5G PPP Technology Board &

5G IA Verticals Task Force

# Empowering Vertical Industries through 5G Networks - Current Status and Future Trends

## Version 1.0

Date: 20-08-2020 Version: 1.0

DOI 10.5281/zenodo.3698113

URL http://doi.org/10.5281/zenodo.3698113

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# Executive Summary

This white paper summarizes the p**rogress and key findings produced by 5G PPP projects to provide 5G network services for vertical industries**. It provides information about requirements and business cases addressed by the projects. It discusses in detail several **exemplary use cases from 11 different vertical sectors** and **identifies key 5G features that have been used** to meet the specified requirements.

The building of sustainable business cases is based on the identification of the problems which verticals are facing, that are worthwhile to be solved through solutions based on distinctive 5G capabilities. The above-mentioned projects have suggested robust hypotheses about business and societal benefits and are validating the sustainability of their use cases. The **benefits reported** in this white paper have been **categorized as society critical, business critical, cost decrease and quality increase benefits**. Some achievements in vertical sectors, apart from the **key players and large industries**, are starting to appear **also for some SMEs**, where their technological achievements make a difference. **The 5G PPP Initiative has demonstrated the feasibility for SMEs** to develop and deploy 5G innovative solutions in vertical markets. This will hopefully allow more SMEs to follow a similar path, eventually increasing the European market share on a global scale. 5G flexible solutions for verticals will support various deployment options and business models in an optimum way with respect to spectrum usage, avoiding potential issues like spectrum fragmentation, underutilised spectrum, coexistence between public and non-public networks etc.

5G networks are providing significant improvements in terms of throughput, delay, reliability and guaranteed QoS. Moreover, 5G networks introduce several architectural enablers that capitalize on network softwarization. An indicative list of these enablers spans from network slicing, Multi-access Edge Computing (MEC), adoption of service-based architecture (SBA), functional split in Radio Access Network (RAN), security intelligence, smart network management, support of location services and context awareness. **5G PPP projects have used these 5G features to address challenges identified by verticals**. Moreover**, in the context of the 5G PPP Initiative**, the use of **satellite communications** has been investigated as a **cost-effective way for the deployment of 5G services to underserved rural and remote areas as well as maritime and airborne platforms** (ships, planes).

The evolution of 5G networks to address verticals' needs is having an impact on standardization activities. **5G PPP projects have provided a number of concepts and solutions to SDOs.** This work is expected to further continue during the following years as the full digitization of vertical industries will be one of the drivers for the evolution of 5G specifications.

**5G PPP projects have contributed to the design of many of these technological enablers.** At the same time, they have worked to provide specific solutions for verticals. These solutions will change our way of living, open new business opportunities for Europe and create new jobs across all vertical sectors. Although one may consider that some of the described functionalities could be supported by 4G networks, a closer look clarifies why 5G networks are needed to transform the vertical industries and support emerging applications.

A **key lesson learned** from the trials performed in the context of 5G PPP projects, is that **5G networks are not only about faster and more reliable networks.** 5G is introducing a level of **flexibility in the deployment of new services** that have a diverse set of characteristics, which 4G networks would not be able to support. This has enabled researchers to create novel services, parts of which can be implemented over different network slices. 5G networks have been designed to be **fully modular and allow the dynamic chaining of virtual functions and allocation of**

**resources. These characteristics are the catalyst for the creation of an innovation ecosystem that is expected to shape the full digitization of vertical industries.**

Although the 5G PPP Initiative has achieved many goals, many challenges still remain. The outcomes of 5G PPP will serve as the basis for the **Smart Networks and Services (SNS) Programme** that aims to organise the European research and innovation activities for the evolution of communication networks in the timeframe until 2028. One of the main objectives of the SNS Programme is the **full digitization of vertical industries**.

