5G PPP Automotive Working Group

Business Feasibility Study for 5G V2X Deployment

Version 2, February 2019

Executive Summary

The key technology enablers for 5G Vehicle-to-anything (V2X) communication are well studied and understood in the wireless industry, while standardization of 3GPP Rel. 16 V2X is in its final phase. Nevertheless, there is still some lack of insights into the required rollout conditions, roles of different stakeholders, investments, business models and expected profit from Connected and Automated Mobility (CAM) services. It is foreseen that these advanced CAM services, including high-definition (HD) maps support, highway chauffeur, teleoperated driving, highly and ultimately fully autonomous driving, will be enabled through next-generation 5G vehicular networks, starting with 3GPP Rel. 16.

This second version of the white paper from the 5G PPP Automotive Working Group builds on the first one, which was published in early 2018 [1]. With respect to the first version, this paper includes further work and enhancements that targets the description of the 5G V2X ecosystem and stakeholder relationships, different sharing models for network infrastructure, as well as a business setup and finally a techno-economic assessment of the investment. The scope of the paper is to provide insights and trigger discussions on business models for CAM services, 5G V2X deployment costs and potential revenues. Available research studies, ongoing discussion within the 5G PPP, standardization bodies and other alliances are used as references to build the arguments in this paper.

The starting point is that, due to the technical requirements of CAM services, the deployment of a so-called 5G digitalized highway is a main enabler. The exemplary highway environment considered through this work includes 5G radio base station sites, civil work and fibre backhaul connections. It is further assumed that this investment could be used to a certain extent to provide enhanced Mobile Broadband (eMBB) services in parallel to CAM services. The overall costs are standard-wise formed by CAPEX and OPEX including maintenance and service overhead.

The assumptions that have been made in the context of this white paper rely on working hypothesis and estimates aiming at identifying the most suitable investments model(s), but yet they should not prejudge the effective level of economic viability of the CAM business cases as it will result from market developments in the coming years.

This work aims at drawing the 5G CAM landscape of main stakeholders and relationships. Moreover, an investment and business model are proposed to describe the value flow between the involved actors. It shows under which conditions a return on investments for the 5G-digitalized highway can be expected, depending on investment costs, user fees and number of users. Moreover, a positive business case can be expected, especially when network infrastructure is shared between different operators. Particularly in the early phase of the 5G network deployment, synergies between the private and the public sector could speed up the deployment, allowing more users to get access to CAM services with lower charging rates and ultimately lead to much safer roads and efficient transportation.

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List of Acronyms and Abbreviations

3GPP	3rd Generation Partnership Project
5G	Fifth Generation
5G PPP	5G Public Private Partnership
5GAA	5G Automotive Association
ACN	Automatic Crash Notification
ADAS	Advanced Driver Assistance Systems
AECC	Automotive Edge Computing Consortium
CAM	Connected and Automated Mobility
CAPEX	Capital Expenditure
CEF	Connecting Europe Facility
eMBB	enhanced Mobile Broadband
ETSI	European Telecommunications Standards Institute
gNB	Next generation NodeB
HD	High Definition
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IIC	Industrial Internet Consortium
IRTF	Internet Research Task Force
ISO	International Organization for Standardization
ITS	Intelligent Transport System
ITU	International Telecommunication Union
LTE	Long Term Evolution
MEC	Mobile Edge Computing
MNO	Mobile Network Operator
NGMN	Next Generation Mobile Networks
NR	New Radio
OBU	On-Board Unit
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
PC5	Proximity Communication 5

QoE	Quality of Experience
RAN	Radio Access Network
Rel	Release
SAE	Society of Automotive Engineers
SDO	Standards Developing Organization
SLA	Service Level Agreement
SME	Small to Medium sized Enterprise
TCO	Total Cost of Ownership
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Anything
VAI	Vehicle as Infrastructure

1. Introduction

This white paper brings insights on the deployment costs for 5G Connected and Automated Mobility (CAM) solutions with a profit analysis for its financially and socially beneficial commercialization. With more advanced CAM services, automated driving is seen as a technological highlight that will shape the future mobility concept and improve quality of modern life by providing traffic safety together with added environmental and information improvements. Connectivity, and more precisely V2X communications, is seen as one of key technological enablers of autonomous driving, especially in SAE levels 4 and 5 [2]. Already in 2015, an early 5G Automotive Vision insight was provided by 5G PPP [3] and in 2018 the 5G Automotive Working Group followed up with a 5G V2X deployment white paper [1]. Here, in contrast to the first version of the white paper, we are focusing on the business feasibility for 5G CAM deployment from a network operator perspective (in this white paper, the focus is given to key roles in the ecosystem, as it is possible for different actors to take ownership of certain roles in different markets. For example, the role of "network operator" could be taken be a traditional mobile network operator or, e.g., by a road operator willing to deploy and manage its own network).

In technological terms, the advance towards fully automated driving is understood as an evolutionary process and is mainly driven by the corresponding stakeholders in the automotive industry. From the communication technology point of view, it is meanwhile widely accepted that future CAM services, ultimately leading to autonomous driving, will require a high level of connectivity of vehicles through an advanced communication technology as 5G V2X. The multitude of CAM services with heterogeneous requirements calls for a flexible radio air interface, where multiple radio access technologies may potentially co-exist. In parallel, 5G core functions and features as Mobile Edge Computing (MEC) and slicing are being developed to enhance the end-to-end performance and fulfil the technical requirements of CAM.

