5G for CAM cross-border corridor deployment studies

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***Abstract*— The three Horizon 2020 ICT-18 projects 5G-CARMEN, 5GCroCo, and 5G-MOBIX conducted deployment studies on 5G for Connected and Automated Mobility (CAM) on European road transportation cross-border corridors based upon upon their target cross-border corridors. These cross-border corridors represent a broad sample of road arteria of the Trans-European Transport Network (TEN-T) with very different geographic characteristics, representative of a wide range of 5G for CAM deployments in Europe and even beyond. The deployment studies share technical commonalities like 5G New Radio deployment in the low band and mid-band spectrum but take into consideration distinct assumptions, e.g., penetration and load for radio planning and deployment. Dimensioning for evolving capacity requirements is applied based on 5G for CAM use cases including non-CAM background traffic. The deployment of Mobile Edge Computing (MEC) is considered for CAM in all three studies, partly with different deployment options. The studies include a range of cost indications for 5G deployment and partially discuss the economic viability of 5G deployment on road corridors based on commercial assumptions, and, in economically challenging corridor sections, even with potential support of public co-financing schemes. Complementing these three studies, a metastudy has been produced, providing a comparative analysis plus a gap analysis identifying additional elements for further study to foster cross-border deployment of 5G for CAM. Elements and findings of these deployment studies can be used in ongoing research and innovation projects, but also in future deployment studies and real deployment activities related to 5G for CAM, namely in the context of the Connecting Europe Facility (CEF2)-Digital 5G corridor initiative.**

Keywords— 5G for CAM, 5G New Radio, cross-border corridors, CEF2-Digital, deployment studies, Horizon 2020, Mobile Edge Computing, MNOs, network infrastructure, technology/financial/regulatory aspects

I. INTRODUCTION

The three Horizon 2020 European-funded projects of call ICT-18, **5GCroCo** [1], **5G-CARMEN** [2] and **5G-MOBIX** [3], independently conducted their own deployment study in the context of the so-called Exploitation Plan activity. These studies focused on cost calculation for 5G deployments aimed at enabling 5G for Connected and Automated Mobility on European cross-border corridors. In **5GCroCo**, the focus was on three corridor sections, corresponding to the three countries: France, Germany, and Luxembourg. The corridor sections have different lengths and were selected because they involve distinct early deployments of 5G and distinct architectures and solutions for the involved Mobile Network Operators (MNOs).. In **5G-CARMEN**, nine segments of the 600 km long corridor between Munich and Bologna, were selected, illustrating a variety of geographical characteristics, such as mountainous, rural, or urban areas. In **5G-MOBIX**, five cross-border corridors (CBC) in nine different countries were selected. Each of the selected corridor segments has a length of approximately 40 km, including both soft- and hard-borders. For each of the three deployment studies, 5G deployment is simulated on the respective corridors or segments, using different 5G Radio Access Network (RAN) deployment variants for different types of scenarios. Furthermore, capacity requirements are independently estimated based on CAM-enabled vehicle penetration rates, future data consumption and road traffic forecasts. The investment delta and the deployment cost difference is determined between the existing/planned deployment to fulfil license obligations, and the necessary deployment to deliver continuity of service across borders.. Finally, a metastudy [4] was conducted, comparing the above approaches and identifying the gaps towards providing 5G for CAM in low-density border regions. This paper provides a first look into the additional investment required to deliver advanced CAM services over 5G in such challenging areas where market alone will not deliver advanced CAM services in the foreseeable future.

II. DEPLOYMENT STUDIES

A. *Corridor Selection*

All three ICT-18 projects independently performed their 5G for CAM deployment studies based upon different cross-border corridors (CBCs) in their geographical scope. They have specific geographical characteristics representative of the diversity of European corridors, including tunnels, urban and rural areas, toll zones, rivers, bridges, and mountainous areas.

