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From 5G to 6G Vision

A Connected and Automated Mobility perspective

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6GSNS

INTRODUCTION

Mobility is a fundamental necessity of our society. We need to move people and goods from one place to another for many different motivations. As a fundamental cornerstone of our way of life, mobility must be efficient, secure, inclusive, green, and smart. Smart in the sense that mobility must leverage the potential of digital technologies to achieve all the other goals. In this digitalization of mobility, connectivity emerges as a key element. Interconnecting all the elements involved in mobility and enabling the exchange of information is an extremely powerful tool towards this dual green and digital society of the future.

For that reason, different research and innovation projects across the World have been working in the past, and are still doing so, to devise and standardise the way that the communication and mobility sectors must cooperate with each other.

Along this way, 5G technology has been the first communication technology, the first generation that has tried to systematically integrate and support all types of CAM services. In addition, the 5G ecosystem has also been developing a 360° analysis of the different pieces that must get together for a successful deployment of advanced CAM systems; this includes, among others, all regulatory aspects, deployment options and cooperation models, legal and business implications, as well as cross-vendor, cross-operator, and even cross-national implications.

5G is now entering into the massive-deployment phase. However, many challenges are to be solved, but we can already anticipate that, even though 5G is going to create a revolution in many sectors, bringing a huge positive impact on our economy and society, it will also find its limitations to provide the highly demanding requirements that some advanced services will call for. For that reason, the research community is already starting to think of what will come next: 6G.

As the 5G for CAM Working Group of the 6G Industry Association, we want to contribute to this ongoing global brainstorming by providing our initial views on what 6G might look like and what implications this will have for CAM. We want to briefly reflect on the lessons learnt during the execution of the key 5G PPP projects which have been working on 5G for CAM and contribute to identifying, from the very beginning, new mobility requirements for the evolution of 5G and 6G communication systems. We also want to anticipate our view on the impending new technologies that are being considered for 6G and we believe hold the potential to have a highly positive impact on CAM.

To do so, in what follows, we provide an answer to 5 key questions that we believe must be solved at this very early stage of jointly defining and designing the next generation of smart networks.

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Question 1:

How Mobility is going to change?

How Mobility is going to change?

The sustainable and smart transformation of transportation sector for the mobility service of people and goods will bring various socio-economic benefits e.g., via automation, zero-emissions[1], efficiency, safety and security. The role of connectivity is crucial in the digital transformation of the transportation sector and includes several enablers (such as network infrastructure, cloud-to-edge resources, data technologies and governance, etc.) that could evolve and modernize the road, rail, waterborne and air transport.

5G communication systems provide a wide range of services and functionalities that can support the connectivity requirements of various transportation means and mobility applications. The design and standardisation of 5G communication systems have taken into consideration use cases and scenarios that mainly involve vehicles with automation capabilities, rails, and drones (unmanned aircraft). 5G communication technologies were enhanced to address the performance requirements of the above transportation means (e.g., in terms of higher reliability, lower latency, higher network capacity, more accurate positioning), also considering their key features such as high mobility/speed, automation and the energy constraints mainly at the user equipment (UE) side (e.g., for vulnerable road users, drones).

The transformation of the transportation sector will be gradually developed to achieve the goals of 2030 or 2050, as they have been described in the EU Mobility Strategy[2]. Consequently, the involved communication technologies will be also evolved to support the new needs and requirements of future transportation means and mobility environments. The design of beyond 5G and 6G communication systems should consider the wider usage of autonomous vehicles and drones for commercial applications as well as new types of devices and novel mobility applications. Delivery robots, robotaxis, motorbikes (powered two-wheelers), personal air vehicles, and vessels in waterways are examples of transportation means that could have an important role in a multimodal mobility system in the years or decades to come.

The future mobility environment with new types of devices will set new performance and technical requirements for beyond 5G and 6G communication systems, by further extending the uninterrupted coverage of connectivity infrastructure and increasing the density of connected devices, while new types of more demanding services may be introduced (e.g., for SAE Level 5 autonomous vehicles, collaborative robots, haptic and multi-sensory communication for tele-operation). Future transportation means will be diverse, in terms of computational, power, sensing and Artificial Intelligence (AI) capabilities. Thus, the communication infrastructures could support in a flexible manner, the potential demand of computational or other resources by the broad variety of devices (e.g., via off-loading to cloud or edge servers). Furthermore, AI will be important for the automation of different modes of transportation, hence reliable real-time communication among AI agents will be needed with the support of native security and data privacy. In some cases, more localized interaction and cooperation among smart devices (/ transportation means), may ask for high accuracy localization and tracking, as well as for more flexible resource management schemes together with higher bandwidth requirements.

[1] *The European Green Deal calls for a 90% reduction in greenhouse gas emissions from transport, in order for the EU to become a climate-neutral economy by 2050, while also working towards a zero-pollution ambition, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en*

[2] *EU Mobility Strategy, https://transport.ec.europa.eu/transport-themes/mobility-strategy_en*

Question 2:

Why and How 5G will change road mobility?

Why and How 5G will change road mobility?