Looking towards the future radio access, the first efforts to define a standard for V2X by 3GPP had already resulted into the LTE-based Release 14, where broadcast V2V communication is supported. In order to enable more advanced CAM services, 3GPP is currently working on Release 16, which will be the first 5G V2X standard, supporting different connectivity modes between vehicles. In order to accelerate and satisfy the growing demand, the main focus on Release 16 will be on eMBB services and operating frequencies below 6 GHz, whereas it is envisioned that more ambitious CAM services requiring URLLC and even larger data rates shall be supported by the next releases of the 3GPP standard.

From the deployment perspective, it is non-realistic to expect that 5G V2X will be deployed over the whole road network within a short time period but will be rather deployed over a period of several years. However, road authorities and car manufacturers (car OEMs) cannot expect services interruption during a trip; especially if CAM is used for safety applications. Even when crossing borders at corridors there should be seamless service. According to the European 5G Action plan, the milestone is set to 2025 [4]. Therefore, coexistence of 5G-based systems with legacy technologies such as 3GPP Rel.14/15 may be seen, also including possible synergies between those systems.

As for any new technology, the establishment and success of 5G CAM will strongly depend on the required investment costs and expected revenue, especially during its initial years of deployment. As the level of required investment has not been yet clarified, there might be reluctance by some Mobile Network Operators (MNOs) and other possible road infrastructure investors to invest in 5G deployment to target the 5G CAM services. To cope with the large investment costs and to support the natural need for multi-operator vehicular communication, network operators also consider solutions of sharing network infrastructure and other resources.

The conducted modelling approach is generic for both revenue and cost analysis. In an early stage, advanced driving solutions are foreseen to be applied in relatively less challenging areas with more predictable mobility behaviour and with easier to handle algorithmic complexity. One such area are the highways, where only 8% of the 2017 road fatalities in Europe took place [5]. To bring Europe even closer together, the Commission is promoting the testing of 5G CAM technology in cross border corridors in Horizon 2020 projects like 5GCroCo, 5G CARMEN, and 5G-MOBIX, and further supported by the Connecting Europe Facility (CEF). Considering all this, our 5G V2X business feasibility study is conducted in a highway setting.

The remaining part of this paper is organized as follows. Section 2 introduces actors and relationships as well as provides an initial take on investment and revenue model options for network deployment. In Section 3, the investment costs and profits are estimated, providing insights on sharing and non-sharing options. Finally, conclusions are summarized in Section 4.

2. Business Blocks in 5G V2X Deployment

2.1 Ecosystem of actors and relationships

Based on the 5G PPP projects target stakeholders [6] we have identified key stakeholder categories involved in the deployment of 5G V2X technologies: 5G industry (network operators, network and devices vendors), automotive industry, Standards Developing Organisations (SDOs), road infrastructure operators, policy makers, and users. The relationship between them are depicted in Figure 1.

