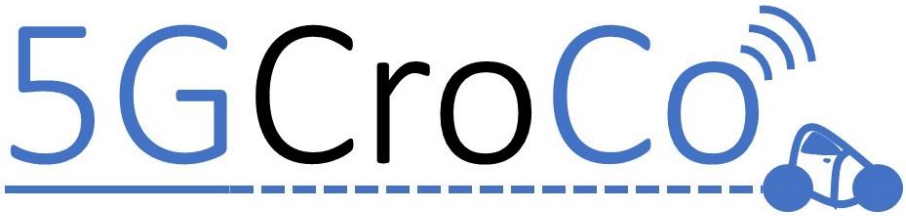

Fifth Generation Cross-Border Control

Detailed deployment planning in view of CEF2 Digital (5G Corridors for Connected and Automated Mobility)

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Abstract

The paper is providing an indicative deployment study of 5G for Connected and Automated Mobility on the extended 5GCroCo corridor, which is based on the Metz-Merzig-Luxembourg corridor of the Digital Testbed France-Germany-Luxembourg. Seamless cross-border 5G coverage and service continuity for Connected and Automated Mobility services based on three exemplary use cases defined and implemented by the ICT-18 project 5GCroCo are the basis of this deployment study. It leverages the project deliverables provided by technical and ecosystem work packages and extrapolates a 5G deployment envisaged as part of a future exploitation activity in the context of private investment by the telecommunications sector, and potential co-investment activities such as the CEF2 Digital and the RRF programme.

5GCroCo provided a cost breakdown per stakeholder and their processes and technology components which materialize the CCAM ecosystem. All assumptions and costs have been mapped to the 5GCroCo cross-border scenarios, as representative examples for CCAM services, based on detailed insights for the road transportation corridor region of France-Germany-Luxembourg.

The study covers all relevant parts of the ecosystem, like spectrum usage, RAN planning and deployment, MEC usage, 5G core adaptation, service development / operation and other infrastructure adaptations.

The calculations are based on real conditions in all three border areas with a solid cost estimation per kilometre of motorway.

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List of Abbreviations and Acronyms

3GPP	Third Generation Partnership Project
5GAA	5G Automotive Association
5G-PPP	5G Private Public Partnership
ACCA	Anticipated Cooperative Collision Avoidance
AD	Automated Driving
ATB	Automobile transmission board
AV	Automated Vehicle
B2B	Business to Business
B2C	Business to Customer
BMC	Business Model Canvas
C-V2X	General term for V2X based on cellular technology
CAD	Connected and Automated Driving
CAPEX	Capital expenses
CBA	Cost Benefit Analysis
CCAM	Cooperative, connected and automated mobility
CEA	Cost – Effectiveness Analysis
CPE	Customer Premises Equipment
eCall	Emergency Call System
eMBB	Enhanced Mobile Broad Band
ETSI	European Telecommunications Standards Institute
Euro NCAP	European New Car Assessment Programme
GDPR	General Data Protection Regulation
GHG	Green House Gas
HAD	Highly Automated Driving
HGV	Heavy Good Vehicles
ICT	Information and Communications Technology
IaaS	Infrastructure as a service
IEEE	Institute of Electrical and Electronics Engineer
IETF	Internet Engineering Task Force
IR	Internal Report
ITS	Intelligent Transportation Systems
k	Thousand (financial)
KPI	Key Performance Indicator
LTE	Long Term Evolution
MAMCA	Multi Actor Multi Criteria Analysis
MEC	Mobile Edge Computing
MM	Million (financial)
MNO	Mobile Network Operator
MSL	Minimum Service Levels
MWC	Mobile World Congress
NHTSA	National Highway Traffic Safety Administration
OEM	Original Equipment Manufacturers
OPEX	Operational expenses
QoS	Quality of Service
RSU	Road-Side Unit
SaaS	Software as a Service
SLA	Service Level Agreement
SME	Small and Medium-sized Enterprises
TCO	Total Cost of Ownership
ToD	Tele-operated Driving
UC	Use Case
V2I	Vehicle-to-Infrastructure (communication)

V2N	Vehicle-to-Network (communication)
V2V	Vehicle-to-Vehicle (communication)
V2X	Vehicle-to-Anything (communication)
VCoC	Vehicle Control Center
WG	Working Group
WP	Work Package
xaaS	Anything as a Service

1 Introduction

The validation of relevant 5GCroCo business potentials is an important part of the project activities. The combination of technical innovation with new ideas for the ecosystem will support a wide range of new stable use cases for CCAM.

The selected use cases from 5GCroCo (Tele-operated Driving, HD Mapping, Anticipated Cooperative Collision Avoidance) are perfect examples to demonstrate the power of the different partners in the project (vehicle OEMs, automotive suppliers, mobile network operators, road operators/authorities, ICT providers and academia) for developing the CCAM ecosystem.

- In the cross-project meeting of 13/02/2020 in Brussels the Commission services agreed with the leaders of the 3 projects 5G-CARMEN, 5G-CroCo, 5G-Mobix to launch deployment studies for each project to enable the exploitation of each project in view of deployment under CEF2 Digital.

- The 5G-PPP Automotive WG will set up an expert group to define common requirements for these studies.

- The network planning, e.g. grid density, capacities, coverage will depend on the concrete service requirements. These service requirements are not binding and remain illustrative.

- The Commission services and the projects agreed that the projects jointly define a number of scenarios for categories of use cases leading to different service requirements (e.g. for data rate per car) in a forward looking way. By default, the service categories of the Commission study (WIK-IDATE) will be used. The expert group is free to adjust or complement the categories and service requirements. The scenarios should cover a baseline scenario (5G deployment without stricter CAM requirements) and a number or CAM scenarios (more basic and advanced CAM requirements).

1.1 Objective of the Document

The objective of this document is to set the baseline for the deployment approach of both the network and the MEC infrastructure as well as the resulting cost required to support 5G for CAM services based on 5GCroCo use cases along the cross-border corridor between France, Germany and Luxembourg.

2 Basic Information Sources and Implications

2.1 Basic Assumptions

The calculations are be based on standard configurations of the networks of the MNOs involved in 5GCroCo. This means:

- the upgrade of existing and setup of new base stations (geographical location, frequency spectrum) follows general principles common across MNOs
- MEC/edge computing facilities are considered in one location per MNO serving the respective national section of the corridor

The study focused on the overall costs of deployment without detailed description of who pays what and without detailed money flows for the different infrastructure and service elements under consideration.

2.2 Relevant Stake Holders & Authorities for CCAM Deployments

5GCroCo had identified the key stakeholders in both Deliverables D5.1 and D5.2. The content is duplicated in this report with a focus (see the ones highlighted in green) on the actors actively involved in the deployment.

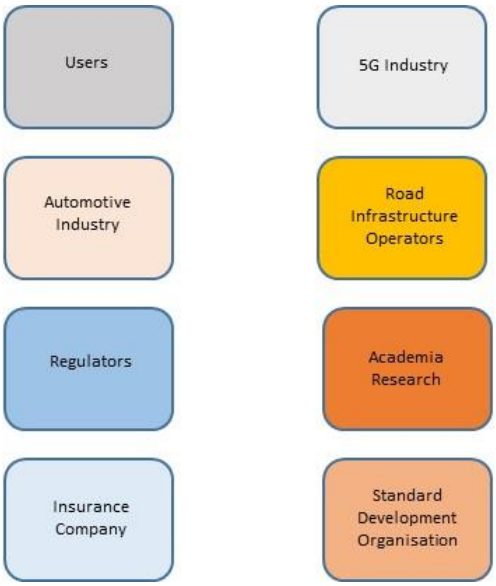

Figure 2.1: Main Stakeholders Categories

In the envisioned 5GCroCo ecosystem, the following stakeholders will take a structural role:

The Automotive industry players, including vehicle manufacturers and Tier 1/OEM providers will be in charge, along with other partners in the ecosystem, of embedding both intelligence and communication components in vehicles and in dedicated infrastructures (e.g. Mobile Edge Cloud). Vehicles that are smoothly collaborating with other vehicles or devices, will enhance awareness and problem-solving functions for safety, automation and traffic efficiency under very strict time/space performance requirements. In the early days they will be the drivers of novel 5G empowered applications, especially related to the safety of the vehicles. The existence and growth of the 5G infrastructure (through eMBB for example) will motivate development in the application market and favour the development of additional services.

5G Industry: telecom infrastructure providers and manufacturers will develop the infrastructure to meet the 5G requirements, as defined by the regulation bodies. Telecom industries including operators, vendors and telecom manufacturers will need to collaborate and align their developments to the automotive industry and other sector demands. In this context, the manufacturers need to have an influence on early harmonization and system specifications, in order to create the corresponding markets and address them with competitive products at the appropriate time. This is achieved today thanks to their presence in regulation bodies.

Industrial and Telco equipment vendors recognize the need to disassemble vertically integrated technologies and to support success stories to validate the KPIs that stand their technological assumptions. The generation and ownership of intellectual property is essential to ensure profitability of the manufacturer's business, and at the same time, to provide incentives for competition through open platforms or cross-license agreements on fair and reasonable terms.

Mobile network operators recognize the potential that the automotive sector offers to expand their total service offering, thereby increasing their market size and growth rate. The need to enhance existing infrastructure or functions has also been identified in order to achieve V2X Services' QoS metrics. Yet, the risk of a single infrastructure technology will polarize the stakeholder's opinion, enabling alternative ecosystems to further develop (e.g., IEEE802.11p vs C-V2X).

Small to medium sized enterprises (SME) in the sector will create strong R&D links with both academia and leading industrial entities, which helps them within the value chain. The SMEs, at the same time provide, an innovative character with necessary edge competence, services and products. In the figure 3.3. MNO is included in the 5G industry.

Road infrastructure operators: Road Traffic Authorities (RTA) are mainly responsible for operating road infrastructure; they can be public or private entities and usually manage a large infrastructure for long periods of time. RTA's take into consideration the necessary requirements to address the most challenging scenarios such as the cross-border corridor. RTA will need to be convinced by Telecom industries to adopt 5G technologies with the automotive industry playing a fundamental role. Without a clear alignment in the ecosystem of Regulator-RTA-Vehicle Manufacturer-Telecom industry, the expected growth of the vehicular connectivity will not develop.

Standardization bodies: V2X standards are being developed at different bodies; e.g., the ETSI, 3GPP, IEEE, and others are developing core specifications to regulate the communication of vehicles at different layers and sometimes proposing competing technologies. The role of standardization bodies is crucial to ensure that the investment of large companies is taking the right directions while also allowing for interoperability among different vendors. Standardization bodies must, therefore, define clear pictures of the technologies and align, when possible, to avoid non-coexisting, non-compatible and fragmented markets.