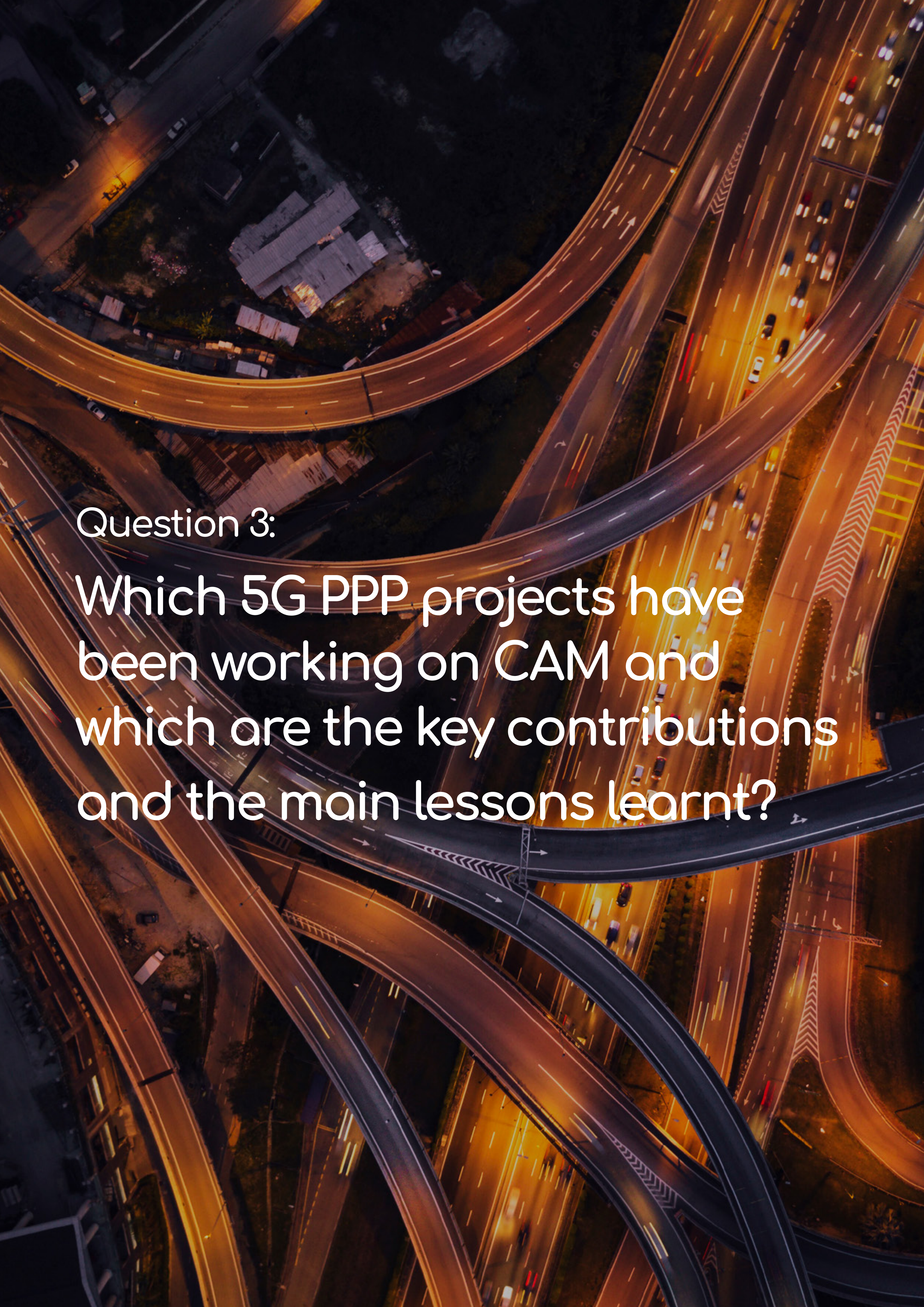
5G communication systems will change future mobility services by facilitating their digital transformation, involving different transportation means and revolutionising the way that people and goods are travelling. Focusing on-road vehicles (e.g., cars, trucks) 5G will enable Vehicle-to-Everything (V2X) communication and interaction, supporting all communication modes, including network-based and device-to-device (D2D) that are involved in different V2X scenarios. 5G communication systems will change the mobility by enabling new services as we well as by enhancing the capabilities of vehicles e.g., complementing the on-board sensors by extending vehicles' vision and detection ranges even when visual line-of-sight is not available. More information about vehicles' surroundings will be monitored and quickly provided to vehicles and thus help the drivers and automated vehicles to have a safer and more efficient trip. Diagnostics and insights into driver's behaviour and route efficiency will be provided using real-time information. 5G will assist the improvement of public transport operations, especially for cities with heavy road traffic, and provide dynamic transport plans with the ability to reduce traffic congestion that leads to the provision of more space for pedestrians and cyclists.

5G Automotive Association (5GAA)[3] and the Third Generation Partnership Project (3GPP)[4] have specified various V2X use cases that could be supported by 5G, which are grouped under the following categories, considering their key objective: Safety, Vehicles operations management, Convenience, Autonomous driving, Platooning, Traffic efficiency and environmental friendliness, Society, and community. 5G communication systems have been specified taking into consideration the diverse performance requirements that V2X use cases have, which in many cases are very demanding, to provide better support to advanced V2X use cases.