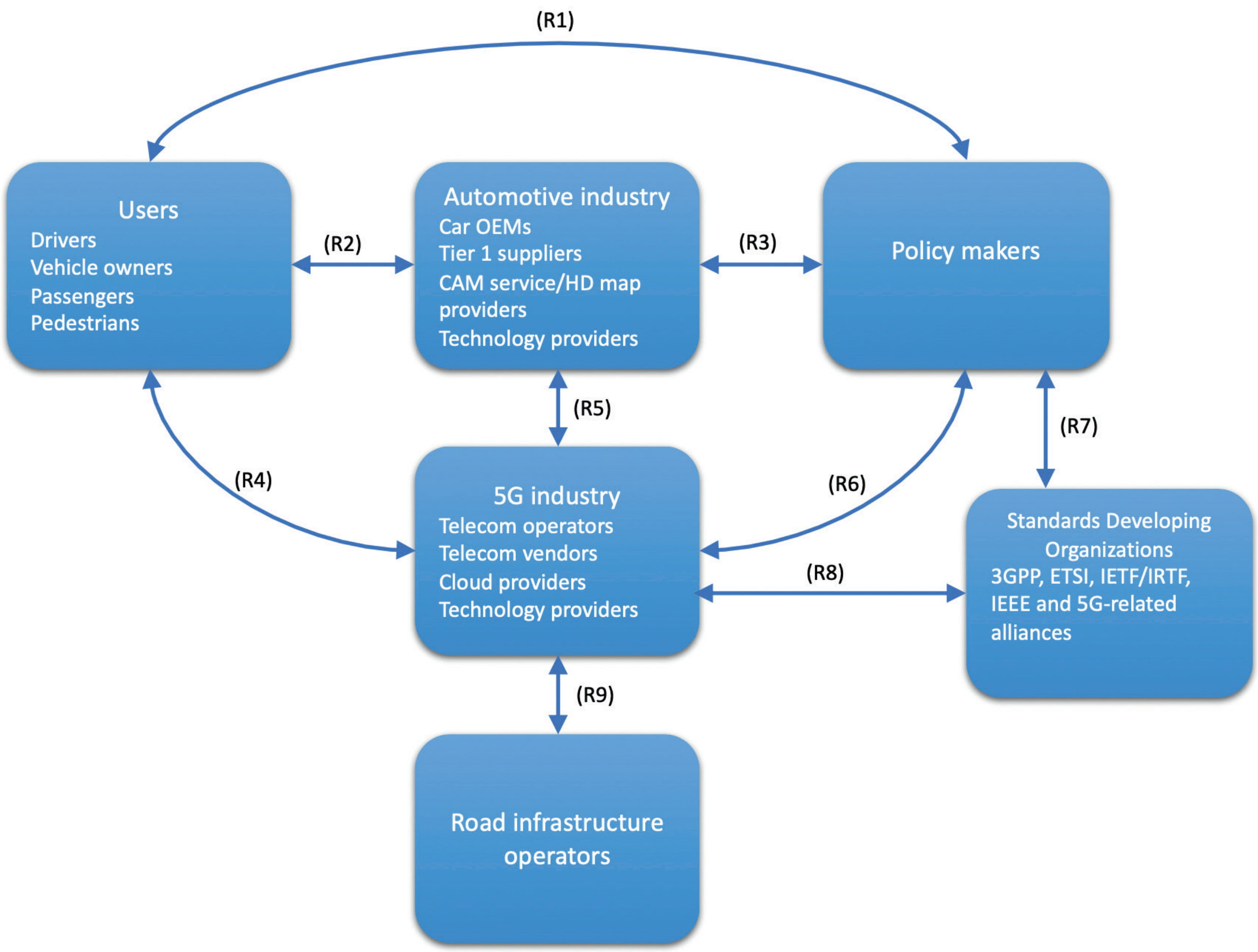

Figure 1: Diagram of the main stakeholders and relationships in the context of 5G V2X deployment.

From the diagram, we first elaborate on the key stakeholders and the main roles they take in the 5G V2X deployment ecosystem, followed by a description of the key relationships among them.

2.1.1 Stakeholder categories

5G industry: these actors include any general business activity or commercial enterprise developing or using 5G technology or providing 5G-related services. Considering the deployment of 5G, this may include Mobile Network Operators (MNOs), Telecom vendors, Cloud providers and other Technology providers such as device providers, software developers, etc.

Automotive industry: this category includes car OEMs (car manufacturers), component manufacturers, Tier 1 suppliers, CAM service providers and HD map providers and other automotive-specific technology providers (it also includes other services such as the logistic sector). The category brings the automotive expertise and services (including mobility services) to customers (business and consumers).

Standard Development Organizations: correspond to entities whose activities coordinate the development, interpretations and production of technical standards that will be adopted by the 5G industry, including 3GPP, ETSI, IETF/IRTF, IEEE, as well as 5G-related alliances such as NGMN, IIC, 5GAA, AECC. In the case of safety-related 5G applications (e.g. ADAS and autonomous driving), pertinent standards developing organizations such as ISO (c.f. the recent ISO/PAS 21448:2019 Road vehicles -- Safety of the intended functionality) may be relevant.

Road Infrastructure Operators: national or regional entities in charge of the deployment, operation and maintenance of physical road infrastructure. In some cases, they also have the responsibility of managing road traffic operations, own or operate the toll system, etc. Each European country has its own regulation about road infrastructures. Some of them are operated by public entities, while others are operated by private companies, which may be partially owned by local governments.

Policy makers: correspond to international, European or national government authorities or organizations responsible to define the legal framework and policies, such as road and transport authorities or telecom regulators. The ITU as well as national spectrum regulators also belong to policy makers. Policy makers provide the highest authorities and regulate the relationships within the whole stakeholder ecosystem.

Users: The end users could be either drivers, vehicle owners, passengers or pedestrian. Passengers are expected to take a more active role in the near future due to the decoupling of the "owner as driver" and the embrace of the "passenger enjoying different mobility services" paradigm that autonomous vehicles will support.

2.1.2 Primary stakeholder relationships

The primary relationships between the main stakeholder categories, as depicted in the Figure 1 diagram, are defined and briefly described in Table 1. The list does not contain all possible relationships, the objective is rather to highlight key relationships from the 5G perspective that are relevant in the case of network deployment. For example, it is assumed that there is an existing link between the Automotive Industry and the Standard Development Organizations, but it can be assumed that this link is indirectly handled by the 5G Industry as intermediary.

Table 1: Description of the relationships between stakeholders shown in Figure 1.

Index in Figure 1	Stakeholders involved	Description of the relationship
R1	Users and Policy Makers	Users are covered by regulation provided by public authorities. In the automotive and communications context, this usually involves environmental, safety and financial aspects. Users are licensed by authorities.
R2	Users and Automotive Industry	The Automotive Industry collects feedback and the needs of end users to define the requirements and features of the new products, functionalities and services. Users are buying vehicles, products and services from the Automotive Industry