Academia and research are interested in building on and further developing existing software skills and research strength in V2X systems. The gained expertise will permeate into the daily university life and will be disseminated within academic education as preparation for future European ITS and 5G experts.

Insurance companies: among other sectorial institutions related to risk assessment, updates in the vehicular/transport infrastructure and the early focus of 5G technologies to provide extended security services in vehicles are of utmost relevance to insurance companies' business models. To this end, it is expected that 5G enabling extended services and tailored audits will improve risk assessment in such companies.

User: are the consumer of dedicated services, in different relation B2C, B2B or B2B2C. This includes "mobility service providers and logistics" (MSP) fleet operators, freight transport services, etc.

Stakeholder category	Subtype	Description	Symbol
Users	Drivers	Person managing the vehicle.	D
	Passengers	E.g., passengers of public transportation or taxis.	P
	Vehicle Owners	E.g., Rental Car SME (Small and Medium Enterprise).	VO
	Mobility Service Provider	Logistic & Mobility Service Provider	MSP
Automotive Industry	Car OEMs	Car manufacturers.	OEM
	Tier 1 Supplier	On-Board Unit (OBU) manufacturer.	1TS

Stakeholder category	Subtype	Description	Symbol
	HD Map provider	Provides HD maps in streaming.	MP
	Map provider	Provides updated maps in real-time, e.g. Open Street maps.	MP
	Tele-operated service providers	Enables automated vehicles to be tele-operated in critical situations.	TO
	Vehicle Control Center	New business opportunity. For safety and security purposes, in private or rental fleets. For example, it could be an SME providing this service.	VCoC
5G Industry	MEC providers	Provide the virtualization of edge computing facilities close to the Telecom operator infrastructure.	MEC
	Mobile Network Operators & Infrastructure Provider	The provider of the ICT infrastructure or network services. Can be cellular but also other technologies can be considered. There can be neutral operators leasing the infrastructure.	MNO
	Cloud provider, backend system host	Provide computing infrastructure. Coordination with MNOs will be required in order to guarantee QoS.	CL
Regulators & Law-makers	Transport and road authorities	Authorities should regulate the use of 5G in the vehicular space.	TRA
	Telecom and spectrum regulators	Need to drive the technology growth by providing the needed regulations to support the requirements of the technology.	TSR
Road Infrastructure Operators	Road operators	Owners/managers of the infrastructure. Play a critical role as they must deploy and operate the technology in the infrastructure.	RIO

Stakeholder category	Subtype	Description	Symbol
Standard Developing Organizations	-	Should drive the technology to be more secure, more efficient and enable market defragmentation.	SDO
Academia and Research	-	Should research novel approaches and techniques to improve the technology. Should also be the tool to disseminate and train new professionals in the sector. Can also act as neutral players when decisions must be taken based on technical and societal criteria, and not only commercial interest.	AR
Insurance companies	-	Should be in touch with regulation authorities and the manufacturing sectors. Should be vigilant to the regulations and technical possibilities.	IC

3 Service Requirements in the Corridors

Detailed definition of service requirements along the corridor over time based on the common use case categories are identified by the expert group. This lead to the planning for deployed technologies and expected penetrations/densities for vehicles and cellular/road infrastructure, respectively, as well as classes of service for C-ITS and beyond. The service requirements are mirrored on the selected use cases in 5GCroCo.

ToD (Tele-operated Driving)

ToD has very demanding requirements with respect to functional safety as errors generated by the automated vehicle system might cause injuries to passengers and other road users. Today's concepts for functional safety, like the one specified mainly in the ISO26262 standard, are not considering the case that vital parts of the system are developed not considering the rules specified in the ISO26262. To keep the possibility to provide functional safe ToD, concepts have to be developed that allow the existence of system elements that are not developed according to ISO26262 while still keeping functional safety under full control (this could be but is not limited to a safe control of the respective system elements). A functional safe and reliable control of the communication is one of the key needs. For this, 5G concepts like predictive Quality of Service (pQoS) are indispensable. These requirements, especially in cross-border environments, can only be covered with extended 5G functions (e.g. MEC, local breakout, make-before-break) to support interruption free services.

In addition, high quality of the information provided to the tele-operator, e.g., from cameras in the vehicle is necessary to allow safe tele-operation. This means that camera information together with data from other sensors must be provided to the tele-operator with short latency, high quality and high frame rates. This is only possible with new 5G uplink capacity, latency and reliability capabilities.

HD Mapping

Seamless availability of the autonomous and automated driving functionality is key for acceptance of such functionality. This is especially true in a fully autonomously driving car, where outages of the functionality would cause passengers not capable to drive themselves to be stuck. To get such seamless availability, it is very important to have accurate HD maps, especially the dynamic, fast changing parts, available any time and everywhere.

Such an order of magnitude of availability cannot be achieved with today's communication networks that are lacking full area coverage and a reliable prediction of the availability of connectivity and with long outages (up to 1 min) while crossing borders. For HD maps a function like predictive Quality of Service that is currently discussed for 5G is essential to allow the availability always and everywhere.

In future traffic scenarios there might be many autonomous vehicles active in quite small areas meaning that the HD map updates must be provided for many vehicles at once. This leads to new

requirements for high capacity or novel data distribution capabilities in downlink (e.g. efficient multicast) which are not fully available yet in 4G and below. Furthermore, the quality of the HD maps is highly correlated with the number of sensing vehicles that participate in the HD map generation. This means that, even though the amount of data for individual cars might be small enough to be covered by 4G Networks, the number of contributing communication units likely cause data traffic that goes beyond the capacity of today's networks.

HD map content hosting and receiving updates in MEC assures data is kept local where it is needed and enables rapid cycles of uploading detected HD map changes and distributing this change to vehicles in proximity. MEC hosting enables the MNO to have control over the full end-to-end path of the communication, which is not true when only relying on hosting in the public Internet. This MEC function must also be provided in handover situations from one MNO to another.

ACCA (Anticipated Cooperative Collision Avoidance)

The ACCA use case also require 5G in cross-border situations for the following reasons:

- Need of high and guaranteed reliability of the connectivity between the vehicle and the off-board, MEC-hosted Geoservice,
- Need of low and guaranteed latency of the connectivity between the vehicle and the off-board MEC-hosted Geoservice,
- Need of backend interconnection between the Traffic Management System hosted on the public Internet and the MEC-hosted Geoservice.

It shall be noted that the ACCA use cases will not stress the 5G capability of high throughput per vehicle.

To provide useful information, the MEC service shall demonstrate that it can:

- provide trustable information by running fusion of hazard information coming from multiple sources (vehicles and backends),
- provide information with a low latency,
- aggregate information from multiple sources (vehicles and backends) and of different nature, to deliver contextual information, which can be more easily used by ADAS systems.

These requirements are mandatory to be used in ADAS systems, but they are not sufficient: safety and cybersecurity concerns shall also be addressed before V2X information can directly influence sensors or actuators. In ACCA use case, an Geoservice is instantiated and hosted in a MEC host covering a given geographical area. Each instantiation of the Geoservice collects the local road perception of the vehicles and/or the status and position of vehicles under its coverage and builds a consolidated view of the local road events. In the meantime, any vehicle can request the Geoservice to send back information about events of interest in a given Region of Interest (ROI). The range of the ROI usually depends on the vehicle speed.

4 Network Planning in Selected Corridors

A full network planning (map with exact “illustrative” locations of all sites and coverage) along the corridor concerned for the different scenarios. This is enabling the launch of an early CEF deployment project based on this concrete draft planning. However, site locations might remain hypothetical for the purpose of the study and might be modified in the final (pre-)deployment project.

4.1 Network & Infrastructure Deployment

The main objectives followed in the radio network and the MEC infrastructure deployment in our corridors are the throughput, the resiliency, as well as the coverage. The main hypotheses taken are listed below.

The corridors components cross urban as rural area. For simplification purpose, we haven’t made any distinction.

In every existing site there will be 3.x GHz as well as 700MHz antennas (or low medium bands with re-farming). We have not considered possible new sites deployed for mass market and which could be used for CCAM by sharing CCAM infrastructure with mass market one.

All sites of the different MNOs are merged (passive sharing). We take the assumption that the towers are shared with the stakeholder which will deploy the infrastructure component for CCAM.

We have taken 3 hypotheses in terms of densification for inter 3.x GHz sites:

- Basic low/medium band 5G coverage
    - We are assuming that no supplementary sites (mast) are deployed (or only few). Low/medium band will ensure basic connectivity likely in all sections of the road.
- Higher band coverage 3.x GHz : 1 site per 3 Km
    - Should be sufficient to cover the road within a limited area and limited coverage
    - The 3 kilometres distance between sites has been chosen based on the radio planning exercise done for each corridor.
- High throughput coverage 3.x GHz : 1 site per Km
    - 1 site per kilometre choice is based on WP6 assumption and using the scenarios developed by 3GPP and captured in TR 38.913 [1]with the base station (BS) being deployed directly along the road or in closed proximity, and with roughly constant distance. In other words, every BS serves an identical section of the road. The

inter-site distance used for 3.x GHz deployments is 500 m in the urban scenario and 1000 m in the rural and highway scenarios. In our project, for our corridor cases, mainly highways have been chosen.