Some examples of key 5G technologies are presented below, indicating how they have supported specific V2X use cases and thus enhanced mobility services. Advanced physical layer (e.g., scalable numerology, wider bandwidth, new channel coding, MIMO etc), localization capability, time-critical communications, and network slicing are some of the technologies, which have been introduced to support stringent performance requirements for the communication layer (e.g., delay, reliability, throughput), better coverage and guaranteed Quality of Service (QoS). Such technologies are essential for the reliable operation of Tele-operated Driving (ToD), which is used for specific automated vehicle operations as well as for driving tasks e.g., valet parking, and industry areas. Also, many safety and autonomous driving use cases are also benefited, while it should be noted that higher degrees of automation generally lead to more stringent requirements. Edge computing is another feature of 5G systems that may contribute to reduce communication latency due to the data proximity to the end-users. An important feature for use cases such as computational offloading for constrained devices and to ensure that data is kept locally. Advanced QoS management schemes (e.g., QoS prediction, Alternative QoS profiles) have been introduced to increase the awareness of V2X applications about changes in availability or QoS and adapt their behaviour accordingly. Schemes to ensure service continuity in cross-border and cross-Mobile Network Operator (MNO) scenarios have been provided, a feature that several EU-funded projects have contributed and validated, as analysed in the third question (Q3). Advanced schemes for D2D communication (NR Sidelink) have been developed in 5G that can enable cooperative maneuvres among automated vehicles to coordinate their trajectories in a safe and fast manner as well as vehicles' environment perception. Finally, Sidelink connectivity and network-based connectivity can support advanced vulnerable road user (VRU) protection use cases, which are essential for the protection of pedestrians, cyclists, motorcyclists etc using embedded 5G components or even smartphones.

[3] *5GAA White paper, "C-V2X Use Cases Volume II: Examples and Service Level Requirements", https://5gaa.org/wp-content/uploads/2020/10/5GAA_White-Paper_C-V2X-Use-Cases-Volume-II.pdf*

[4] *3GPP, "TS 22.186 Service requirements for enhanced V2X scenarios (v16.2.0, Release 16)," 3GPP, Tech. Spec., Jun. 2019.*



Question 3:

Which 5G PPP projects have been working on CAM and which are the key contributions and the main lessons learnt?

Which 5G PPP projects have been working on CAM and which are the key contributions and the main lessons learnt?

CAM enabled by state-of-the-art mobile networks such as 5G has been the focal point of multiple research projects since the mid-10s (e.g., 5G-Drive[5], 5GCAR[6]), attempting to document the requirements, evaluate the performance and validate certain CAM 5G-enabled use cases in Proof-Of-Concepts (POCs) and/or trials/pilots. This pioneering research led to the establishment of a baseline with regards to what the various modes of communication could and should support, which are the most likely CAM services to be supported by the first generation of 5G networks. Also, which are the more demanding CAM services that would have to wait for the evolution of 5G networks and what is the average performance that can be expected in realistic conditions. Most of this work had to take place using test-networks as 5G networks were not commercially available at the time.

To take advantage of the widespread commercial availability of 5G networks since the late-10s early 20s and the observed increase in production of higher automation vehicles (L3+), the 5G Infrastructure Public Private Partnership (5G PPP) and the European Commission supported two main waves of innovation projects that set out to prove the feasibility and showcase the performance of 5G enabled advanced CAM use cases in real-life highway conditions and to investigate the largest bottleneck known for their operation, i.e., operation in cross-border conditions. These two waves of projects were the H2020-ICT-18-2018 projects (5GCroCo[7], 5G-CARMEN[8] and 5G-MOBIX[9]) and the H2020-ICT-53-2020 projects (5G-BLUEPRINT[10],5G MED[11], 5G ROUTES[12] and 5G RAIL[13]). The Connecting Europe Facility (CEF2) Digital programme[14] that is considered as a continuation of the work conducted by the above-mentioned projects, aims to support, and catalyse investments in digital connectivity infrastructures and pave the path for the Trans-European Transport Network (TEN-T)[15].

The three ICT-18 projects were the first projects to deploy and interconnect neighbouring 5G networks in cross-border conditions and using them to validate and demonstrate advanced CAM use cases in main European Transport paths such as the Metz-Merzig-Luxembourg corridor between France, Germany and Luxemburg (5GCroCo), the Bologna-Munich corridor, between Italy, Austria and Germany (5G-CARMEN) and the Vigo-Valenca corridor between Spain and Portugal and the Kipoi-Ipsala corridor between Greece and Turkey (5G-MOBIX). The provisioning of 5G enabled CAM services across national borders while the vehicle is experiencing an inter-PLMN handover and roaming is considered the most challenging setting for CAM operation as service continuity for the user must be ensured and/or session and service