Index in Figure 1	Stakeholders involved	Description of the relationship
R3	Policy Makers and Automotive Industry	Policy Makers define the regulation framework that the Automotive Industry follows. The Automotive Industry provides feedback to the Policy Makers to define and improve regulations.
R4	Users and 5G Industry	The 5G Industry collects feedback from the end users to define the network requirements, usually in terms of Quality of Experience (QoE), as well as their needs in terms of services and new applications. Users are buying products and services from the 5G Industry
R5	Automotive Industry and 5G Industry.	The 5G industry collaborates closely with the Automotive industry to design a 5G V2X technology that meets the needs of both on system and component level. The Automotive Industry defines the network requirements to be met for their products and services, while the 5G Industry puts requirements for the functionality and performance enhancement of communication (sub-)systems. Within the automotive industry, the component manufacturers supply the Tier 1s, so that the latter ones can integrate these components and build higher-level components for the OEMs. Tier 1 companies are direct suppliers to OEMs, which are the ones producing the products for the consumer marketplace. This traditional chain has been extended with the advent of advanced driver assistance systems (ADAS) and autonomous driving solutions. Now, CAM service providers and HD map providers are important drivers, together with technology providers including start-ups, SMEs, research labs and the academia. The Automotive Industry players are buying products and services from the 5G Industry
R6	Policy Makers and 5G Industry	Policy Makers define the regulation that the 5G Industry must follow. The 5G Industry gives feedback to the Policy Makers influencing the definition of new regulation. Policy Makers also make spectrum available to the 5G Industry
R7	Policy Makers and SDO	SDOs have to consider regulatory conditions in standards development. For example, ETSI is working based on a mandate of the EU Commission.
R8	SDO and 5G Industry	The Standard Developing Organizations define the standards that are implemented in the 5G deployments. The 5G industry and the automotive industry need to work hand in hand with standardisation organisations. In particular for autonomous driving applications, where high levels of service (e.g. ultra-reliable low-latency) are needed, technical solutions need to undergo assessment based on safety standards.

Index in Figure 1	Stakeholders involved	Description of the relationship
R9	5G Industry and Road Infrastructure Operators	Road Infrastructure Operators may participate in the deployment of 5G V2X and provide or facilitate licenses or other infrastructure requirements that are under their responsibility (This would require involvement of policy makers). In this way, they may influence the 5G V2X deployment procedure by defining network requirements to be considered by the 5G Industry. After having deployed the 5G network, the 5G Industry shall offer communication services to the Road Infrastructure Operators based on commercial agreements. It is expected that 5G network providers will own and operate most or parts of the network infrastructure. Potentially, this entity can be further distinguished between RAN infrastructure provider and cloud infrastructure provider. The former owns the physical infrastructure such as the antenna sites and the hardware equipment for the antenna. The latter owns and manages local and central datacentres providing the virtual resources such as computing, storage and networking. Such roles of 5G network providers can be taken by the MNOs. However, it is also possible that the Road Infrastructure Operators go one step further and deploy or operate (parts of) the 5G V2X network, directly providing the necessary coverage for CAM services to the users.

2.2 Investment and revenue models

2.2.1 Infrastructure and network sharing models

One of the main messages from [7, 8] was that the cost of deploying and operating 5G V2X for providing CAM and other Intelligent Transport System (ITS) services will be very high and challenging to be carried by one single network provider, e.g., a single MNO or Road Infrastructure Operator. In what follows, four different sharing models are briefly presented, according to the level of sharing of network infrastructure, network functionalities and radio spectrum between different network operators. A possible scenario is that, in an earlier phase, sharing is more extensive, followed by independent and separate investments by each operator. These models will co-exist and be used according to the area and users' density. Different sharing models have significant implications on the required investments to deploy and operate 5G V2X networks and the savings in CAPEX and OPEX with regards to the baseline of no sharing based on the estimates provided by [8]:

- **Passive infrastructure sharing:** each network operator deploys its own network in the service area. Only passive infrastructure elements are shared between operators, e.g. space, masts, power generators, and air conditioning equipment. These elements could be deployed by Road Infrastructure Operators, a joint MNOs venture or third-party infrastructure providers. Savings: 16% to 35% CAPEX and 16% to 35% OPEX [8].
- **Active infrastructure sharing excluding spectrum sharing:** active elements of the cellular network such as base stations are shared. Each operator is still transmitting on his own spectrum. Savings: 33% to 35% CAPEX and 25% to 33% OPEX [8].
- **Active infrastructure sharing including spectrum sharing:** active elements such as base stations are shared. One single operator operates the dedicated spectrum. The RAN connects to the core network of the visitor's

operator (the different MNOs) directly. Savings: 33% to 45% CAPEX and 30% to 33% OPEX [8].

- **Core network sharing:** elements of the core network are shared by more than one network operator. Savings: the savings corresponding to just sharing elements of the core network are reported as very low [8]. If the sharing agreement includes some aspects of the RAN, then the savings are similar to active infrastructure sharing including spectrum sharing model.

National roaming can be considered a form of active sharing [8]. According to this approach, subscribers can roam to other networks within a country (e.g., in case coverage is provided by an exclusive operator in a locality). As in the general international roaming case, the connection goes to the core network of the exclusive operator before going to the core network of the visitor's operator; this is referred to as Home Routing and it could generate additional delays if used as the default roaming option. Other alternatives, such as Local Breakout should be considered for latency-sensitive services. In addition, international roaming should be supported especially for cross border corridors.

Any type of sharing will require a certain set of agreements between the network operators, related to the passive sharing (also on a lease base), active sharing involving a joint deployment, agreements of using other network operator's network for a specific technology (e.g. 2G) or sharing agreements related to specific locations. Moreover, they need to be in line with the regulatory frameworks in each country. This implies both telecom regulation and also any possible concerns from the competition authorities.