4.2 Planning Aspects

Rough outline of deployment project with time phases are described in the following picture (finalisation of network planning, permit requests, preparation of works, works, testing, service launch)

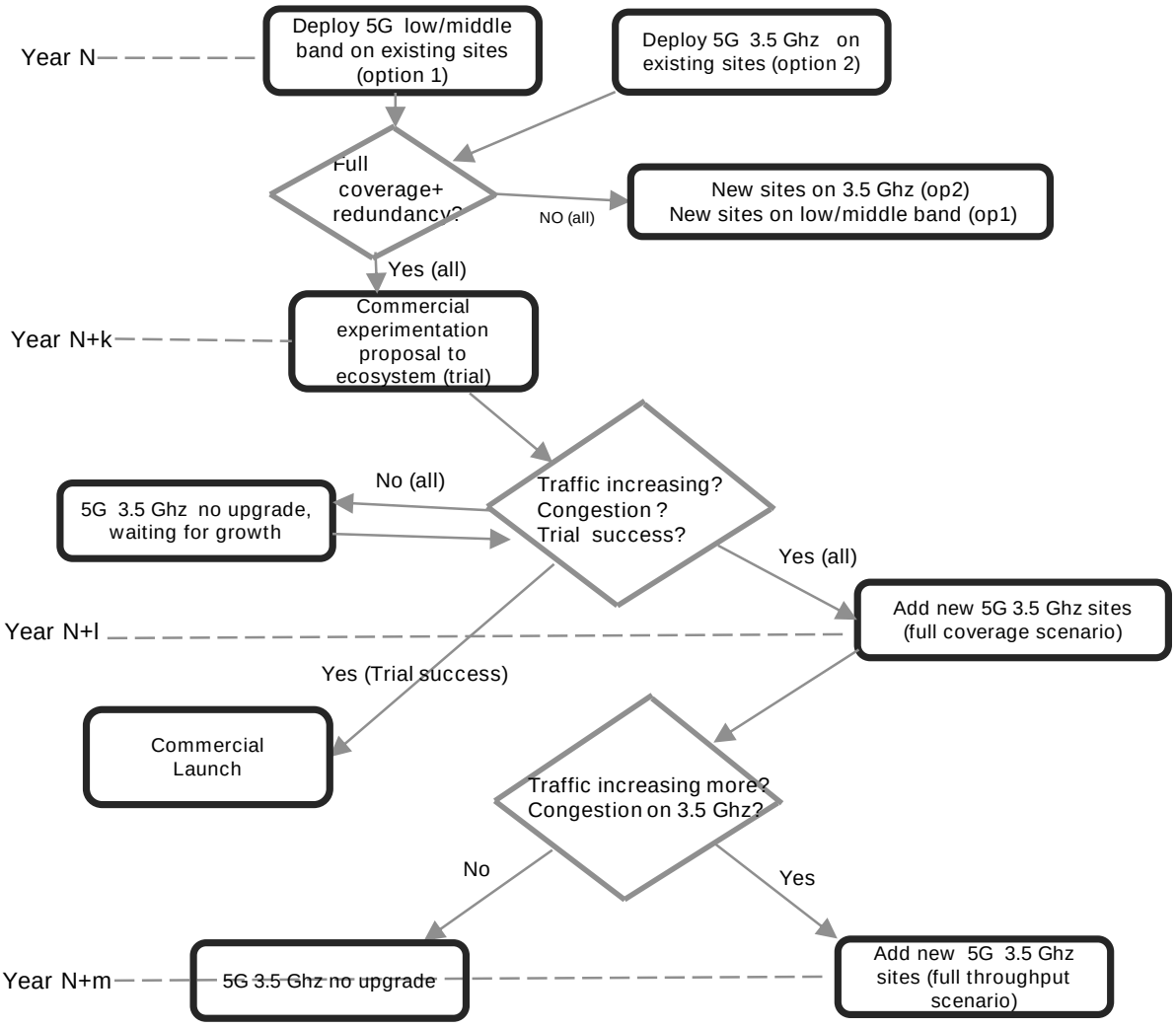

Figure 4-1: Example of Planning Process

Rollout of each phase will depend on the service penetration which will trigger following phase of deployment. Rollout will also depend on agreement between cooperative MNO(s) inside each country for network sharing conditions. Figure 4-1, gives an example of possible planning process for 5G deployment for CCAM along corridor. The assumption that the deployment will begin on the basis of the existing 5G infrastructure at year N was made. This existing infrastructure will be deployed by several MNO inside one country. Commercial agreements should exist between them to reduce cost for deployment as well as ensuring resiliency, in particular, resilience against failure should be provided by increased coverage density, by using alternative spectrum for fall-back connectivity, possibly in a degraded manner, or by using the network of a 3rd party MNO.

Two options exist for 5G deployment: using a low/middle band with/without refarming or using the 3.x GHz band. SA deployment should be preferred. Year N will be the beginning of deployment of 5G deployment for CCAM. A strong requirement should be to obtain full coverage for deployment along corridor, and a mechanism ensuring redundancy and resiliency. The effort will depend on the existing 5G deployment for mass market for entertainment service, infotainments services, etc. in B2B2C, or in B2C mode. When full coverage and redundancy is obtained, trial could begin. For that purpose, an European trans-frontier consortium could propose to external partners or internally to launch trials, or pre-commercial launches. As there is a risk that this phase will not be a success, the effort for first deployment will be likely limited to cross-border sections.

If the trial is a success at year N+l, traffic will probably increase, with network densification at 3.x GHz for instance depending on the type of service involved. This will lead to the full coverage scenario at 3.x GHz, which could be realized after or before official commercial launch of some CCAM services. After that, as explained before, deployment could rely on low/middle band ensuring more easily full coverage. At the end of the day, at year N+M full throughput scenario will be realized by applying 3.x GHz site densification with 1 site per kilometre in order to support for example significant ToD deployment, and/or cooperative/perception with high-definition video or sensor sharing.

Depending on the country, different options could exist in practice. Several phases for funding should exist. In the given example, 3 phases exist: pre-deployment, adjusted deployment and full deployment.

4.3 France

In the following section the different corridor components in the scope of 5GCroco inside France side, as well as assumptions for the study are described.

4.3.1 Introduction

There are three corridor components to be taken into account in the deployment inside France (see Figure 4-2, Figure 4-3, Figure 4-4).

In these simulations, we don't take into account future sites deployed for 5G independently of CCAM services. Sites further than 1 Km from highway are not considered. For simplification purposes, the metric is the distance following the road.

Some radio budget simulation shows that throughput for UL with high throughput 3.X scenario should be comprise between 70-90 Mbs at the edge of the cells if the cells are not loaded. Meanwhile throughput for UL in the 3.X coverage scenario should be 8 Mbs at the edge that should be enough for ToD service with degraded features (reducing speed of vehicles, reducing quality of video, etc). These simulations have been performed on the basis of omni antennas installed on the roof of car in order to improve radio link budgets.

In the case of a real deployment, a compromise should be set between the two scenarios depending of the number of vehicles requiring the ToD service in a given cell.

In the case of low/medium band 5G coverage scenario the use of 4G sites should be sufficient to ensure basic connectivity all along the road. Indeed, the maximum inter site distance of existing 4G sites is approximatively 6-7 km ensuring relatively good coverage, approximatively 15 Mbs DL, 10 Mbs UL at the cell edge with low traffic load.

4.3.2 Corridor Sections

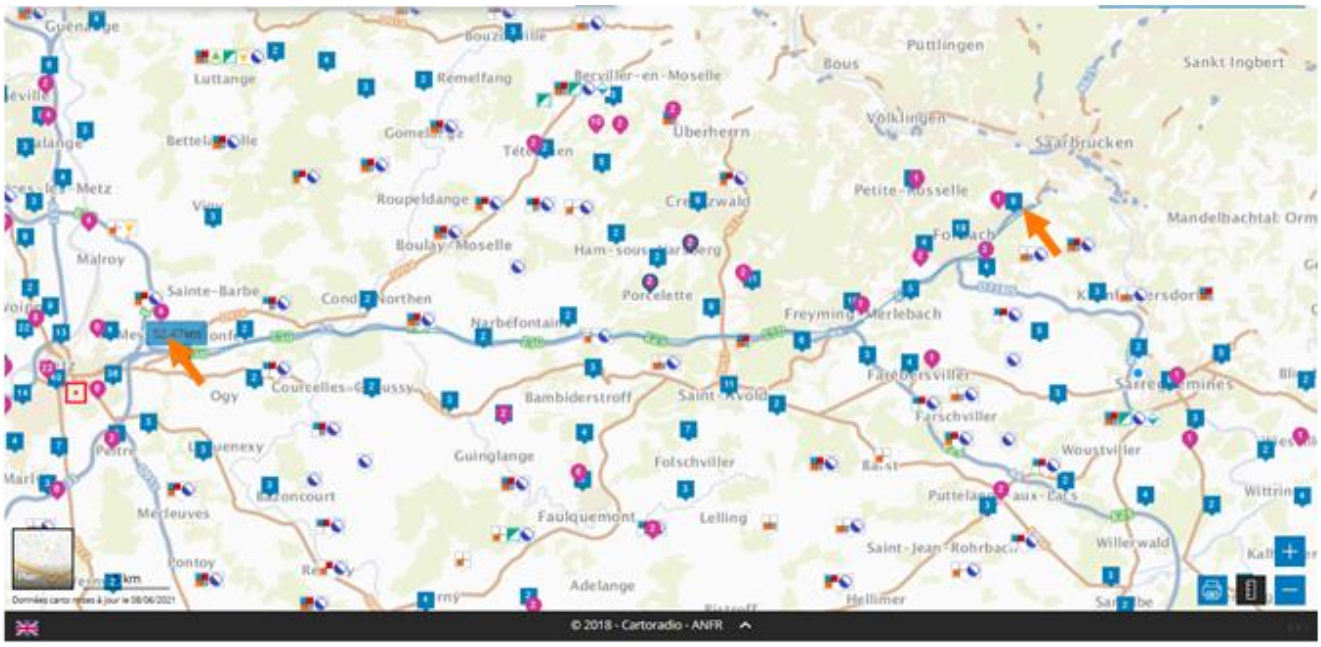

Figure 4-2: Forbach to Metz (*from cartoradio, ANFR : French National frequencies agencies***)**

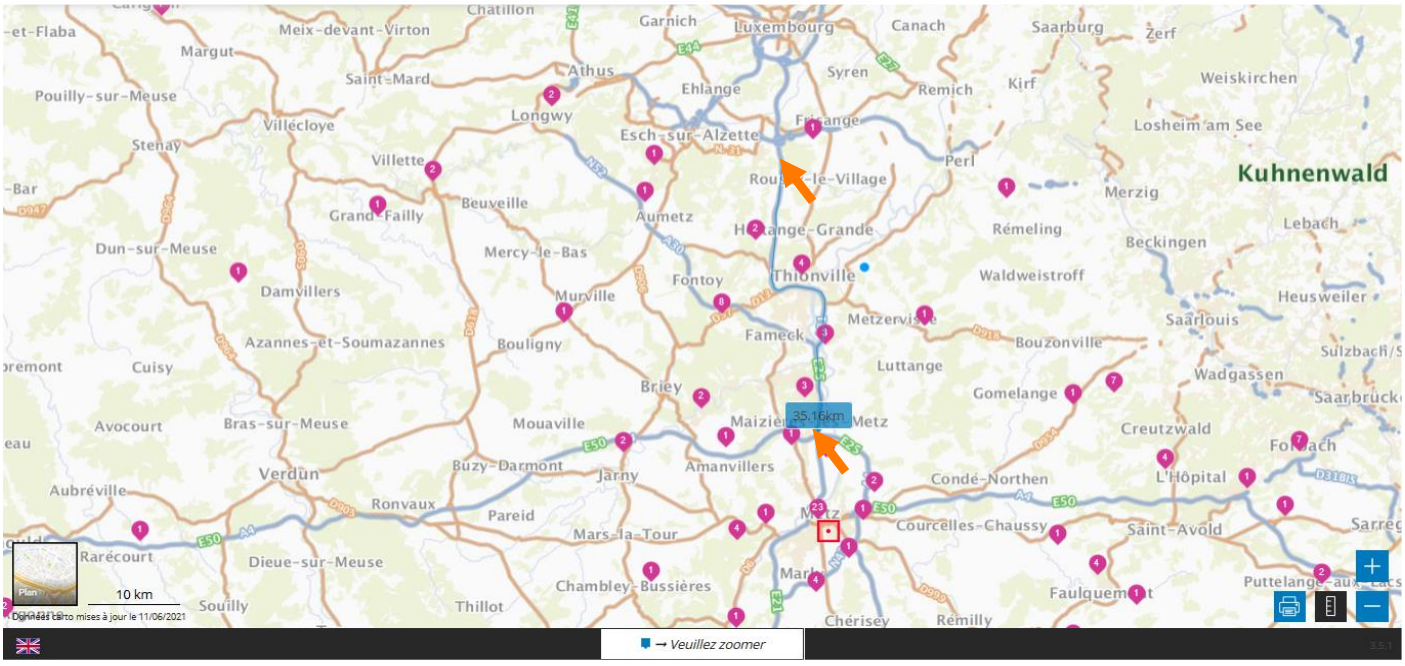

Figure 4-3: Luxembourg to Metz (from cartoradio ANFR)