. **5GCroCo** addressed the deployment on three corridor sections. A 78 km long section in Germany, between the border to Luxembourg and along the French border. A 24.5 km long section in Luxembourg, between the borders to Germany and to France, and a 96.76 km long section in France, between the city of Metz and the borders to Luxembourg and to Germany at the city of Saarbrücken. In **5G-CARMEN**, nine segments of a 600 km long corridor between Munich and Bologna were considered. The segments are located in Germany, in Austria and in Italy, and range between 3.3 km and 7.5 km in length. They have specific geographical characteristics representative of the diversity of European cross-border corridors with tunnels, urban and rural areas, toll zones, rivers, bridges, and mountainous areas. Finally, in **5G-MOBIX,** all five cross-border corridors chosen are approximately 40 km long, 20 km on each side of the border. The CBCs are located between France-Spain, Turkey-Greece, Spain-Portugal, Netherlands-Germany, and Finland-Norway. They also have specific characteristics such as soft and hard borders, rural and urban areas, forests, bridges, rivers, and mountainous areas. The location of all corridors can be seen in **Error! Reference source not found.**.

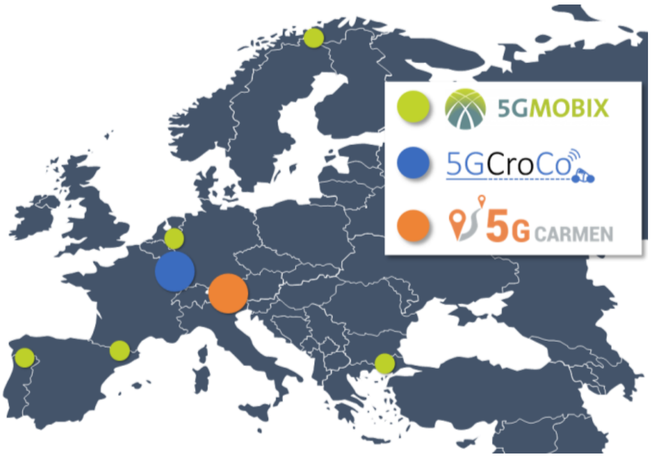

Figure 1: Location of the corridors of the three deployment studies

B. *Scenario Selection*

Each study was developed independently and took different approaches regarding the timeline and the overall deployment methodology. Starting with **5GCroCo**, the study focused on an immediate deployment scenario with two different base station densifications. To achieve this, the study assumes two different "Inter-site Distances" (ISD), one of 3 km, and one of 1 km between base stations. These result in two deployment scenarios for each corridor section. In **5G-CARMEN**, two 5G for CAM service penetration scenarios have been considered. One "conservative" penetration, with estimates between 0.02% by 2021 and 0.30% by 2025, and one "optimistic" penetration, with up to 21.87% by 2025. Furthermore, the deployment is simulated based on continuous upgrades and deployment of new sites, starting from the year 2021 to 2025 and resulting in two scenarios for each segment. In **5G-MOBIX,** each CBC deployment has been simulated for two scenario years, one in 2023 and one in 2025. Existing differences in the networks between both years are determined based on national regulations and planned upgrades or deployment of new sites within this timeframe. This was based on information obtained through research and interviews with relevant stakeholders.

C. *Assumptions for Capacity Requirements and Calculation*

All three studies made assumptions to simplify the overall deployment and cost calculation. One is network sharing, which is assumed in both **5G-MOBIX** and **5GCroCo**, apart from the Luxembourgish section. **5G-CARMEN** does not assume full network sharing but uses for each segment-specific Mobile Network Operators (MNO) site locations. Additionally, backhaul is assumed to be based on fiber in all three studies, while the types of vehicles circulating on the corridors is only detailed in **5G-MOBIX**.