# 1 Introduction

5G has become commercial in 2019 ahead of schedule. Only one year later, 62 operators had launched 5G services in 32 markets; while a further 94 operators have announced plans to launch the service [1-1]. 5G subscriptions will account for the 20% of the world customer base in 2025 with operators investing 1 trillion Euros in mobile infrastructures, 80% of which in 5G [1-2]. In most countries, operators started offering 5G to customers for enhanced Mobile Broadband (eMBB) services such as Cloud Gaming not supported by 4G. 5G handsets of the most popular brands are now available and new models are launched on a weekly basis. Industrial 5G will be implemented through 3G PPP Release 16. This new version will empower 5G with new revolutionary capabilities such as Ultra-Reliable Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC) that will accelerate digital transformation across different industries in the next coming years. 5G is expected to generate 62.5 B€ of economic benefits across four sectors (automotive, healthcare, transport and utilities) by 2025 [1-3].

Europe has been at the forefront of 5G launches. At the end of 2019, 5G commercial services were available in 10 countries [1-4]. While 5G appeared on the mass market with consumer facing offers, 5G was validated (i.e., design was checked for its appropriateness to meet verticals' requirements) and evaluated (i.e., quantitative information of some characteristics of a certain design, such as key performance indicators, were computed) for industrial applications in more than 180 trials across 28 member states. In the automotive sector trials are taking place at a pan-European scale through 11 cross border corridors. Vertical trials have been performed through 5G Public Private Partnership projects (5G PPP) funded by 700M€ of the European Union research funding grants and matched by 3,5B€ of private funding in the 2014 – 2020 timeframe.

This white paper summarizes the progress and several key findings produced by 5G PPP projects to provide services for vertical industries. It starts with an analysis of requirements and business cases which are addressed by the projects. Then, it describes the key findings for 5G architectural extensions needed to support services for vertical industries. It summarizes an indicative list of 5G features that have been already demonstrated, or that are currently in the planning and implementation phase by several 5G PPP projects. Then, detailed information is provided for several exemplary verticals use cases and the use of 5G networks to support their requirements. The 5G PPP Partnership has already covered more than 10 different vertical industries. This description includes also some justification why 5G is needed to support these use cases and how European Union (EU) funded projects have demonstrated or plan to demonstrate the key benefits of 5G for the verticals. Moreover, it reports several examples on how generic enablers could be used for more than one vertical industry.

For reasons of completeness the white paper also discusses the contribution of satellite networks, the spectrum landscape, the impact in standardization activities as well as the involvement of Small and Medium-sized Enterprises (SMEs) in the abovementioned 5G PPP activities. Finally, the white paper concludes with a brief presentation of the planned activities in the context of the Smart Networks and Services (SNS) Partnership proposal under the Horizon Europe framework. One of the main objectives of this proposal is the full digitization of the vertical industries.

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# 2 5G PPP: Requirements and business case analysis for the vertical industries

This section provides a short summary of the 5G PPP Programme and explains how the current activities to empower vertical industries through the use of 5G networks are being implemented. Also, the section discusses the business cases motivating vertical industries to enter their full digitization era using 5G networks.

## 2.1 Vertical industries digitization in the 5G PPP Programme

Following up on the successful completion of Phase 1 projects, the technological development continued by 5G PPP Phase 2 projects [2-1] has kept Europe in the leading position in the 5G race [2-2]. The importance of EU funded projects to build a worldwide consensus at a pre-standardization level, the specification of advanced use cases and the raising of public awareness about the capabilities of 5G networks is undeniable. 21 Phase 2 projects, having started in June 2017 are delivering high-value results. Although some Phase 2 projects have completed their operations in June 2019, several projects continued their work into 2020. The Phase 2 *key achievements* include 60 highlighted technological results [2-3], having prototyped, validated, tested and piloted 5G in several vertical sectors.