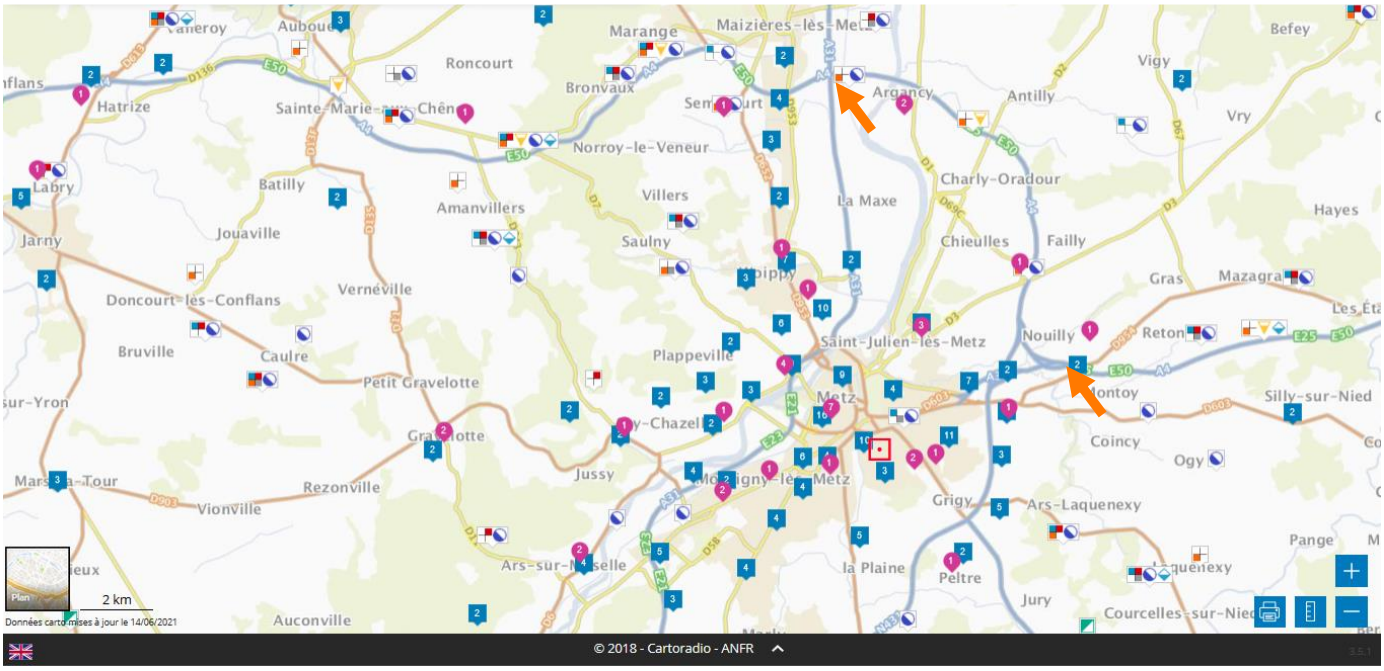

Figure 4-4: Suburb Metz (ring road), from cartoradio, ANFR.

Figure 4-5: Focus on Forbach to Metz corridor, rural area, example of possible deployment in real condition, from cartoradio, ANFR

4.3.3 Results

Table 4-1: Results for 3.X high throughput scenario

All corridors components		
Number of existing sites	38	
Densification (1 site per)	1	km
Total Number of new site	73	

Table 4-2: Results for 3.X coverage scenario

All corridors components		
Number of existing sites	38	
Densification (1 site for)	3	km
Total Number of new sites	14	

The results shows that there is a strong increase of number of new sites when densification increase. Densification scenario will then be very costly. Thus there is a real compromise to find between throughput and cost. Study has shown that, if all the sites (existing, or new one) are placed in an optimal way without

taking into account the real location of existing sites, number of new sites will be 4 instead of 14 if we take into account the real placement of existing sites.

The difference between optimal placement for the throughput scenario between optimal placement and sub-optimal is reduced (69, instead of 73).

If we perform simulation with intersite of 4 Km, only 7 new sites are needed (1 with optimal placement).

Table 4-3: Basic low/medium band 5G coverage scenario

All corridors components		
Number of existing sites	38	
Densification (1 site for)	6	km
Total Number of new sites	1	

Finally, the table Figure 4-3 shows the number of new sites with the low/medium band coverage scenario, this number is reduced to one (0 in theory).

4.4 Germany

4.4.1 Introduction

The German section of the 5GCroCo corridor stretches over 78km of motorways between the French-German border at Forbach/Saarbrücken and the German-Luxembourgian border at Perl/Schengen. The motorways are running through urban environments such as the cities of Saarbrücken, Saarlouis and Merzig, and rural environments with sparsely populates areas featuring only few towns and villages in proximity of the corridor. Moreover, a corridor section of 8km length and situated east of the German-Luxembourgian border is running parallel and in close proximity to the French-German border.

Coverage and service requirements are identical with the ones applying to France and Luxembourg. Accordingly, only existing sites within a distance of 1 Km are considered for the deployment, plus new sites where required in the respective deployment phase.

4.4.2 Corridor Sections

The following figures show the 5G site planning for the German 5GCroCo corridor section stretching from the border with Luxembourg at Perl/Schengen to the border with France at Saarbrücken/Forbach. The selection of sites (existing/new) is based on the database and map of all mobile network sites maintained and issued by the German regulatory authority BNetzA (Bundesnetzagentur) for transparency on radio sites and electromagnetic fields [reference: https://www.bundesnetzagentur.de/DE/Vportal/TK/Funktechnik/EMF/start.html].

Figure 4-6: Corridor Planning from Schengen/Perl to Schwemlingen

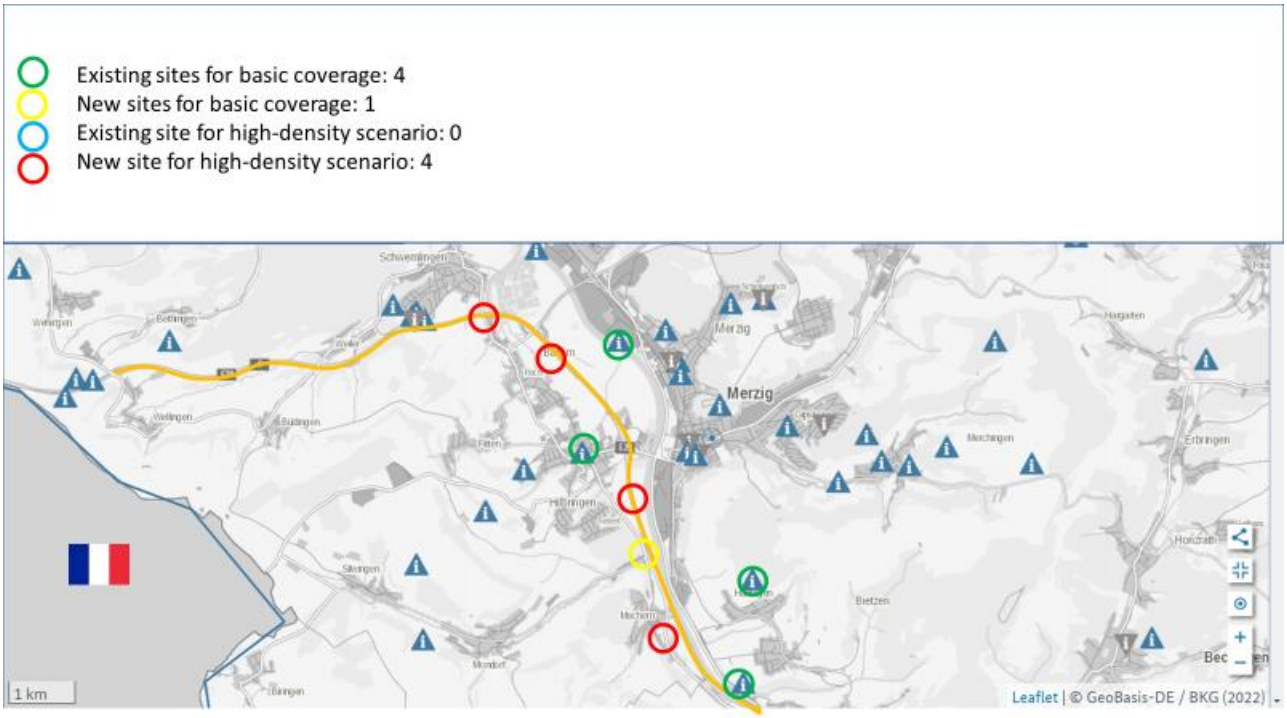

Figure 4-7: Corridor Section from Schwemlingen to Fremersdorf (District of Merzig)