Additionally, backhauling options and other possible sharing models are envisaged. While certain areas already count with optical fiber backhaul deployed along roads, commercial agreements are sometimes unfeasible to allow sharing mechanisms for such fiber access. In any case, sharing options should be encouraged to reduce additional deployment costs; for example, if a road operator owns fiber backhaul infrastructure, it could collaborate with MNO(s) to cover different geographical segment.

The new regulatory business models for co-investment and wholesale-only network provisions that have been introduced by the European Legislator in the European Electronic Communications Code [9] have been identified as relevant for 5G for corridors deployment, but yet have not been integrated in the modelling work of this white paper as there is not yet a sufficient relevant experience in the field. Co-investment agreements in particular offer significant benefits in terms of pooling of costs and risks. Moreover, they are particularly relevant in challenging areas where there is insufficient infrastructure-based competition due to a lack of economic viability.

2.2.2 Charging and revenue models

The revenue models for the 5G V2X deployment are highly dependent and related to how revenues are, or can be, generated on the application level. For the analysis, we consider a "pay per use" model to estimate the network revenues. In pay per use, it is considered that a fee is paid every time a section of a road is used (similar to toll fees in highways). Other options (not considered in the study) include one-time payment; in this case, it is assumed that users pay an intermediary up-front fee that guarantee service subscription. Recurring subscription (with fair-use policy) is also an important and likely model.

The monetization from the network is highly dependent on the services enabled by connectivity. For example, in-vehicle applications today the focus is mainly on infotainment (e.g., audio/video streaming). However, they are expected to cover, through virtualization and artificial intelligence, other use cases requiring isolated software execution environments and a secure interaction between applications and vehicle's smart devices, sensors and actuators. This translates into new business opportunities for municipalities, insurances and other service providers, as well as road and connectivity infrastructure owners. Other possible financing and revenue models include:

- Advertisement: since in autonomous driving, the driver will have time to engage in other activities, it is possible to envisage additional revenues coming from ads. The same reasoning applies to other commercial offers.

- Outcome-based (reduction of operational costs, maintenance, insurance, accidents prevention, etc.).

As 5G deployment progresses and the industry moves toward demanding vehicle applications (especially advanced driver assistance, autonomous driving, and other safety related applications), network slicing will increasingly be used to provide a high-grade 5G connections with guaranteed SLAs regarding in particular ultra-reliable, low-latency communications for these applications. This will create new opportunities for the network deployer to create differentiated connection pricing policies and charge significantly higher fees for advanced applications with high-grade SLAs. At the same time, however, the investment may rise (e.g. expenditures for first-time and continuing safety certification by relevant authorities) as more ambitious applications are supported.

3. Costs and Profit Analysis

3.1 Business setup and geographical area

In order to make a deployment evaluation, we make important assumptions to ground the study:

- The network deployment investment is done by one actor. For simplicity, we call this actor network operator (it could be a traditional MNO or potentially any actor (from Figure 1), such as a road operator, willing to invest in network deployment).
- The network operator might have the possibility to reuse physical infrastructure (such as towers, power supply or fiber network) from a road infrastructure provider.
- CAM services might be provided by road operators, OEMs, MNOs or other service provider to have this role. For the analysis purpose, we consider that it is not necessarily the same actor in charge of the network deployment and operation.
- The CAM service provider receives a fee from end customers. It could also be envisaged that service fees are indirectly covered by OEMs in their service offers to end customers.
- The CAM service provider will then pay a fee to network operators for the provision of connectivity products and added-value services. This is the main revenue source considered in the analysis.

The simplified diagram in Figure 2 presents the assumed business scenario. But it is important to, once again, highlight that other setups are perfectly feasible depending on the market conditions and the regional or national interests and regulatory frameworks.