[5] *5G-Drive project, https://5g-ppp.eu/5g-drive/*

[6] *5GCAR Project, https:// www.5gcar.eu*

[7] *5GCroCo project, https://5gcroco.eu/*

[8] *5G-CARMEN project, https://5gcarmen.eu/*

[9] *5G-MOBIX project, https://5g-mobix.com/*

[10] *5G-Blueprint project, https://www.5gblueprint.eu/*

[11] *5GMED project, https://5gmed.eu/*

[12] *5G Routes project, https://www.5g-routes.eu/*

[13] *5G RAIL project, https://5grail.eu/*

[14] *Connecting Europe Facility — CEF Digital, https://digital-strategy.ec.europa.eu/en/activities/cef-digital*

[15] *Trans-European Transport Network (TEN-T), https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en*

interruption must be kept to a minimum. The three ICT-18 projects have outlined the challenges and opportunities that exist for 5G enabled CAM services in cross-border conditions, along with a description of their work and addressed use cases in a recent 5G PPP white paper[16].

As the three projects have matured and are soon concluding their cross-border trials, some significant insights have been gained regarding the deployment and interconnection of neighbouring 5G networks and the cross-border operation of CAM services, along with some lessons learned and best practices that can be used by follow-up projects and the relevant industries. Some of these insights are highlighted below:

Technology aspects

- Neighbouring network interconnection can become quite challenging especially in cases where edge sites from the respective sides of the border need to be interconnected. Sufficient time for the actual interconnection and configuration should be scheduled as well for testing. Special care should be given to the roaming settings implemented, as they can result in unwanted steering of traffic (vehicular or otherwise) and/or ping-pong effect experience for the subscribers.

- Node synchronization is a critical aspect for the proper operation of CAM services. Synchronization among network nodes (gNBs, edge sites, core functions, etc.) should be a given but also precise synchronization with the neighbouring network nodes should also be implemented or at least the same Network Time Protocol (NTP) servers should be used. Tight Synchronization among the UEs/ On-Board Units (OBUs), Road-Side Units (RSUs), application servers and the network is also important and it is not a trivial thing to achieve. Especially in cases where stateful CAM applications are performing an inter-PLMN Handover and they also need to change application servers, synchronization plays an important role for the successful operation and the avoidance of user experience degradation.

- Inter-PLMN handover settings: The inter-PLMN handover is a complex process and significant effort must go into its configuration and optimization in order to avoid long service interruption for CAM users and/or ping-pong effects. Even so, it is nearly impossible to always achieve a handover at the same location between two countries/networks, as the exact handover point will always depend on variable factors such as the channel conditions, the OBU antenna sensitivity and the current traffic on the road and the cell. The handover point is also expected to change depending on the direction of movement (from home to visited network and vice-versa). As such, CAM service developers should be prepared for the handover to take place at any number of points between the two countries.

- Scalability challenges: Scalability is an important concern for all CAM related technologies and solutions, as they are expected to operate seamlessly across all networks and transport paths irrespective of the exact network operator or network. There are many solutions that tend to optimize the performance of CAM services however, such as the direct interconnection of neighbouring MNO networks and the use of multi-SIM OBUs, seem to have inherent scalability challenges. Scalability should be a primary design goal for all network or application-level solutions that target real-world deployment.

[16] *5G PPP H2020 ICT-18-2018 Projects White Paper, "5G Trials for Cooperative, Connected and Automated Mobility along European 5G Cross-Border Corridors- Challenges and Opportunities", https://5g-ppp.eu/wp-content/uploads/2020/10/5G-for-CCAM-in-Cross-Border-Corridors_5G-PPP-White-Paper-Final2.pdf*

Standardisation aspects

Testing and profiling of involved standardised interfaces and processes can help the fast implementation of CAM services, especially in cross-border scenarios. Testing and evaluation of inter-PLMN handover interfaces, including cross-vendor interoperability tests, are needed to identify issues that harmonization and further standardisation is needed. Investigation of further enhancements whether proactive actions (e.g., context transfer, proactive registration) are needed before the inter-PLMN handover, to further reduce the time required for the exchange of this information. Service and session continuity at country borders when switching gateways and/or MEC hosts (considering different architectures and MEC deployment strategies in different countries by the MNOs) is important to be maintained. The slice selection impact during the transition from one operator to another, when accessing a service in the visited network is another example that standardisation enhancements should be studied.

Regulation and Business aspects

Besides the technical challenges, there are also many regulatory topics that should be addressed for the realization of 5G-enabled (cross-border) CAM services to ensure their successful mass-market adoption. Certification, liability, safety, as well as data management and ownership are some of the challenges of CAM services. The different CAM stakeholders are responsible only for a part of the data, while the privacy of the vehicle driver is of utmost importance. Regulation and protection of data ownership are needed. The definition of data sharing agreements among involved stakeholders e.g., MNOs, road authorities, vehicle manufacturers, and map providers etc is needed to enable various CAM services. Cross-border data exchange should be regulated to enable cross-border V2X services to retrieve and process data from different countries. Furthermore, homologation (certification) of different hardware and software components involved in automated mobility services are needed together with the regulation of homologation among different countries. The specification of the regulatory and legal framework for the identification of responsibilities among CAM stakeholders (liability management), within one country and across borders is also important.