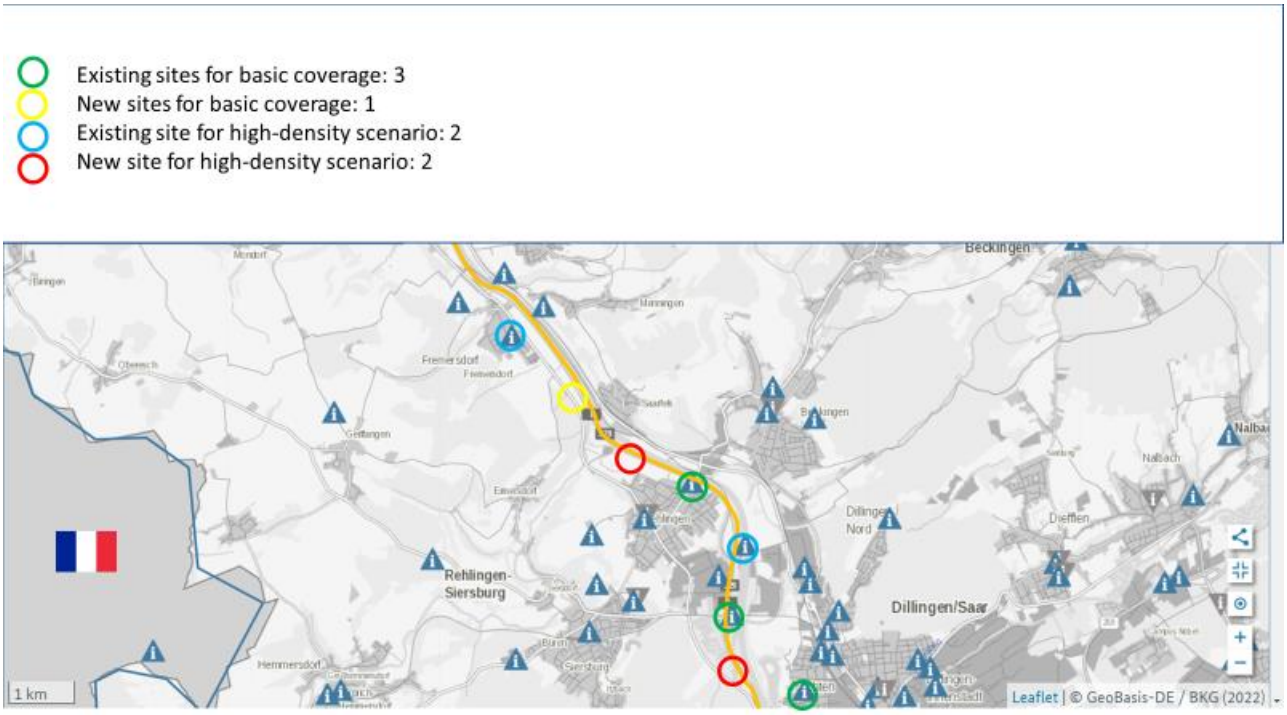

Figure 4-8: Corridor section from Fremersdorf to Dillingen/Saar

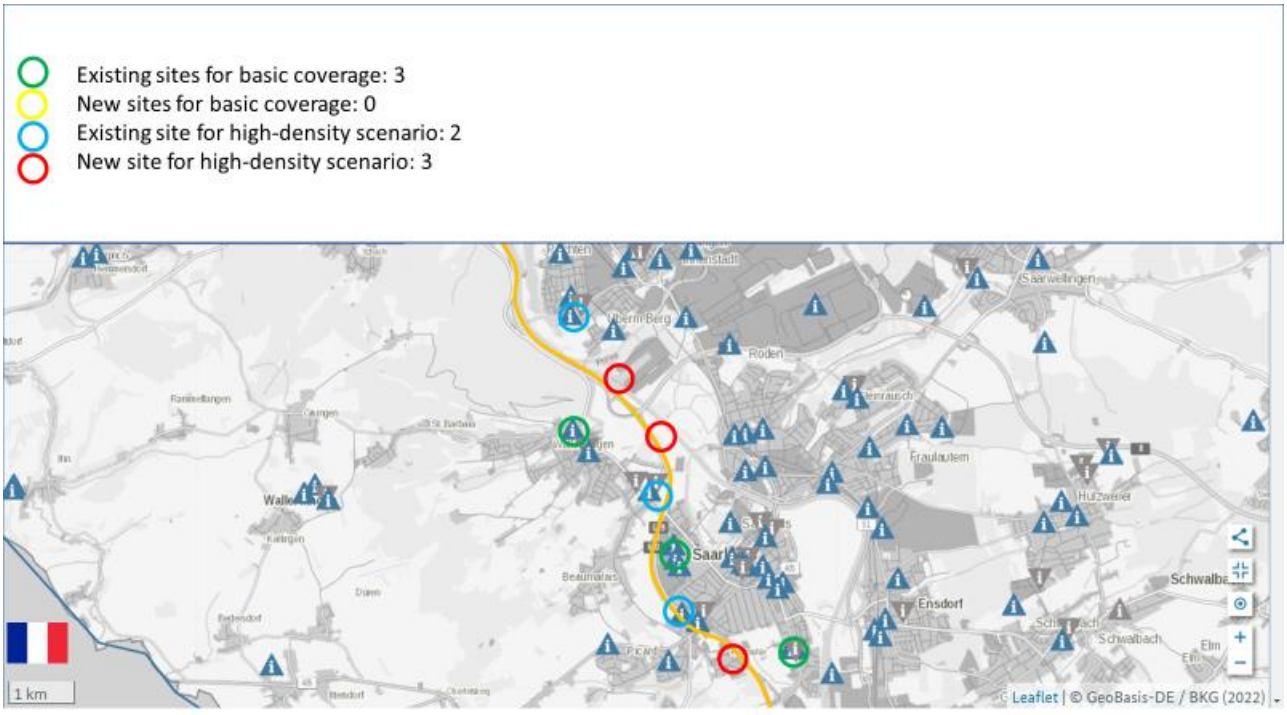

Figure 4-9: Corridor section from Dillingen/Saar to Saarlouis

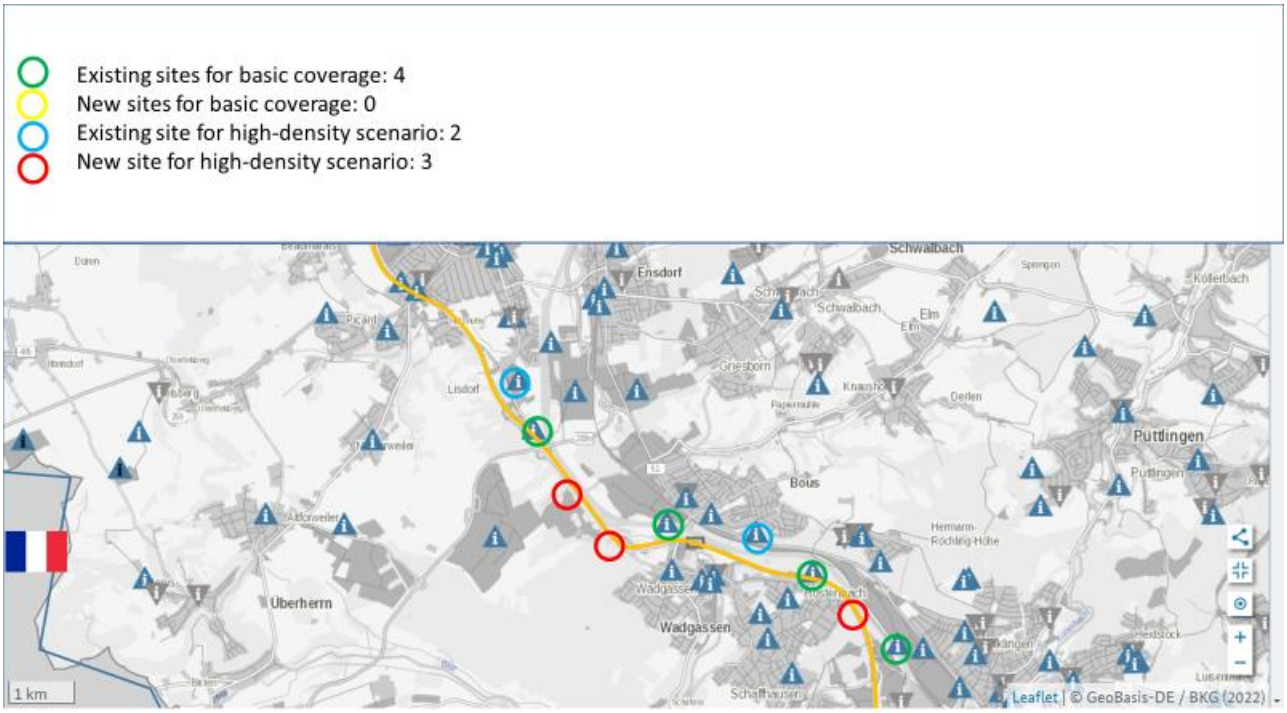

Figure 4-10: Corridor Section from Saarlouis to Völklingen

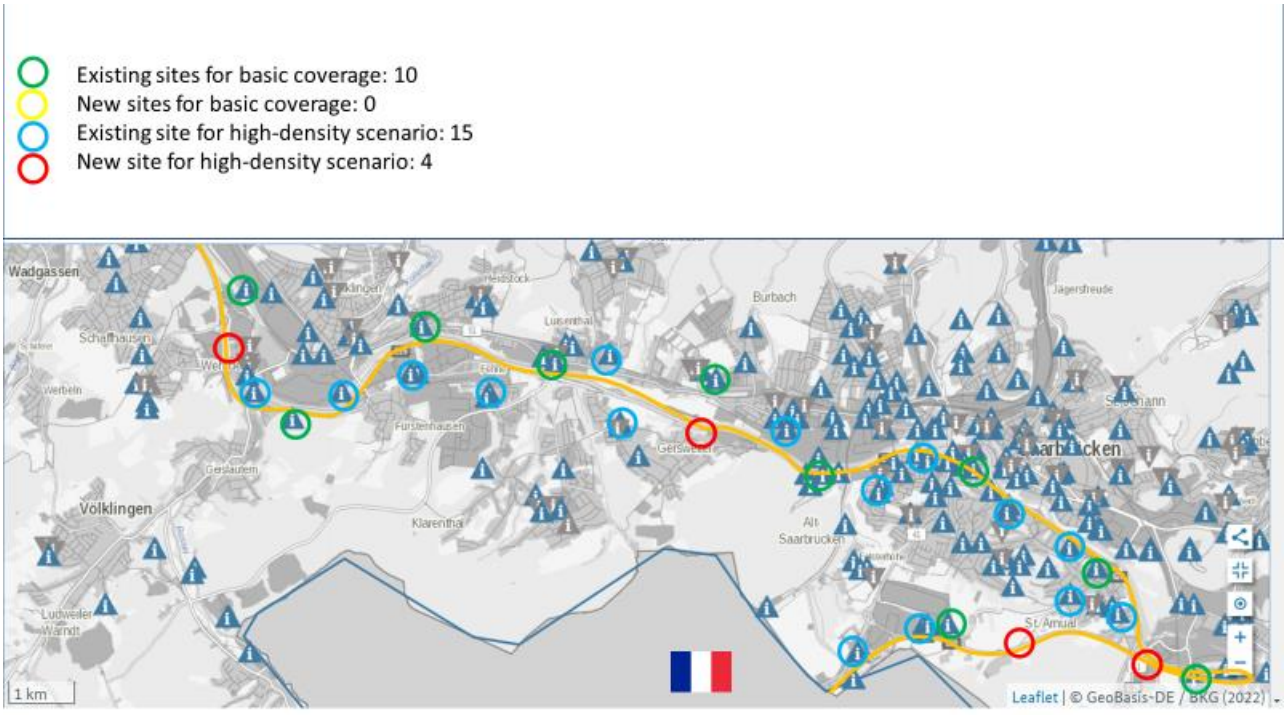

Figure 4-11: Corridor Section from Völklingen to Saarbrücken/Forbach

Independent of the components needed for providing 5G coverage along the German section of the corridor, a set of systems with core network components including a packet gateway with APN and a MEC cluster is required to support CCAM services. As part of a georedundancy approach, in case of outages of the closest core network components set, the functionally same core network components set located next could take over to cover the period until restoration of normal operations.