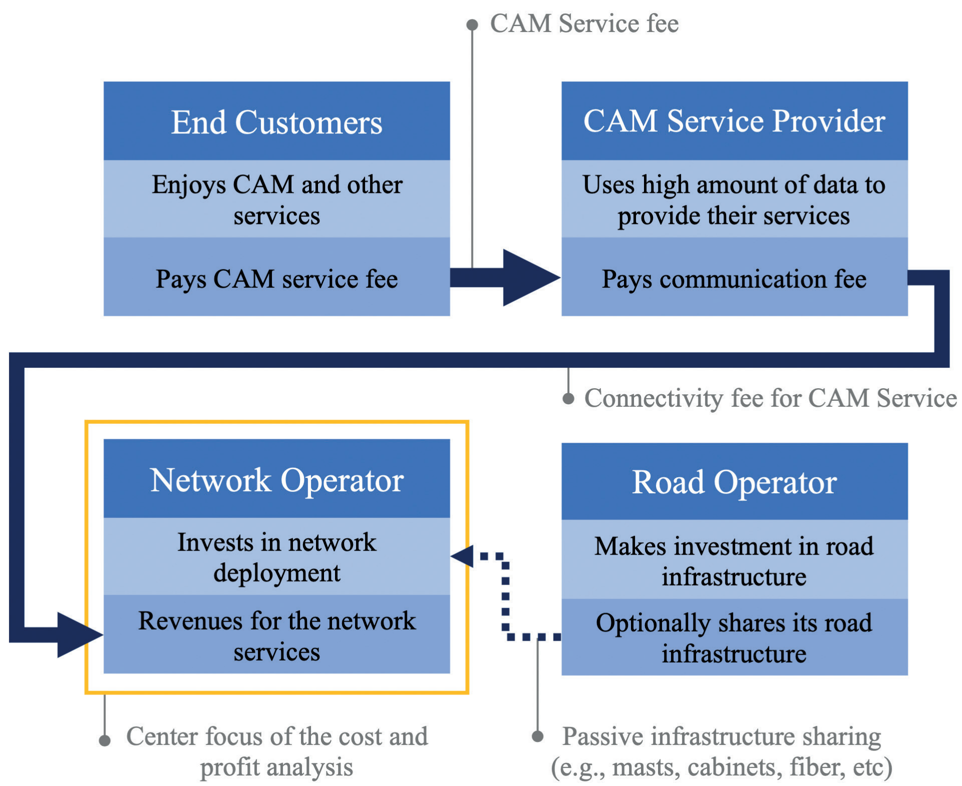

Figure 2: Main business setup for the network deployment analysis. The roles of “Network Operator” and “CAM Service Provider” can be covered by different actors in the stakeholder ecosystem. These two roles can even be taken by the same actor, depending on commercial interest.

Regarding the geographical area, two important assumptions are taken:

1. To estimate the deployment extent a 100 km highway segment is considered,
2. To estimate the potential income a traffic density of 50000 vehicles is considered to use the highway segment each day. The traffic density numbers are based on measurements provided by the German Federal Highway Research Institute [10].

3.2 Techno-economic model

To handle the complex problem of cost and revenue estimation, some assumptions and parameter choices are taken to model the calculations. The network deployment parameters used for the calculations are based on general assumptions, without any detailed technical requirements for providing network coverage and connectivity service for advanced CAM services.

In what follows, a business period of ten years is considered, e.g. from 2025 to 2035. In this study, an estimation of the deployment costs and revenues is provided for a horizon of ten years. The costs presented in Table 2 are considered as our baseline scenario [11] and should be only understood as coarse estimates for study purposes. The Total Cost of Ownership (TCO) includes CAPEX and OPEX. The main cost contributions for the network investment are [11]:

- CAPEX:
  - Site infrastructure: gNBs, network equipment, cabinets, etc.
  - Civil works: physical cabinets, fences, antenna masts, etc.
  - Fibre backhaul provision along the highway.
- OPEX
  - Network operation, maintenance and replacement, corresponding to the standard assumption of 10% of the accumulated CAPEX.
  - Site lease: permissions to use land perimeters.

The source of income from the perspective of the network operator is a percentage of the CAM service fee, the part associated to communication aspects. A CAM service fee of 1 Euro per 100 km per vehicle is consider for end customer, which shall also cover the connection and HD map fees. This is a conservative assumption, since some estimates suggest CAM service provider fees to be over 5 Euro per 100 km (0.01 USD per mile) [12]. Regarding the charge price to estimate the revenues for the network operator, we consider a rough charged fee estimate of 0.5 Euro per 100 km (this is what the network operator would receive for the enablement of the connectivity for CAM services). The remaining part of the customer fee is to provide the CAM service, e.g. real-time monitoring and updating of HD maps.

Table 2: Deployment costs and assumptions for the baseline scenario.

	Parameter	Value	Unit
Deployment costs	5G site (CAPEX)	64 000	Euro per site
	Civil works (CAPEX)	20 500	Euro per site
	Fibre backhaul (CAPEX)	23 000	Euro per km
	Network operation (OPEX)	10	% of total CAPEX
	Site lease (OPEX)	5 700	Euro per site

	Parameter	Value	Unit
Area and capacity demand	Inter-site-distance (ISD)	1	km
	Deployment length	100	km
	Number of vehicles	100 000	Vehicles/100km/day
Deployment rate	Connectivity cost for CAM	0,25	Euro per 100 km
	Network deployment rate	55	% for year 1 for coverage
		5	% from year 2 to 10 for capacity
	Fiber deployment rate	80	% year 1
		20	% year 2
	Yearly penetration rate	10	% from year 1 to 10
Costs evolution	CAPEX Yearly price evolution	-3	% from year 1 to 10
	OPEX Yearly price evolution	3	% from year 1 to 10

Even if the trend for data costs is to decrease over each year, it is important to consider that more advanced services will be progressively introduced. This will result in an estimated flat charge for the communication services. For advanced driving applications, especially autonomous driving level 4 and 5, a 5G deployment implementing network slicing may offer slices with the necessary guaranteed SLA (e.g. low latency) at significantly higher costs per 100 km (e.g. 1 or even 2 Euro per 100 km), creating a separate scenario.

The required costs for 5G on-board units (OBUs) for vehicles shall be covered by the vehicle owner and are therefore not considered in the current cost analysis. However, these costs may influence the expected user penetration rate and need to be reasonable and in general as low as possible. Forecasts expect that cellular connectivity will be available in 55% of new vehicles globally by 2020 and it is expected to be higher in the European Union [13] since the consumers demand for connected cars in higher and legislation for Automatic Crash Notification (ACN) is required in all new vehicles from 2018. Moreover, spectrum costs, engineering and procurement costs are not considered as part of CAPEX in this study.