In general, uncertainty in the business model and ownership model may slow down expected investments. Another issue is that the transport sector is generally slower than Information and communications technology (ICT) sector in adopting 5G or future 6G technologies. This is partially due to different product lifecycles e.g., for a modern smartphone it is estimated around three years while for a modern vehicle it is estimated around ten years or even more. But at the same time communication reliability requirements are much higher for transport (i.e., especially safety related use cases). This may cause requirements and deployment gaps that need to be managed. Also, there is a need to develop the appropriate cooperation models that will accelerate the deployment and use of 5G infrastructures for CAM, in close cooperation with road authorities and road operators, and stimulate the related business ecosystems in order to establish initial economies of scale[17].

Security/privacy concerns on cross-border operation

A connected vehicle is a cyber-physical system leading to interaction vulnerabilities between safety and security, while threats (malicious) and failures (accidental) have been so far handled separately, leading to a safety-security gap. A holistic vision of protection is required to address the challenges at different

[17] *5G Strategic Deployment Agenda for Connected and Automated Mobility in Europe, https://5g-ppp.eu/wp-content/uploads/2020/10/20201002_5G_SDA_for_CAM_Final.pdf*

involved entities: vehicle security, network security, application, and ecosystem security. Considering the criticality of the infrastructure and the generated data, regulators should clearly define protective laws and enforce that the storage and exchange of vehicle's data be subject to privacy frameworks such as the General Data Privacy Regulation (GDPR). Also, it is needed to define how different security and privacy frameworks (e.g., GDPR) may be utilized by different countries and in cross-border operations.

The four ICT-53 projects used the latest available 5G specification in the context of innovative CAM applications under realistic conditions and seamlessly functioning across borders, addressing not only roads and highways but also waterways and railways. The addressed corridors are the following: 5GMED (Barcelona - Perpignan, between Spain and France), 5GROUTES (Via Baltica, between Latvia, Estonia, and Finland), 5G-Blueprint (North Sea Port, including Vlissingen, Terneuzen, Gent, and Antwerp), and 5GRAIL, with trials in France, Hungary, and Germany.

The projects cover the key 5G innovation in support of innovative CAM ecosystems, notably at RAN and core network levels. Moreover, Future Railway Mobile Communication System (FRMCS) will be demonstrated, envisioning to become a 5G worldwide standard for railway operational communications, conforming to European regulation as well as responding to the needs and obligations of rail organizations outside of Europe. Further, waterways are also showcased, where time critical connectivity is being provided to teleoperate and steer vessels in the waterways and ports. The presented ICT-53 projects also include supporting innovations in the area of Artificial Intelligence (AI) to enable advanced CAM use cases managing a broad range of relevant data sets based on connectivity and sensors.

One of the early lessons learnt by ICT-53 projects, after a thorough analysis of the transport and logistic connectivity requirements, is the understanding of the extremely high demand for uplink connectivity that is needed in order to teleoperate trucks on roads and vessels in the water due to the amount of data that several sensors (lidar, cameras, etc) need to send to the teleoperation centre. This brings scalability issues when making teleoperation a reality.

Finally, another important aspect, concerning the impact of 5G on mobility, is related to the introduction of new and innovative CAM services that are enabled thanks to 5G-specific features. An obstacle to the development of new services is set by the difficulty to test such services in realistic environments. This issue is particularly more critical to Small and Medium Enterprises (SMEs) that may have lower availability for accessing testing facilities. This challenge is addressed by VITAL-5G and 5G-IANA projects under the H2020-ICT-41-2020 call. VITAL-5G[18] has the vision to advance the offered transport & logistics (T&L) services by engaging significant logistics stakeholders (Sea and River port authorities, road logistics operators, warehouse/hub logistic operators, etc.) as well as innovative SMEs and offering them an open and secure virtualized 5G environment to test, validate and verify their T&L related cutting-edge Network Applications (NetApps), open for 3rd party experimenters. The 5G-IANA[19] project aims to overcome these issues by creating an open and flexible platform for developing, testing and deploying CAM services. The availability of such a platform will facilitate the spread of new CAM services resulting in a deep impact on the evolution of mobility.

[18] *VITAL-5G project, https://www.vital5g.eu/*

[19] *5G-IANA project, https://www.5g-iana.eu/*

Question 4:

What has been identified that is missing and beyond 5G will need to address?

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On some key aspects

Advancements in 5G together with 6G research and innovations will continue to enable future improvements of CAM, such as the Advanced Driver Assistance System (ADAS) and Automated Driving (AD), while addressing the need to decrease energy consumption both at the UE and the infrastructure side to enable green mobility. Further, the security of the entire technical system together with a reliable safety focus are two other key enablers that continue to be at the forefront of CAM. In terms of security there are for instance multi-domain and multi-tenant vehicular environments aspects to consider, where e.g., some AI-based V2X security solutions may deliver trustworthiness. Although VRU protection has been discussed and some initial research, pre-standardisation and standardisation work has been initiated there is more work required to enable larger scale adoption. For instance, a C-V2X enabled smartphone may assist a legacy vehicle as a Cooperative Intelligent Transport Systems (C-ITS) enabler or may assist a VRU that is either walking or biking on the street. Additionally, achieving bounded latency will be required for a number of vehicular use cases, e.g., to avoid video quality degradation. This Time Critical Communication (TCC) would for example be applicable for remote supervision in tele-operation. Another challenge is how to guarantee always updated performance and the latest radio features to vehicles that are out in the market, as new radio features are deployed in the mobile network and the vehicle modem may continue to be limited by its features from when it was sent out to the market. Finally, future networks should target the provision of support for faster and more reliable UE mobility procedures (handover, cell reselection), especially in scenarios with high-speed UEs.