4.4.3 Results

All coverage / capacity scenarios for 5G for CCAM require adding new sites on top of upgrading existing sites used for 2G/3G/4G.

The scenario “coverage only” requires the following deployment:

Coverage only mode	3 Km inter-site distance
Number of existing sites	32
Number of new sites	4

The scenario “high throughput” requires a significant deployment of new sites on top of the basic “coverage only” scenario:

High throughput mode	1km inter-site distance
Number of existing sites	22 (in addition to the 32 existing sites of the coverage only scenario), total 54
Number of new sites	25 (in addition to the 4 new sites of the coverage only scenario), total 29

4.5 Luxembourg

In the following section the different corridor components identified for 5GCroCo inside Luxembourg are detailed and analysed for the chosen scenarios and the underlying assumptions.

4.5.1 Introduction

The corridor considered for the deployment inside Luxembourg has a length of 24,5 Km.

Due to the good coverage already existing in Luxembourg, no extra sites are required to assure a 5G “coverage only” scenario in the corridor. The 9 POST Luxembourg sites shown with a green circle in figures X have been selected. Other available sites (red dots on the map) from POST or from other operators could also be added if deeper coverage is requested in the future.

In the case of a real deployment, depending on the evolution of the number of cars equipped with CCAM in future years, plus the development of actual road traffic and related CCAM services

usage mixed with other 5G services, additional sites will have to be upgraded or added (“high throughput” scenario).

4.5.2 Corridor Sections

The corridor in Luxembourg between the borders to France and to Germany has only one section which is illustrated below.

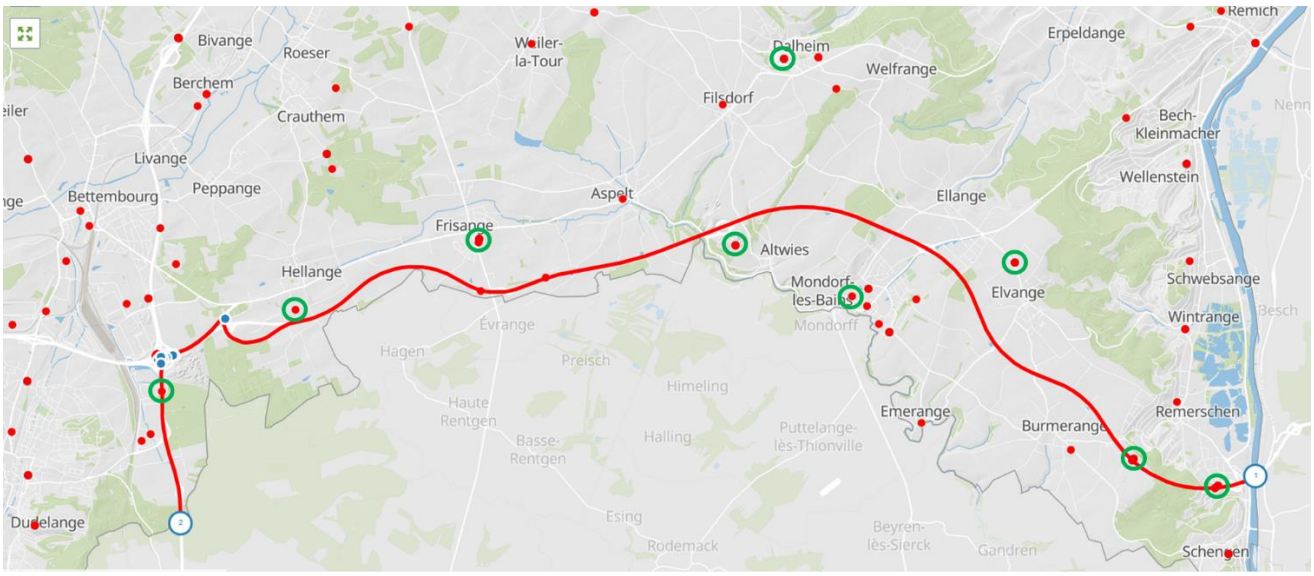

Figure 4-12: Luxembourg Corridor from Schengen to Dudelange

4.5.3 Results

To be able to support the CCAM use cases in a “coverage only” scenario, 9 existing POST Luxembourg sites are necessary. This is in line with the assumptions for a later densification with 3.x GHz sites, starting with 1 site per 3 Km.

Table 4-4: Results for 3.X “high throughput” scenario

Coverage only mode	3 Km inter-site distance
Number of existing sites	9
Number of new sites	0

No extra sites are required for the time being. The associated coverage map is shown in Figure 4-13 below.

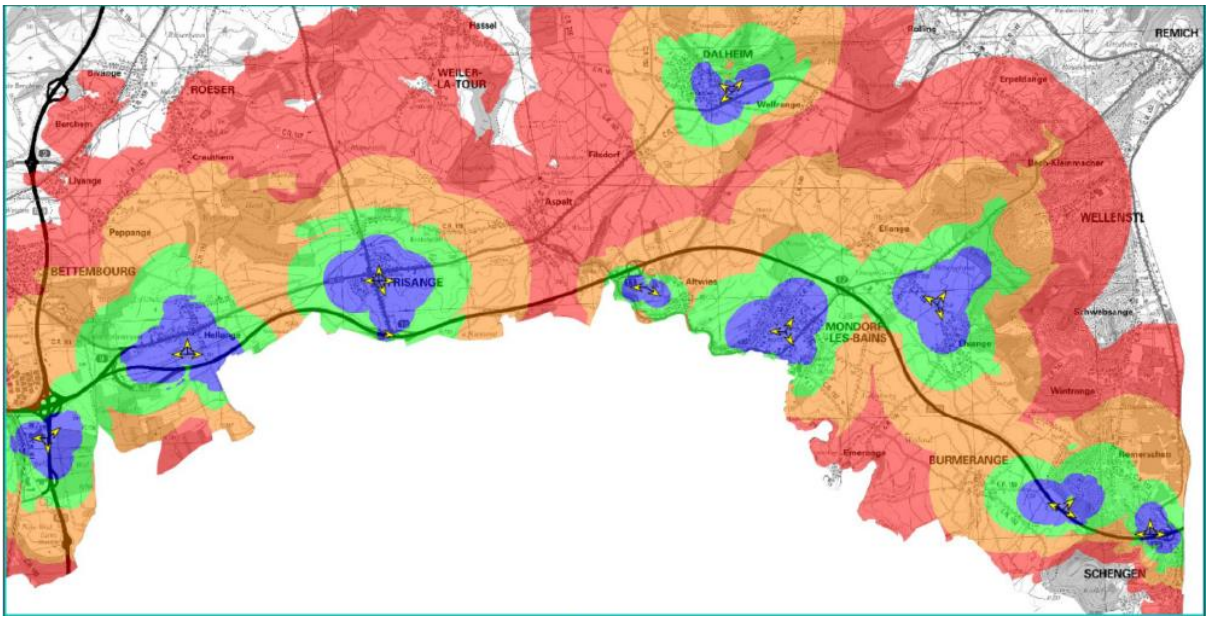

Figure 4-13: Luxembourg Corridor Calculated for "coverage only" Scenario

24 sites will be required for "high throughput" scenario with adequate coverage and capacity. The assumption is that 4 of the existing sites can be upgraded and that 20 new sites are required.

Table 4-5: Results for 3.X "high throughput" scenario

High throughput mode	1 Km inter-site distance
Number of existing sites	4
Number of new sites	20

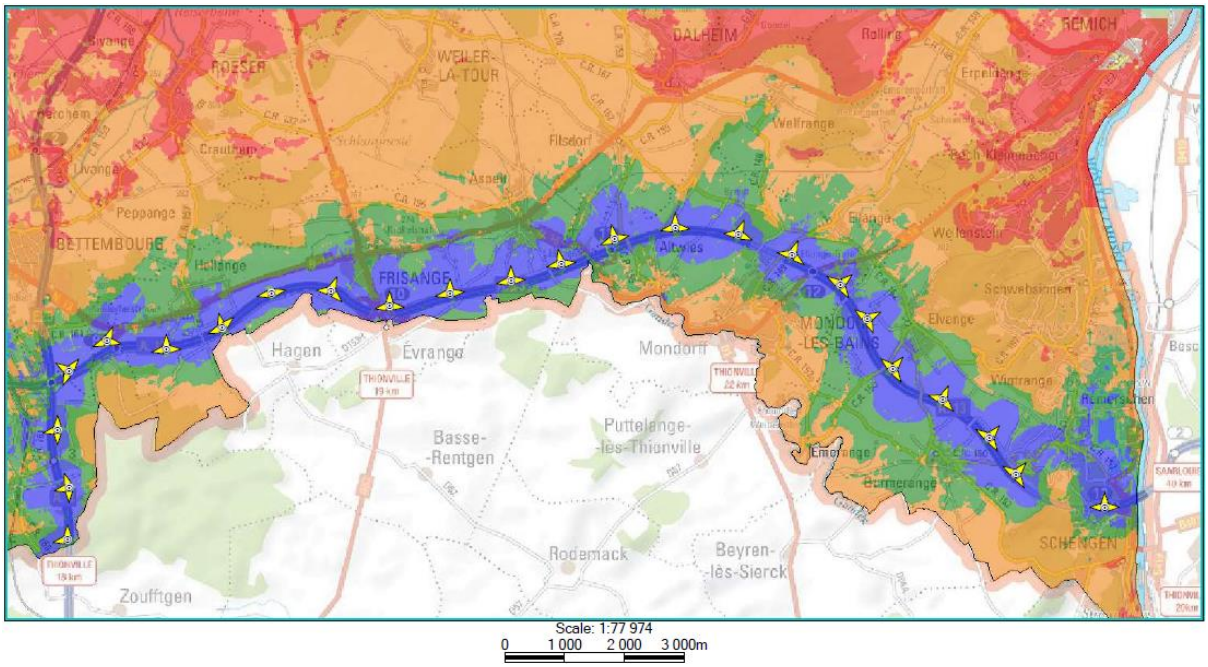

Figure 4-14: Luxembourg Corridor Calculated for "high throughput" scenario

5 Cost Calculation

Following the radio network deployment study done for the different scenarios defined and adapted to the local circumstances of the countries of the corridor, we will determine associated costs for passive and active equipment, civil engineering, etc.