As a realistic market behavior, a 10% yearly penetration of new CAM users is assumed. Considering all above, it is then straightforward to calculate the investment costs, income (revenue) and profit for the period of ten years.

3.3 Deployment scenarios and investment-revenue estimations for connected and automated driving

To gain more insight into the influence of individual parameters on the overall profit, two deployment alternatives are considered (assuming pessimistic cost savings provided in [8]):

- Deployment 1: the CAPEX and OPEX investment for the network and fiber backhaul is carried out by a single same actor (no infrastructure or network sharing is considered). This approach requires national and international roaming to support all users independently of their provider and nationality.
- Deployment 2: the active elements of the network are deployed by a single actor. The passive elements of network infrastructure are shared with the road operator (mast, sites, cabinet, power, conditioning). Cost savings: 16% CAPEX, 16% OPEX [8].
- Deployment 3: besides sharing passive

elements, the active elements in the radio access network are shared by more than one network operator. Cost savings: 33% CAPEX, 25% OPEX [8].

Also, two different pay per use revenue alternatives, as introduced in Section 2.2.2 are considered with different values of CAM service fee and traffic density:

- Revenue 1: baseline scenario presented in Table 2, corresponding to 50000 vehicles using the highway segment each day and a revenue of 0.5 Euro per vehicle on each use of the highway segment. All vehicles are served by a single network operator.
- Revenue 2: it is assumed that several network operators provide connectivity along the highway; a single network operator only captures 35% of the vehicle penetration rate.

The evaluation results for the accumulated profit are depicted in Figure 3 for a fixed user penetration rate of 10% per year. As observed, payback periods between four and eight years are expected, depending on the deployment and revenue alternatives considered.

Nevertheless, where there are parallel network deployments, the number of subscribed vehicles is divided among the different networks, under these competitive conditions it is not profitable to invest in network deployment unless passive or active network sharing options are in place.

From the three deployment alternatives and the two renuve alternatives considered, Table 3 presents the resulting scenarios.

Table 3: Resulting scenarios based on the deployment and revenue alternatives.

	Revenue 1	Revenue 2
Deployment 1	A single network operator makes a full deployment and provides connectivity to all vehicles on the highway. This can be interpreted as the case where all vehicles are served by the same network, using **national roaming**.	More than one network operator makes a full deployment, each provides connectivity only to its subscribers on the highway. In a realistic interpretation, this could be the case of parallel network deployments with **no investment nor network sharing**.
Deployment 2	A single network operator makes a deployment, sharing road infrastructure; it provides connectivity to all vehicles on the highway. This can be the case where all vehicles are served by the same network by using **national roaming and passive sharing** with the road operator.	More than one network operator makes a deployment, sharing road infrastructure; each provides connectivity only to its subscribers on the highway. In a realistic interpretation, this could be the case of parallel network deployment; with **passive sharing** of elements with the road operator.
Deployment 3		More than one network operator makes a deployment, sharing network and road infrastructure; each provides connectivity only to its subscribers on the highway. In a realistic interpretation, this could be the case of **active network sharing**.