For the three studies, capacity planning is performed depending on the estimated 5G use case requirements and the anticipated road traffic:

In **5GCroCo**, the traffic is estimated to be 6,000 vehicles per day for rural areas, with 600 vehicles in peak traffic hours, 6,000 vehicles per day in urban areas, 1,500 vehicles in peak hours, and 24,000 vehicles per day on highways, with 3,000 vehicles in peak hour. For the use cases, three representative use cases are identified: Tele-operated Driving (ToD), HD mapping and Anticipated Cooperative Collision Avoidance (ACCA), with the highest throughput requirements of 10 Mbps in Downlink (DL) and 25 Mbps in Uplink (UL). This data is then used to show that the two ISD scenarios yield sufficient capacity.

In **5G-CARMEN**, the traffic is estimated to be 3,000 vehicles per hour in all the segments. This traffic is simulated using the SUMO simulation tool, which allows simulating realistic vehicular traffic mobility traces. The use cases are specified using a 6-year adoption timeframe, between 2020 and 2026, and include throughput, latency, and reliability requirements. They include local hazard and traffic information, HD map collection and sharing for automated vehicles, information sensor sharing, ToD and cooperative maneuvering. The highest requirements in terms of throughput are 64 Mbps in both UL and DL, reliability 99.999% and latency below 10 ms. Capacity planning is conducted afterwards with different scenarios with target KPIs using the Unity toll of Universitat Politècnica de València.

In **5G-MOBIX**, for each CBC, the traffic data is obtained from local road operators and road authorities. An hourly average is processed, and the peak traffic is determined as double this average. The 5G for CAM use cases are divided into five categories: advanced driving, vehicle platooning, extended sensors, remote driving, and vehicle QoS support, with the highest throughput requirements of 36 Mbps in DL and UL and latency of below 50 ms, based on measurements obtained on trial sites within the project [5]. Capacity planning is performed using the Shannon-Hartley theorem, assuming ideal conditions and a data rate dependent on the implemented RAN technology. Moreover, vehicles are supposed to have a "legacy" data traffic of 160 kbps per vehicle.

D. *Radio Access Network Technolgy and Planning*

Similar to the requirements, the choice of the implemented RAN technology, and the radio planning methodology varies between the studies.

In **5GCroCo**, no details about the onboard vehicle are provided in the deployment study. The RAN technology deployed is 700 MHz and 3.5 GHz in 5G New Radio. For each deployment scenario, suitable existing sites are upgraded to support 700 MHz and 3.5 GHz, and new sites deployed with 3.5 GHz technology. Radio planning is based on publicly available network maps in Germany from the Bundesnetzagentur, in France from the Agence National des Frequences, and in Luxembourg from the MNO POST. Sites for upgrades and new base stations (BS) are then positioned to fulfill the ISD scenarios previously described, i.e., every 3 km or every 1 km.

In **5G-CARMEN**, also no details about the onboard vehicle are provided in the deployment study. Two spectrum bands are used for the Vehicle-to-Network (V2N) infrastructure, i.e., 700 MHz and 3.7 GHz, with two sector antennas in rural areas and three sector antennas for urban areas. Additionally, Vehicle-to-Infrastructure (V2I) is planned, using Road-Side Units (RSUs), each equipped with two sector antennas and functioning at 5.9 GHz. For the radio planning, both the V2N and V2I deployments are simulated using the Universitat Politècnica de València's Unity 5G path loss simulator and the SUMO traffic simulator fed into an accurate geographical model of each segment. An example of this can be seen in Figure 2.

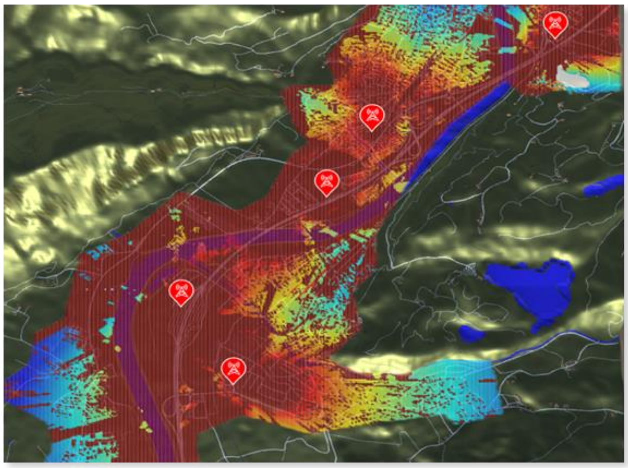

Figure 2: Radio planning example from 5G-CARMEN, a RF map using the UPV's Unity simulation tool