The cost deployment study in the following chapter will be focused on a detailed evaluation of the main cost driving elements mainly focusing on infrastructure (Network, MEC) for CCAM.

The costs assumptions used in this chapter are directly extracted from costs analysis done in chapter 5.7 of this document, explaining more in details how valuation has been done.

In summary, the following table is showing the main costs elements and assumptions which will be used for the different cost deployment study done for the different countries.

		Depreciation (Years)
Cost (CAPEX) per New RAN Site (thousand €)	150	8
Cost (CAPEX) upgrade to 3.x GHz (thousand €)	70	8
CCAM usage sharing (%)	50	
Cost (CAPEX) upgrade to 700 MHz (thousand €)	60	8
CCAM usage sharing (%)	10	
OPEX ratio (%)	100	
MEC Cost (thousand €)	250	5

Cost assumption are directly extracted from the chapter below

5.1 Cost Assumptions

The CCAM ecosystem can be developed in different ways. This summary presents an indication of the total cost per aggregated building block for the infrastructure enabling CCAM and for the CCAM-specific services. While there are multiple options and almost infinite combinations of how such ecosystems could materialize in the European market(s) there is likely still variations country to country despite a Common Single European Market. 5GCroCo will not discuss the various deployment and operating models possible, such as e.g. a multitude of network sharing models from passive to active infrastructure sharing, CCAM services and service platforms per vehicle OEM or shared between vehicle OEMs, independent 3rd party CCAM service providers or road operators etc. Instead, indicative costs not considering sharing with the numerous combinations are considered.

The identified main cost components by domain include the following parts: Telco Equipment Manufacturers, Automotive, Infrastructure, Telco and Software/service providers. An approach per use-case has been developed (ToD, HD Mapping, ACCA), consisting in identifying on one hand the specific cost components devoted to each uses-cases and on the other, the global / nonspecific cost components which are expected to be present in every use-case, and then which could be mutualized.

Common infrastructure cost baseline:

1) Spectrum

   In an evolved CAM service ecosystem, up to 50% of the available and deployed spectrum could be required for CAM, while the other 50% will be used for passenger infotainment, personal communication services and legacy M2M and IoT services.

   During the initial period of a 5G network infrastructure deployment between 2020 and 2025, only a small, but growing fraction of the deployed spectrum will be utilised for CAM, give the announced introduction of first 5G-enabled vehicles towards the end of 2021 in Europe, followed by a growing number of vehicle models being introduced in the years ahead.

   The initial network rollout of 5G will be primarily driven on legacy spectrum (800-2600MHz) on the basis of refarmed spectrum, augmented by designated low band “5G” spectrum, i.e. 700MHz. The assignment of the 700MHz bands is ongoing across Europe, with strongly varying prices in the auction/allocation procedures carried out per country. Without refarming of legacy spectrum, any basic, coverage-driven 5G deployment (regardless of 5G NSA or SA) will fall short of capacity compared to e.g. 4G deployments in the same legacy bands.

   For simplicity reasons, the spectrum costs for 5G for CAM in sub 3GHz bands will not be considered here, as their usage specifically for CAM is negligible in comparison to eMBB type usage.

   Considering a cost factor of spectrum for 5G for CAM, 5GCroCo assumes that only the 3.x GHz spectrum assignment should be considered regarding proportionate costs attributable to CAM services. A large-scale rollout of 3.x GHz RAN infrastructure along major transportation corridors can be envisaged for around 2025, which is 5 years after the first assignments of “5G” spectrum in Europe, and given the typical spectrum assignment period of 15 years across Europe, only two thirds of the total 3.x GHz spectrum costs can be considered accordingly. Again, the assignment of the 3.x GHz bands is ongoing across Europe, with strongly varying prices in the auction/allocation procedures carried out per country so far.

   For simplicity reasons, we assume that any square kilometre of a country contains an average of 2km of roads (based on geodata and transportation infrastructure data for

France and Germany, for Luxembourg the ratio is 1:1.2, while it might be different again for other European countries)

The spectrum assignments per MNO are in the range of around 100MHz TDD in the 3.x GHz band, with an average price of x € per 100MHz

Example Germany:

The cost of 5G spectrum in 3.x GHz was 1.5bln € per 100MHz nationwide, with only the last 2/3 of the assignment period being relevant for CAM (1bln €), of which 50% of the spectrum available being attributable to CAM (500mln €), so for a road network with a total length of 620.000 km (all road types) the 10 year TCO spectrum cost for CAM is approx. 80tsd € per 100km and thus negligible compared to the 5G network deployment costs below.

2) RAN

The rollout of 5G in sub 3GHz legacy bands including the 700MHz band is primarily being done by upgrades of existing sites (base station sites supporting 800-2600 MHz), often in combination with periodic network modernisation. 80% of the sites should be upgradable at a minimum effort, while 20% of the sites will require some civil work primarily related to antenna carrier / pole upgrades

The average upgrade costs are calculated with 60k € per site, of which less than 10% could be attributed to CAM, i.e. 6k €

The rollout of 5G in 3.x GHz sites along the road network will require a dense deployment in the range of approx. 1 km inter-sited distance (ISD), so approximately 80% of the required sites will need to be created from scratch, while only 20% will be deployable with upgrades on existing sites with extra antenna costs for massive MIMO. This upgrade is estimated to come at 70k € per site, with 50% attributable to CAM, i.e. 35k €

The deployment of a new site including backhaul is calculated with 150k € per site, of which 50% could be attributed to CAM, i.e. 75k €

With 80% new sites and 20% upgrade sites, a stretch of 100km of road with an ISD of 1km will require 80 new sites and an upgrade of 20 existing sites, hence 80x 150k € + 20x 70k €, in total 12MM € + 1.4MM € = 13.4MM €, of which 50% are attributable to CAM, i.e. 6.7mln € per 100km.

To include recurring OPEX for a TCO view, approximately the equivalent of the CAPEX over a period of typically 8 years needs to be added, so the RAN TCO attributable to CAM is 13.4MM € per 100km

3) Core network

No extra provisions are being assumed related to CCAM, with the exception of implementation and continuous configuration of interfaces and data elements required for seamless cross-border service continuity and local breakout to MEC instances.

The cross-border service continuity element is estimated to require the setup of a system for network configuration data and integration into the OSS systems and extension of the international roaming interfaces and exchange platform IPX per MNO with a CAPEX of 500k € and an annual OPEX of 20% of the CAPEX, so a 5 year TCO of 1MM €, again 50% attributable to CCAM, i.e. 500k €.

The local breakout to MEC systems is calculated with a 5 year TCO of 100k € per MEC location. 50% of this will be attributable to CCAM, hence the costs are 50k € per MEC location.

4) Multi-access edge cloud MEC

It is assumed to have one MEC location for covering an area of 10.000km2 (100km x 100km), which, according to the calculations applied in the spectrum section above, hosts 20.000km of roads (all road types). Given the level of criticality for some MEC-based CCAM services, redundancy and fail-safe provisions need to be applied. This results in a 5 year TCO of 250k € for the MEC systems per location.

5) Vehicle CAM infrastructure

The 5G communication module, the onboard unit for CCAM and the related sensors and actuators (assuming ADAS level 4 and beyond) required for CCAM are expected to cost as much as 5-10k € per vehicle, so an average of 7.5k € is assumed.

6) Roadside infrastructure

RSU-type ITS stations are in the range of 10k € CAPEX and an equivalent aggregated OPEX over 8 years, so the TCO is approximately 20k €; however, since RSU deployment is not likely to happen for continuous coverage of the road network, but rather foreseen for bespoke and relevant locations with recurring road incidents or co-located with variable message signs and due to the circumstance that 5GCroCo is not deploying and evaluating RSUs, an economic assessment of RSUs is being omitted. In principle, there is an opportunity to collocate RSUs with 5G base stations in the 3.x GHz, and there are synergies achievable in the area of passive infrastructure, energy supply and (fibre) backhaul.

Use case (category)-specific elements:

1) Vehicle clients

Software development, testing and maintenance of vehicles clients

a. Horizontal clients (V2X short range, precise positioning, predictive QoS, security)

A lifetime TCO of 500k € including maintenance and updates is assumed

b. Use case / category-specific clients

A life-time TCO of 250k € per use case including maintenance and updates is assumed, in total 750k € for the three 5GCroCo services; we assume that these services are representative for all CCAM services and SW code can be shared, so adding more, but similar services to the portfolio should not multiply per service, but rather only double the 750k €, resulting in a TCO of 1.5MM € for all “day x” CCAM services

2) MEC and cloud-based server applications

a. Horizontal applications (service orchestration, application management, security)

A lifetime TCO of 1MM € including maintenance and updates is assumed

b. Use case / category-specific applications

A life time TCO of 500k € per use case including maintenance and updates is assumed, in total 1.5MM € for the three 5GCroCo services; we assume that these services are representative for all CCAM services and SW code can be shared, so adding more, but similar services to the portfolio should not multiply per service, but rather only double the 1.5MM €, resulting in a TCO of 3MM € for all “day x” CCAM services being host in the cloud and edge cloud/MEC environment

3) Bespoke service centres (e.g. VCoC for ToD)

a. Infrastructure

VCoC infrastructure consists of servers and bespoke workstations for ToD. It is assumed that an initial VCoC will consist of 10 workstations for peak hour operation and that it could be serving multiple countries or parts thereof, if considering the limitations of signal distance and routing hops for the bidirectional data transfer between the vehicle and the VCoC. The TCO for this infrastructure is in the range of 200k €, including provisions to support non-stop and fail-safe operations.

b. Applications

ToD software is expected to come at a TCO of 500k €

c. Human operators

A 24/7 operations center with up to 10 workstations being active simultaneously will require up to 60 qualified “remote drivers”. The qualification needed and the responsibility coming along with such a profile, it is estimated to incur costs of 5€ per minute of operation (compared to 1€ TCO per minute for call centre agents), all including workspace and overhead costs. In this calculation, an average utilisation of 50% of the workstations is assumed per day, hence 10 (workstations) x 0.5 (average utilisation rate) x 365 (days) x 1.440 (minutes per day) x 5€ will result in an annual TCO of 13.14MM €

Summary

Network and MEC

5G coverage costs are approximately 13.5MM € per 100km based on an 8year TCO

MEC costs including local breakout per MEC location are approximately 250k based on a 5year TCO; since one MEC location is serving 10.000km2 and 20.000km of roads, the effective cost is 1.25k € per 100km

Vehicle

Average incremental system platform costs for CCAM are 7.5 k€ and assuming a lifetime milage of a vehicle to be 200.000 km, the CCAM cost per 100km are just 3.75 €

Services

The cost of CCAM software (vehicle clients and corresponding server applications), plus dedicated service infrastructure like VCoC for ToD, cannot be calculated on a “per 100km” basis; however, they scale with the number of instances deployed, like number of vehicles, number of MEC/edge cloud or cloud instances. VCoC/ToD comes at a rather high cost compared to the other CCAM services and service categories. These costs need to be set in relation with the costs of recovering a stuck level 4 and putting it back on course as it would be done in the classic case of a broken-down vehicle, requiring on-site mobile repair or towing services. In addition, it is expected that parallel to a growing number of AD vehicles, which could require a capacity and hence cost increase of VCoCs for ToD without further improvements to the AD capabilities, the need for human intervention with ToD will gradually be reduced (KPI e.g. number of ToD interventions per 10.000 km of AD driving) through continuous system/software improvements.