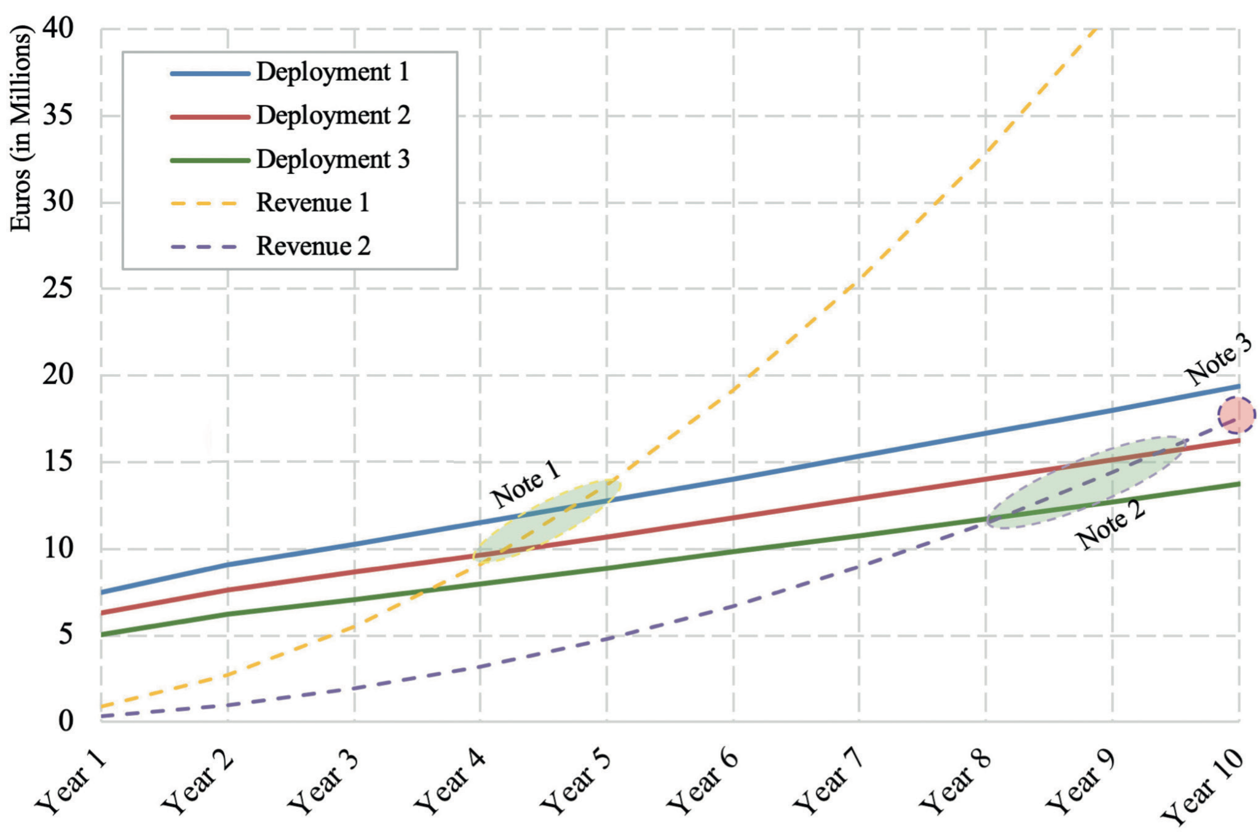

Figure 3: Accumulated cost and revenues for different scenarios.

Note 1: if a single network operator is able to capitalize on all vehicles in the highway segment (revenue model 1), all deployment options break-even within the first 5 years of service.

Note 2: if there is more than one network operator and the vehicle subscriptions are split, the deployment options allowing network sharing break-even after 8 to 10 years of service.

Note 3: if no network sharing is allowed and the number of subscribed vehicles is divided among different network operators, there is no profit reached within 10 years.

3.4 Discussion and future considerations

Considering the sharing models used for the cost and revenue estimations, it is important to highlight that certain sharing concepts assume that the overall investment will be larger for one operator. This disparity in investments is usually compensated by revenue sharing agreements. In addition, network sharing can reduce the investment required by a specific operator. At the same time, the market demand is divided for more than one operator, these conditions will ultimately affect the break-even time.

Due to massive sensor data sharing between mobile users and the access network, a heavy data traffic will be expected mainly in the uplink. At the same time, it is possible that a set of services will require ultra-reliable and low-latency connectivity in very specific locations and conditions. For these reasons, a sufficiently dense cellular network using 5G technology will be a fundamental enabler. The deployed 5G network will enable a multi-service environment, allowing other services like infotainment to be provided over the same infrastructure.

It is important to stress that CAM services can be equally provided by actors coming from the automotive industry or the 5G industry. In this white paper we have considered CAM services as part of the automotive industry, but different realizations are foreseen in this emerging industry.

Standard business models as the one shown in the previous sections are based on the assumption that the user pays for a service provided by the application developer. However, the computing power made available by car electronics today can be also used in a different way in the future, that is, the vehicle owner can in fact be rewarded (e.g., with money or fees discount) for providing computing resources and data. Similarly, a vehicle can be rewarded for forwarding data to nearby vehicles, i.e. serving as a mobile relay. We call this concept Vehicle-as-Infrastructure (VAI), and it is an interesting innovative direction to be explored in future activities.

Finally, it is also clear to us that additional business models may rise since it is expected that the whole traditional ecosystem will be disrupted and changed, as well as new use cases and societal impact could appear.

4. Conclusions

Connected and Automated Mobility (CAM) services require a network with high reliability, speed, capacity, and ultra-low latency, as well as advanced service features such as network slicing. Future 5G network infrastructures are expected to meet the needs of CAM in terms of performance and Quality of Service.

The first part of this study provided an overview of the 5G CAM deployment, including the ecosystem of actors and their relationships, and the investment and revenue models. The second part is focused on the costs and profit analysis an exemplary 5G CAM deployment case.

According to the model used for the analysis, investment in 5G networks along highways can lead to a positive business case. To cover highways and roads, investments are required, whose business feasibility has yet to be verified. In this white paper, a working assumption is that the investment and revenue models only involve the private sector. However, this is not the only foreseen setup, since public investments for societal positive impacts will also be available, as stated in the Action 8 of the "5G for Europe: An Action Plan" [4].

One of the main findings of the analysis is that a key factor influencing the profit of CAM services from the network deployment perspective is the possibility to consider any type of infrastructure and network sharing mechanism. Moreover, in terms of the investment costs, different parameters and scenarios for providing 5G CAM services over the network infrastructure may impact the estimated profit calculations. It is mainly related to the OPEX and CAPEX assumptions, but it also depends on the market share and the percentage of usage of the infrastructure for CAM services. Since the 5G network will enable a multi-service environment, additional revenue streams are also expected, leading to shorter return on investment. A positive business case can be expected for roads with a high density of vehicles. Of course, as the number of users that can be served is limited by the road capacity (number of vehicles per km), the success of investment will also depend on the possibility to monetize additional services, such as those based on eMBB traffic, along roads.

A detailed breakdown of 5G OPEX and CAPEX costs is difficult and not in the scope of the current work. However, the estimated results give trustworthy insights, which are also based on existing know-how from previous studies on network deployment and the extensive available research in the area. Even with strongly conservative assumptions, positive business cases can be expected. Nevertheless, a more detailed modelling and analysis of the investment, which will be required to derive more concrete and quantitative conclusions, shall be considered by the authors for further study.

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