In **5G-MOBIX**, the on-board technology considered is a lossless MIMO antenna with one Transmitter and two receivers, an antenna height of 1.5 m as well as a nominal power of 23 dBm and a gain of 0 dBi [6]. For the deployment, two scenarios are simulated, one scenario where 700 MHz technology is deployed and one scenario where 3.5 GHz is deployed. In the 700 MHz scenario the BS uses FDD duplexing with a bandwidth of 10 MHz and a MIMO with two transmitters and four receivers (2T/4R). The antenna gain is set at 15.1 dBi at a height of 25 m and 43.01 dBm power. In the 3.5 GHz scenario the BS uses TDD duplexing with a bandwidth of 100 MHz and MIMO with eight transmitters and eight receivers (8T/8R). The antenna gain is set at 24.4 dBi at a height of 25 m and 50 dBm power. In both scenarios, the antennas are tilted -3 degrees with an azimuth of 120 degrees. In case of an upgrade, the antennas are upgraded to three sectors, and for newly deployed sites, only two sectors cover the road. Radio planning was performed using the HTDI simulation tool from ATDI, where the corridors were simulated with existing sites and both technologies deployed on the roadside. A minimum signal strength of -80 dBm is used as the minimum coverage condition for the deployment, this can be seen at Figure 3.

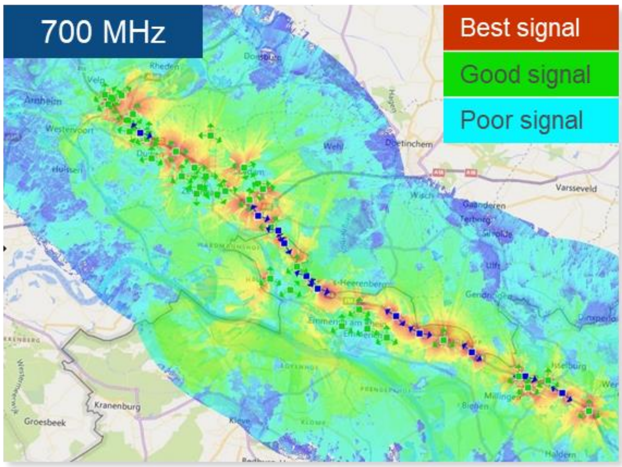

Figure 3: 5G-MOBIX Radio planning, using the HTDI simulation tool, the German-Netherlands CBC, in a 700 MHz deployment scenario

E. Deployment Cost Calculation

The deployment costs reflect the total necessary financial expenditure for a given scenario, given specific financial considerations.

In **5GCroCo**, the study focused on a cost case and uses indicative discounts on network equipment to take into consideration planned upgrades and the usage for different applications other than CAM. As two ISD are considered for each corridor, a resulting Bill of Quantity (BoQ), which includes a list of upgrades and new sites, is determined for each scenario. This BoQ is multiplied by the cost catalog, which consists of the indicative discount on upgraded and newly deployed hardware. For the upgrades, the sites are upgraded two both the 700 MHz, with 10% of costs attributed to CAM usage, and the 3.5 GHz technology, with 50% of the expenses attributed to CAM usage, resulting in 41,000 EUR upgrade cost per site. For new sites, only 3.5 GHz sites are deployed, again with 50% of the expenses attributed to CAM, resulting in 75,000 EUR per new site, including backhaul. The total is then normalized to 100 km to determine the necessary investment along the corridor.