Extended coverage

Networks are constantly deployed to increase coverage and capacity, however in areas that so far have not been fully built out in terms of cellular network capabilities or in areas that may not be financially viable to have everywhere network coverage, complementary connectivity solutions should be investigated by extending the coverage for certain non-critical CAM services. Though with such an approach one needs to ask if it is feasible for the vehicle to integrate more complex receivers and separated antenna systems.

Business and MNO Challenge for services in roaming scenarios

An important aspect for future networks is that services can be provided from regional/local sources. This means that a device should be able to get ‘Internet’ connectivity and other mobile network services in the visited country when roaming, e.g., use services and applications located at the edge of the visited network and by that experience lower latency. This means that the traditionally used method for roaming with routing the connectivity back to the users’ home network (the so-called home routing) needs to be changed, with 5G this mindset begins to appear, but to change this is a lengthy process, involving roaming agreements, network configurations etc. so it is advisable that 6G networks are designed with this mindset from the beginning.

Architecture

Handling of connectivity and network services needed for vehicles will involve the utilization of several network procedures (mobility, policy management, network exposure, etc.). In the 5G system design, execution of network procedures usually spans across multiple entities of the whole system, with complexity arising from e.g., hierarchical interactions and dependencies among network entities which is not ideal in cloud environments. Considering the increase in the number of connected vehicles as well as the possible increase in the number of network services needed by connected vehicles, an important aspect for future networks is how to obtain a cloud-native network architecture design that allows simplifying the execution of network procedures as well as the introduction of new services. For instance, by removing hierarchical interactions and dependencies among network entities, the execution of certain network services could be parallelized. Furthermore, it would be simpler to introduce new services that other entities could re-use and to reduce the negative effects that a failure in a certain network entity would have on other entities and services.

Functional Safety

Safety, in the sense of avoiding unacceptable and predictable risks of physical injuries or damages to people's health caused by failures or functional insufficiencies of the system, has been at the centre of development of ADAS and AD in the automotive industry. Wireless communication is foreseen to play a more and more important role, when ADAS and AD evolve to CAM such as cooperative environment perception using external sensors, maneuvre coordination, remote assistance or remote driving.

Building a functionally safe system of heterogeneous components connected using wireless communication technologies in road transport environments imposes additional challenges comparing to developing a ADAS or AD system in the automotive OEM controlled domain. The modern automotive safety engineering methodology for developing ADAS and AD systems need to be applied and extended to cover wireless communication. A commonly adopted approach for this is the Open Channel approach, according to which safety requirements are fulfilled via safety monitoring and automatic protection functions on both communication sides while a wireless communication network in between does not need to be developed according to Automotive Safety Integrity Level (ASIL) or other similar safety consideration schemes. However, the reliability and availability performance of the network, and the network capabilities of monitoring, notifying and even predicting such performance are essential for the system to meet the CAM service availability requirements and for the network to assist the components connected by such an open channel in corresponding safety concept.

Addressing safety challenges in CAM requires joint efforts and cross-ecosystem players in both automotive and ICT sectors, e.g., the design of adaptive CAM applications based on network QoS performance and QoS notification.

Network Exposure Functions

Exposure functions in 5G Evolution and 6G systems are important to for example QoS policies and for monitoring, notifying, and predicting the QoS performance. Such features are also needed in roaming situations and with network slicing, which are important to support existing and upcoming CAM services with acceptable performance.