The published "5G Infrastructure PPP – Trials & Pilots Brochure" [2-4] highlights 10 of these Phase 2 Trials & Pilots, selected by a panel of experts based on the assessment of the trials' and pilots' impact. Project overviews and results, test architectures and deployment schemes to validate uses cases, as provided by vertical players participating in 5G PPP projects, have covered the most relevant European industry sectors.

Started in 2018, three automotive projects in [2-5], have continued throughout 2019 and 2020 testing advanced cross border scenarios for automated driving. Apart from their testing efforts and achievements, these projects, under the umbrella of the 5G automotive working group [2-6], have provided collective results in two white papers, namely: "Business Feasibility Study for 5G V2X Deployment" [2-7], and "Initial proposal for 5G Strategic Deployment Agenda for Connected and Automated Mobility in Europe" [2-8].

Furthermore, three platform projects [2-9], [2-10], [2-11] that have started their work in July 2018, are providing large-scale end-to-end 5G validation network infrastructures. They cover about 20 European sites and will be operational until 2021. Their infrastructure provides an adequate level of openness to make it possible for vertical industries to test their innovative 5G business cases. A summary of their activities can be found in the "5G Network Support of vertical industries in the 5G PPP ecosystem" white paper [2-12].

Further eight projects [2-5] are conducting advanced 5G validation trials across multiple vertical industries and have started their activities in June 2019. These projects, illustrated in rows 4 to 10 in Figure 2.1 below, will take advantage of the aforementioned platform projects and interwork with them using different infrastructure exposure levels. Overall, platforms and vertical pilot projects cover a wide range of vertical industries as shown in the columns of Figure 2.1. They will create the necessary knowledge, experience and training to smoothly integrate different verticals with the 5G network infrastructure.

| | Industry 4.0 | Agriculture & agri-food | Automotive | Transport & logistics | Smart Cities & utilities | Public Safety | Smart (air)ports | EnergY | eHealth & wellness | Media & entertain. |
|---|---|---|---|---|---|---|---|---|---|---|
| 5G EVE | √ | | √ | | √ | √ | | √ | √ | √ |
| 5GENESIS | | | | √ | √ | √ | | | | √ |
| 5G VINNI | √ | | | √ | | √ | | √ | | |
| 5G!DRONES | | | | √ | | √ | | | | √ |
| 5G HEART | | √ | √ | √ | | | | | √ | |
| 5GROWTH | √ | | | √ | | | | √ | | |
| 5G SMART | √ | | | | | | | | | |
| 5G SOLUTIONS | √ | | | | √ | | √ | √ | | √ |
| 5G TOURS | | | | √ | √ | | √ | | √ | √ |
| 5G VICTORI | √ | | | √ | | | | √ | | √ |

**Figure 2.1 5G PPP Phase 3, part 2 and 3 projects**

A detailed list of all use case experiments, that are taking place in Europe between 2018 and 2020, can be found in the verticals' cartography [2-13]. Using the cartography, interested parties can find information on a vertical industry, country, type of experiment and usage scenario (i.e., eMBB, mMTC and URLLC, as defined by the International Telecommunication Union Radiocommunication Sector -ITU-R- for the International Mobile Telecommunications 2020 Standard - IMT-2020) . Figure 2.2 below shows the entry page of the verticals' cartography website with the verticals' industry filter.

It should be noted that the verticals addressed in this whitepaper is not an exhaustive set and further analysis will be needed to sufficiently address the needs of yet other verticals or sectors.