In **5G-CARMEN**, the study focused on a business case as it includes the income from CAM services and new 5G subscribers in those segments. Four scenarios are determined for each corridor with two varying parameters, the deployed technology and the type of expected service penetration. The study includes a detailed cost calculation for base station towers, as well as hardware, software, installation costs, and both type of antenna, resulting in a price of 69,500 EUR for a 700 MHz site and 71,200 EUR for 3.7 GHz. Added to this price is the backhaul, which varies with the chosen segment and is equal to the fiber 15-year lease of half the segment length per new site. To consider planned MNO upgrades, the study discounts all the cost components, except for backhaul and new site tower, by 15%. The respective V2N and V2I deployment costs are determined using the cost catalog and the yearly BoQ, between 2021 and 2025 for both optimistic and conservative service penetration which impact the capacity requirements. Further considerations, such as a 5% annual inflation rate and a yearly overhead of 22% of the total

CAPEX and yearly OPEX, are applied. For the income, two sources are determined, the 5G non-V2X subscribers, the annual revenue of new 5G subscribers attracted by the new 5G infrastructure deployed, and the 5G V2X subscribers, charged 0.5 EUR per 100 km per vehicle.

In **5G-MOBIX**, the study focused on a cost case for the two technologies for each deployment year and each corridor. The total costs for the active equipment and the costs of new sites are determined on a per-country basis, meaning for each corridor, different prices have to be applied on each side of the corridors. The average total costs are approximately 96,700 EUR for 700 MHz and 103,000 EUR for 3.5 GHz, and the average upgrade costs are 19,600 EUR for 700 MHz and 25,900 EUR for 3.5 GHz. In each scenario, the simulation yields a total BoQ multiplied with the country-dependent cost catalog.

In the three studies, the price catalogs also include cost estimates for Multi-Access Edge Computing (MEC) deployment, which vary significantly both in terms of costs per MEC and costs per corridor based on different assumptions regarding MEC proximity to the network edge and number of MEC sites per corridor section. RSU costs which are always local and per site along a corridor, range from 4,500 EUR for **5G-MOBIX** and **5G-CARMEN** to 10,000 EUR for **5GCroCo**.

III. THE METASTUDY

A. *Objective of the Metastudy*

In contrast to the independent studies conducted by the ICT-18 projects, the metastudy aimed at comparing the three studies by listing and reflecting on the different approaches taken. It analyzes the studies to provide a comparative overview, identifying gaps and shortcomings of the studies, and comparing their deployment costs. It provides guidance on understanding the methodological differences between the studies and to clarify the resulting differences in costs, with a view towards justifying the observed differences as a result of the specificities of the scenarios and of the deployment strategies.

B. *Gaps Between the Studies*

The metastudy defines three categories of gaps: technical gaps, regulatory plus institutional gaps, and financial gaps.

First, twelve technical gaps are identified, such as the limited accuracy of CAM service penetration estimations. Indeed, although considered in the radio planning, the assumptions on CAM service penetration are inaccurate and many factors add to the uncertainty about the deployment of vehicles with 5G technology and applications. Use cases and actual CAM requirements are also hard to predict as they depend primarily on car manufacturers, on the harmonization of services and on their roadmaps for implementation. These play a significant role in the deployment as they define the necessary throughput, latency, and reliability, directly impacting the RAN layers and density of sites required.

Furthermore, five regulatory and institutional gaps were identified, and they all lead to a similar conclusion, i.e., the need for alignment between national regulatory authorities across Europe. Cross-border policies for data access and control, and different regulatory obligations for MNOs present significant challenges that need to be addressed for a harmonized rollout in Europe.

Finally, seven financial gaps were identified related to revenue models, price evolution, communal benefits and new stakeholders. Big tech companies and logistic companies, for example, are part of the stakeholders that have not been mentioned yet in the deployment studies but could be profiting from, and ideally co-investing in such deployments.