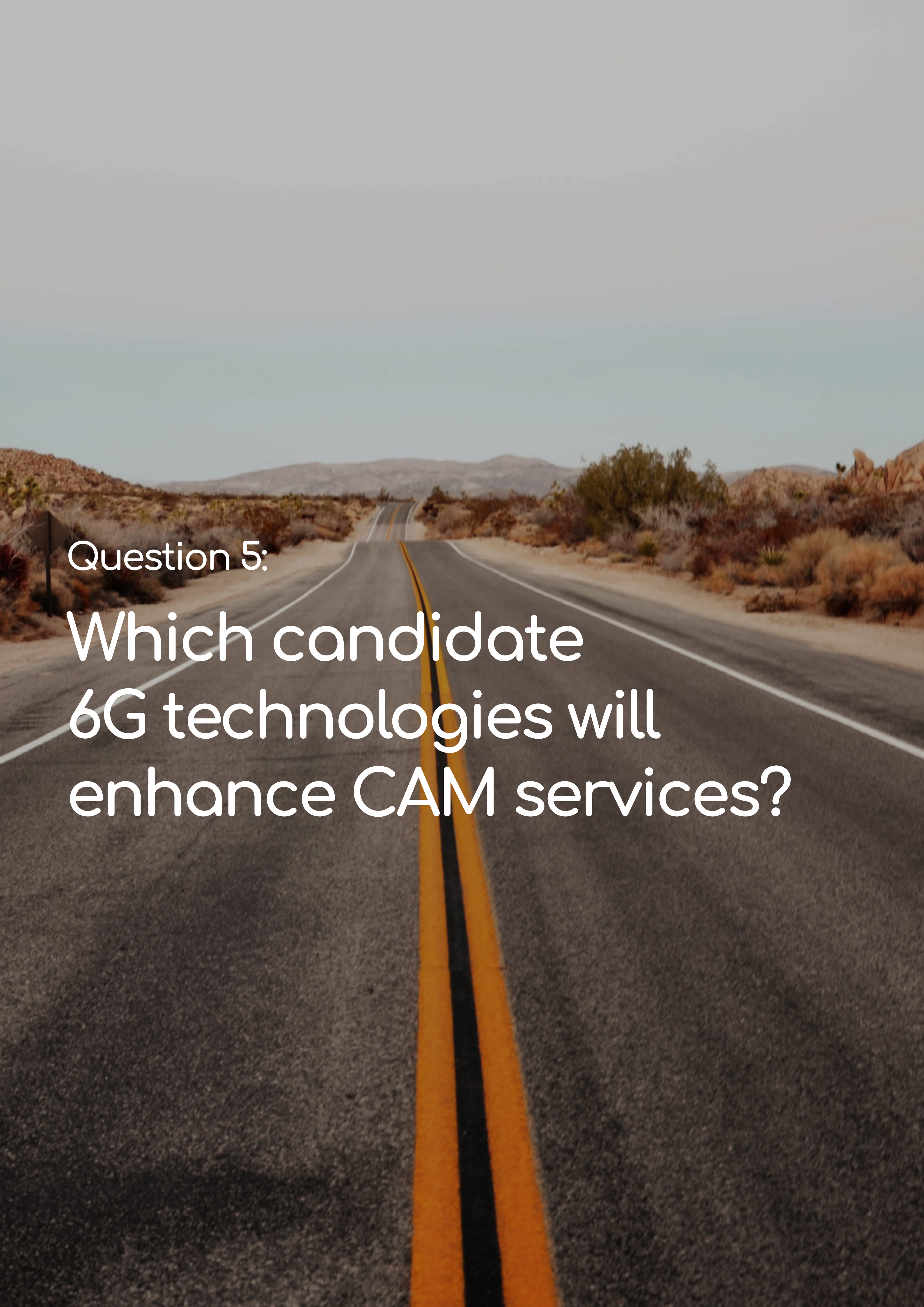
Positioning and Localization

It is anticipated that an important need for future applications and services is to have accurate geographical positioning. This means that there is a need to have a good position determination provided from the mobile networks as well as introduce the scalable distribution of Real Time Kinematic (RTK) correction data by broadcasting the correction data as system information from radio nodes.

Energy Efficiency

The development of CAM technologies will have an impact on network deployment as they will need additional digital infrastructure to provide services to the cars and to the end users. This will increase comfort and safety of the end users, but it will also increase the impact on the environment (i.e., more network elements, more energy requirements etc). One of the key challenges of the 6G is to transform networks into an energy-optimized digital infrastructure and will deeply revise the full resource chains of wireless networks towards sustainability and carbon neutrality and CAM should also contribute to this objective. For energy efficient 6G communication networks in accordance to the Green deal[20] objectives, various technologies and aspects may need to be investigated e.g., architectures, algorithms, software and hardware components, protocols etc.

[20] *A European Green Deal, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en*



Question 5:

Which candidate 6G technologies will enhance CAM services?

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In the first question (Q1), it was highlighted the highly heterogeneous environment regarding transportation means (computational capabilities, power availability, sensing ability, …), which results in the general requirement that communication infrastructures should be flexible and be able to, e.g., provide massive off-loading computing capabilities from vehicles to network, provide real-time AI support, endow the vehicles with refined localization and tracking abilities and do all this with native security and privacy features. In the previous question (Q4), key challenges related to advancements in 5G and research and innovations in 6G that are needed to endow the future network infrastructure with these capabilities have been presented. To achieve the ambitious goals, 6G will require the synergy and integration of a range of disruptive technologies including more efficient air interfaces, connected intelligence with decision making and computing. It is the focus of this question to identify which are the 6G technologies that have the potential to address these challenges, which are listed next:

Joint communications and sensing

It is expected that 6G will be used for purposes beyond purely communication-related tasks and delve into the realm of sensing the environment. This would enable, e.g., THz imaging for 3D mapping and accurate environment modelling and, also, centimetre-level precise localization. In the case of mobility applications with a high number of high-speed vehicles and users, this can further enable distributed perception, which can create and keep up-to-date a feature-map of the environment. This environmental information together with all the network related-metrics can be exposed as a service to the applications or feed distributed AI-based algorithms that can, e.g., assist navigation services for safe and efficient robot/vehicle mobility.

