover, it is important for 3GPP to provide more guidance on latency criteria for vertical services uitilising SEAL, which is particularly relevant for VAE given its customization for V2X services, which heavily rely on SEAL. However, such criteria are currently absent from 3GPP.

## VI. CONCLUSION AND FUTURE WORK

Leveraging the 3GPP SEAL framework to enhance CCAM as an EdgeApps enables universal message generation between VRUs and UAVs. This approach holds the potential to overcome existing communication barriers, thereby fostering a more secure mobility environment. As current technologies for CCAM, i.e., ITS-G5 and C-V2X lack a unified communication stack that connects all types of users (e.g., UAVs, VRUs, among others).

Therefore, this paper presents a real-life proof of concept for the integration of a SEAL enhanced EdgeApps into CCAM communication in a real-life 5G SA pilot site. The utilisation of CCAM communication in the 5G and Beyond ecosystem as a vertical service of SEAL-enhanced EdgeApps eliminates the dependency on current specific hardware, such as ITS-G5 and C-V2X, and simplifying CCAM systems that only require a 5G and Beyond connection. We presented a use case to validate the proof of concept of the enhanced SEAL EdgeApp and discovered gaps in the SEAL framework. We also conducted experiments to obtain a view of the latency characteristics at all different levels of the enhanced SEAL EdgeApp.

Towards the future, more research should be conducted on the latency characteristics at all different levels of the enhanced SEAL EdgeApp, as latency is an important KPI for communication between VRUs and UAVs. More research should focus on experiments in crowded and diverse environments with multiple VRUs and UAVs, while simultaneously analyzing the security and privacy implications.

## VII. ACKNOWLEDGEMENT

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