C. *Aggregation of the Financial Results*

Financial results were normalized, and specific scenarios and parameters chosen, to compare the studies. Corridor length plays a significant role, as none of the studies work on similar lengths. From small 3.3 km segments to more than 90 km long corridors, the results were normalized to 100 km. Geographical landscapes and characteristics also impact the existing network and radio planning. Therefore, two corridors and one segment with similarities, such as rivers and suburban areas, are chosen. Additionally, the deployment scenarios selected are low and high densification, as seen in Table 1.

Scenario	5GCroCo	5G-CARMEN	5G-MOBIX
Low Density	3 km ISD scenario	Conservative model	700 MHz in 2023
High Density	1 km ISD scenario	Optimistic model	3.5 GHz in 2023

Table 1: Scenario selection from the three studies for the Low- and High-density scenarios

The resulting costs are compared in Figure 4**Error! Reference source not found.**. **5GCroCo** has the highest average costs for high-density deployment at around 7.4 million EUR, similar to **5G-MOBIX**, which comes at approximately 7.3 million EUR. **5G-CARMEN** is 28 % less expensive at about 5.3 million EUR. For low-density deployment, **5G-MOBIX** has the highest average costs at around 3.1 million EUR while **5G-CARMEN** is 26 % less expensive at about 2.3 million EUR. The differences in these figures can be attributed to varying assumptions for the price catalogues, and different modelling approaches for the RAN planning.

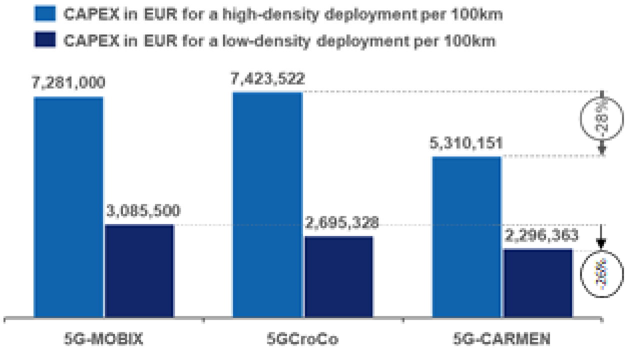

Figure 4: Average deployment costs per 100 km for a low- and high-density deployment of the three deployment studies

IV. CONCLUSIONS

In this paper, the three deployment studiesof the H2020 ICT-18 5G for CAM cross-border corridor projects 5GCroCo, 5G-CARMEN, and 5G-MOBIX have been described and their deployment methodology explained, including their cost calculation models. The three studies took different approaches to estimate a cost delta, which would have to be partially subsidized, to accelerate and sustain the roll-out of 5G for CAM across Europe in border areas where mild market failures would lead to late if any deployment. . The metastudy provided a comparative analysis of the three studies and therefore has been shortly described in this paper. The gaps and shortcomings identified show the uncertainty regarding requirements and use cases, and the necessity for regulatory alignment in Europe for a successful deployment of 5G CAM services. Finally, the aggregated financial results of the three studies show similarities in the total cost calculations and give an estimation of the CAPEX delta per 100 km cross-border corridor for both low and high density deployments. Having such an order of magnitude of investment is essential for potential co-funding sources.

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V. REFERENCES

[1] E. Fischer, D. Hetzer and O. Laaroussi, "5GCroCo Deployment Study," 2022.

[2] D. G. Roger, A. M. Handzel, J. F. Monserrat and e. al., "5G-CARMEN Deployment Study," 2021.

[3] W. Knospe, R. Antun Saakel and A. Sorokin, "5G-MOBIX Deployment Study," 2021.

[4] R. Antun Saakel, T. Scheich, W. Alhallak and A. Nambiar, "5G for CAM: A Deployment Metastudy," 2022.

[5] 5G-MOBIX, "D3.3 Report on the 5G technologies integration and roll-out," 2020.

[6] 5G-MOBIX, "D3.2 Report on vehicle development and adaptation for 5G enabled for CAM use cases," 2020.