Integrated non-terrestrial networks

Non-terrestrial networks (NTN) are going to be part of the technologies that will be featured in 6G systems. The non-terrestrial elements can be based either on drones, unmanned aerial vehicles (UAVs) and high-altitude platform stations (HAPSs) or on satellites and their most immediate application is to enhance the coverage in remote and underserved areas. These elements can also provide different types of services to vehicles mostly related to localization, but also including relaying, caching, and computing. These types of networks have elements (such as UAVs, very low-earth orbit (VLEO) satellites etc) placed at high altitudes that in some cases can also move rather unrestrictedly, and this is why they are also often referred to as 3D networks.

AI technologies

AI will be both one more service and a native feature in the 6G communication systems. AI-based CAM services will be enabled by 6G considering their communication requirements (e.g., low latency, massive capacity uplink access), computation needs etc. As a built-in feature of different components, AI will contribute to the optimisation of the performance and operation of communication systems, reducing their complexity, and thus supporting the provision of future advanced CAM services. A list of examples of how AI is involved in different aspects of future CAM services is provided in the following:

- **AI-extended edge computing infrastructure:** The support of AI-based CAM services at the network edge in order to provide distributed AI, requires an update of edge computing infrastructure and extensions to the orchestration of services on top of it. To this end, novel compute infrastructure, such as Graphical Processing Unit (GPU) and Tensor Processing Unit (TPU), which is particularly stressed with AI services, needs to be considered. Furthermore, the orchestration of the AI-based services needs also to consider the available novel capacities of the edge computing infrastructure, thus extensions need to be provided.

- **AI-based network orchestration:** Certainly, Management and Orchestration (M&O) of the network is a challenging task due to monitoring, control, and decision-making processes, which are intrinsic to M&O. The complexity of this task increases, in particular when low latency communications are demanded by critical applications such as safety applications in the CAM context and due to mobility, several network domains become involved. The number of variables to control and to consider has and will hugely increase. In order to cope with the complexity of CAM, native AI/ML in 6G networks must kick-in to timely and effectively orchestrate and automate the network operations by leveraging the network intelligent functions , which based on the learning process can anticipate the fluctuations of the network and pro-actively and timely reconfigure the network.

- **Dealing with Adversarial AI:** One of the key concerns related to the integration of AI-based techniques in V2X security refers to adversarial attacks which may cause trained models to behave in undesired ways. Dealing with adversarial attacks is non-trivial and requires solutions to foster trust and stimulate confidence in AI/Machine Learning (ML) models. In an effort to render AI/ML resilient to adversarial attacks, adversarial AI aims at assessing the security robustness of learning algorithms and designing appropriate countermeasures. While adversarial AI has already attracted considerable interest in the field of computer vision, future research efforts need to be devoted to mastering how AI-based attacks are launched in V2X environments and ensuring the safety of AI models.

Intelligent Reconfigurable Surfaces

Intelligent Reconfigurable Surfaces (IRS) – programmable meta-surfaces – is another candidate technology to investigate as it may enhance the vehicular channel conditions by either increasing the coverage area or by providing a better, more stable channel less prone to fluctuations. The main application for IRS in general 6G scenarios would be to install them on the surfaces of buildings and other elements in the landscape to extend the coverage from base stations to users in specific directions, with reflected or transmitted signals. However, to apply IRS in vehicular environments, many challenges especially mobility management need to be resolved[21].

Quantum technologies for E2E Trustworthiness

In 6G, another paradigm shift is expected to be the transition from simple security to native trustworthiness. The operation of 6G communication systems will evolve towards a multi-party and multi-actor model with different integrated capabilities (communication, sensing, computing, and intelligence) that will be used by CAM and other services. Data, as well as the knowledge and intelligence derived from it, will also be another essential aspect. This shift involves dealing with the security-by-design, including capabilities for data governance, multilateral trust models and privacy protection. To guide the design of a trustworthy 6G system and define the corresponding key capabilities, new enabling technologies will be considered; among them, it is worth highlighting quantum technologies. Quantum technologies can enhance the security of vehicular communications pertaining to entanglement-based solutions (as they cannot be accessed without leaving traces) and to quantum key distribution (QKD) solutions that enable the detection of eavesdropping attacks.

[21] *S. Zeng et al., "Reconfigurable Intelligent Surfaces in 6G: Reflective, Transmissive, or Both?," in IEEE Communications Letters, vol. 25, no. 6, pp. 2063-2067, June 2021*

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From 5G to 6G Vision

A Connected and Automated Mobility perspective

This white paper has been prepared by the 6G IA 5G for CAM Working Group.

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- **R&I:** the WG aims at becoming a knowledge base to facilitate the exchange of information on ongoing R&I activities in the field and to disseminate it, e.g., in the form of white papers. The WG also aims at developing suggestions for Strategic Research and Innovation Agendas for Smart Networks and Services (SNS) Joint Undertaking and the new European PPP on Cooperative Connected and Automated Mobility (CCAM).

- **Deployment:** the WG aims at developing elements of strategic guidance in view of European deployment programmes on the field, in particular 5G Corridors for CAM under the CEF2 Digital Programme. The group also aims at facilitating broader stakeholder cooperation and building of project pipelines through workshops and networking activities.

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