5.1 Corridor France

Table 5-1: Cost for high 3.X throughput scenario

Number of existing sites	38
Densification 3.5 GhZ (1 site for x kr	1
Total Number of new sites	75
Number of MEC	1
Total number of km	96,76

		Global (Ke)	Per year (ke)	Global (Ke)/100 km
CAPEX cost 700 upgrade		228	28,5	235,6345597
CAPEX cost new 3.5 GhZ sites		5625	703,125	5813,352625
CAPEX cost 3.5 GhZ upgrade		1330	166,25	1374,534932
MEC cost		250	50	258,3712278
Total CAPEX		7433	947,875	7681,893344
Total OPEX		7433	947,875	7681,893344
Total		14866	1895,75	15363,78669

Table 5-2: Cost for for 3.X coverage scenario

Number of existing sites	38
Densification 3.5 GhZ (1 site for x kr	3
Total Number of new sites	14
Number of MEC	1

		Global (Ke)	Per year (ke)	Global (Ke)/100 km
CAPEX cost 700 upgrade		228	28,5	235,6345597
CAPEX cost new 3.5 GhZ sites		1050	131,25	1085,159157
CAPEX cost 3.5 GhZ upgrade		1330	166,25	1374,534932
MEC cost		250	50	258,3712278
Total CAPEX		2858	376	2953,699876
Total OPEX		2858	376	2953,699876
Total		5716	752	5907,399752

Table 5-3: Cost for for 3.X Basic low/medium band 5G coverage scenario

All corridors components	
Number of existing sites	38
Densification 3.5 GhZ (1 site for x kr	3
Total Number of new sites	1
Number of MEC	1
Total number of km	96,76

	Global (Ke)	Per year (ke)	Global (Ke)/100 km
CAPEX cost 700 upgrade	228	28,5	235,6345597
CAPEX cost new 3.5 GhZ sites	75	9,375	77,51136833
CAPEX cost 3.5 GhZ upgrade	1330	166,25	1374,534932
MEC cost	250	50	258,3712278
Total CAPEX	1883	254,125	1946,052088
Total OPEX	1883	254,125	1946,052088
Total	3766	508,25	3892,104175

5.2 Corridor Germany

The “coverage only” scenario results in costs as depicted here:

	Total (1000 €)	Per year (1000€)	Total (1000€)/100Km
CAPEX cost 700 upgrade	192.00	24.00	245.84
CAPEX cost new 3,5 GhZ sites	300.00	37.50	384.12
CAPEX cost 3.5 GhZ upgrade	1,120.00	140.00	1,434.06
MEC costs	250.00	50.00	320.10
Total CAPEX	1,862.00	251.50	2,384.12
Total OPEX	1,862.00	251.50	2,384.12
Total	3,724.00	503.00	4,768.25

The “high throughput scenario” requires a significant investment in additional RAN layers and new sites with low (1 Km) inter-site distance:

	Total (1000 €)	Per year (1000€)	Total (1000€)/100Km
CAPEX cost 700 upgrade	324.00	40.50	414.85
CAPEX cost new 3,5 GhZ sites	2,175.00	271.88	2,784.89
CAPEX cost 3.5 GhZ upgrade	1,890.00	236.25	2,419.97
MEC costs	250.00	50.00	320.10
Total CAPEX	4,639.00	598.63	5,939.82
Total OPEX	4,639.00	598.63	5,939.82
Total	9,278.00	1,197.25	11,879.64

5.3 Corridor Luxembourg

Costs for “coverage only” scenario is low as we have already sites available in production to perform a good coverage. Only upgrade costs to 700 MHz and 3.5 GHz and MEC are quoted.

Table 5-4: Costs for “coverage only” scenario

Number of existing sites	9
Densification 3,5 GhZ (1 site for x km)	3
Total numbe rof new sites	0
Number of MEC	1
Total number of km	24,5

	Global (Ke)	Per year (Ke)	Global (Ke)/100Km
CAPEX cost 700 upgrade	54,00	6,75	220,41
CAPEX cost new 3,5 GhZ sites	-	-	-
CAPEX cost 3.5 GhZ upgrade	315,00	39,38	1.285,71
MEC costs	250,00	50,00	1.020,41
Total CAPEX	619,00	96,13	2.526,53
Total OPEX	619,00	96,13	2.526,53
Total	1.238,00	192,25	5.053,06

For “high throughput” scenario, 24 sites will be required to organize the coverage. The assumption is that we could reuse 4 of our existing sites to be upgraded and will then require 20 new sites.

Table 5-5: Costs for “high throughput” scenario

Number of existing sites	4
Densification 3,5 GhZ (1 site for x km)	1
Total numbe rof new sites	20
Number of MEC	1
Total number of km	24,5

	Global (Ke)	Per year (Ke)	Global (Ke)/100Km
CAPEX cost 700 upgrade	24,00	3,00	97,96
CAPEX cost new 3,5 GhZ sites	1.500,00	187,50	6.122,45
CAPEX cost 3.5 GhZ upgrade	140,00	17,50	571,43
MEC costs	250,00	50,00	1.020,41
Total CAPEX	1.914,00	258,00	7.812,24
Total OPEX	1.914,00	258,00	7.812,24
Total	3.828,00	516,00	15.624,49

6 Summary / Conclusion

In the early days of 5G deployment along transportation corridors, standard eMBB traffic generated by individuals living in closer proximity of the corridors or traveling on these corridors, plus M2M/eMBB traffic generated by connected vehicles (without the cooperative aspects and without higher level of automation such as ADAS level 3 and beyond) will be the key driver for 5G deployment. This deployment is primarily based on 5G NSA, leveraging previous investments in both 4G RAN and 4G core networks. Over time, the deployments will evolve to 5G SA, driven by the evolution of connected vehicles, the advent of 5G for CAM/CCAM enabled vehicles support automated driving functions of level 3 and beyond. Again, this evolution will thrive on the existing 5G (NSA) deployment in the RAN and focus then more on the core network, network interconnect (evolved roaming) and local service delivery in the respective visited network, primarily with regards to CCAM applications involving MEC. From the very start, it is pivotal that CCAM services will function ideally seamlessly cross-border or only with short, well defined interruption and mitigation measures. The deployment of cross-border corridors will require a change of radio planning approaches at the borders, a constant exchange of up-to-date RAN planning parameters (like it is the case today for national roaming scenarios), an extension of roaming interfaces and a harmonisation of service delivery, with latency-sensitive services being provided in the visited country/network, seamlessly across borders. While the initial deployment along transportation corridors is primarily driven by the main telco players, i.e. MNOs, network vendors and tower companies, it will become necessary in the light of future network densification that the telco players and road operators/road authorities cooperate on building, maintaining and operating the communication infrastructures along the transportation corridors. The network densification in mid/higher band spectrum (3.x GHz and beyond) presents a significant cost driver along hundreds/thousands kilometres of transportation corridors, which is likely to be only economically sustainable if national MNOs, network suppliers, tower companies and operators / authorities of the transportation infrastructures cooperate. It does not stop at the communications infrastructure, but will extend to the CCAM services area beyond underlying ICT infrastructures. Further studies will be required to explore and exploit these ecosystem potentials.

7 Annex: Additional stakeholders considered / Limitations of this study and gaps

This study is based on contributions and feedback from internal 5GCroCo partners, who are part of almost all significant stakeholder categories listed in chapter 2, plus external sources listed in the references section. In addition, information coming from one tower company, one other mobile network operator, one public road authority and multiple other vehicle OEMs outside of the 5GCroCo project consortium was considered in the study. Ideally, more key stakeholders in the key sectors (primarily telco players, road operators/authorities and automotive players) should be inquired – for all countries being part of a corridor.

No assumptions have been made with regards to which CCAM services, with their aggregated service communication requirements, and their implementation in vehicles, could be roll out over time in the period 2023-2025-2030. While connected vehicles (vehicle-to-vehicle cloud) are increasingly becoming commonplace, ranging from European eCall-only connectivity up to sophisticated vehicle cloud services, and first short-range only V2X/ITS-enabled vehicles are being introduced to the markets across Europe, realistic roadmaps for the introduction of CCAM-enabled services and respectively related vehicles remain opaque and speculative. Hence this study has described the approach of a continuous rollout of 5G coverage and 5G capacity along observed increasing communication demand beyond certain thresholds. Various scenarios of potential 5G capacity rollout along the 5GCroCo corridor remain for further study and need to be investigated in “Study” proposals as an element of the CEF2 Digital Cross-Border Corridor Calls.

The actual utilisation of the motorways of the extended 5GCroCo corridor – availability of such data provided - was not analysed. Ideally, information about the daily and peak hour utilisation per corridor section / subsection during the past 10 years should be taken into account to both identify a usage trend and provide a basis for calculating the required peak network capacity and its evolution over time in combination with a future, phased introduction of CCAM services.

Prediction of 5G coverage was only calculated for the corridor section in Luxembourg using planning tools, while the indicative planning for the sections in France and Germany was solely based on databases containing existing sites, with assumptive placement of new sites based on approximation with required inter-site distances for coverage and capacity deployments. A full-scale and detailed deployment study will need in-depth RAN planning with exact geolocation and detailed site data for existing sites to assess if existing sites could accommodate additional 5G RAN layers with all prerequisites (e.g. site space, static capacity, legacy radiated power etc) or if new sites will need to be implemented. This will be important for taking concrete decisions on network investment as part of pre-deployment activities.

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