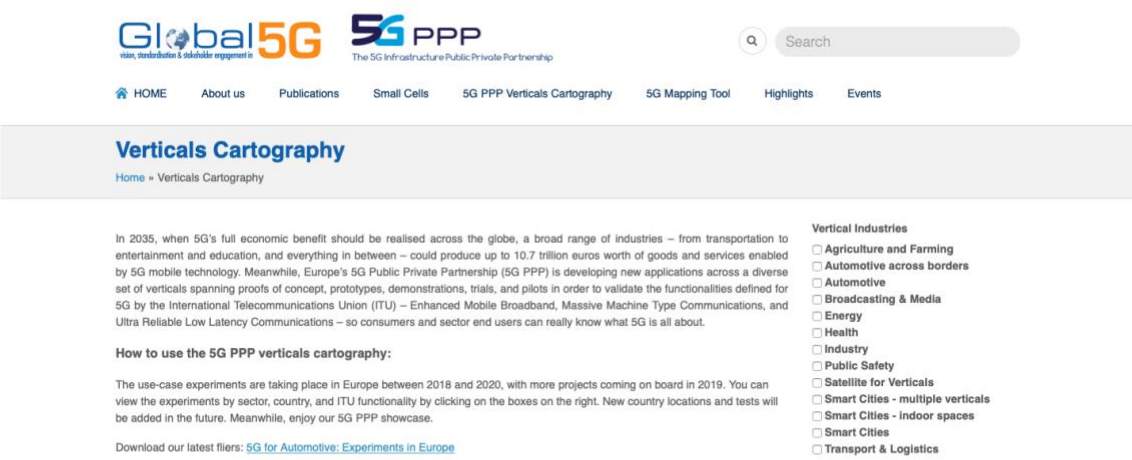


**Figure 2.2 5G PPP Vertical Cartography website entry page**

An analysis of the work of 5G PPP projects clearly shows (c.f., Figure 2.3) that in phase 2 the focus was on the development of key technical breakthroughs whereas phase 3 projects cover all vertical industries and perform trials and pilots.

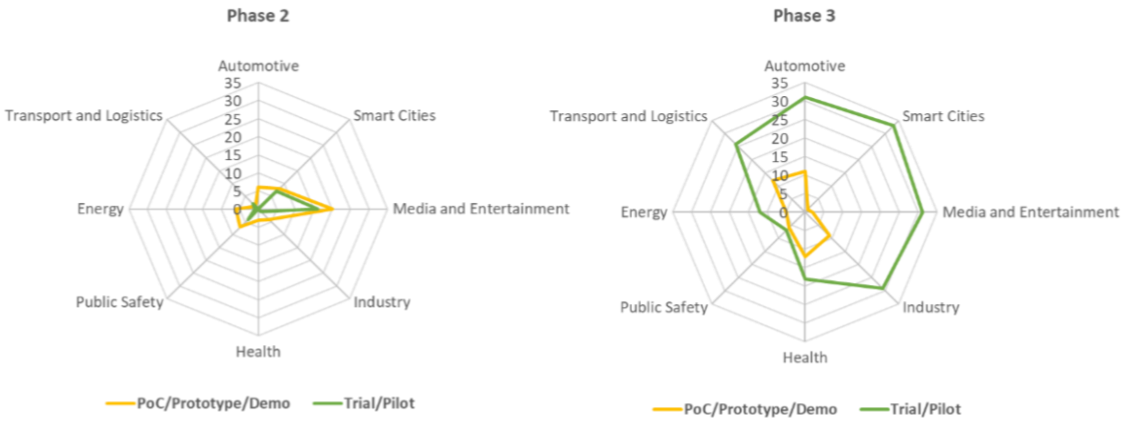


**Figure 2.3 Comparative focus of 5G PPP phase 2 and phase 3 projects**

## 2.2 Use case business motivation

The ongoing 5G evolution is built on strong beliefs in benefits from new applications, with many specific use cases coming from verticals. In 2018 and 2019, firms and associations in different verticals have been mobilized and approached the 5G community with pressing problems to be solved. Bidirectional communications between vertical industries and the 5G community have proven important for filtering the use cases with most value for the verticals. The efforts of the 5G Infrastructure Association (5G IA) [2-14] to engage verticals to share their current challenges and ambitions, discussing their requirements for 5G have been pivotal – memorandum of understanding and partnership agreements have been signed with prominent vertical industry associations in the Public Safety (Public Safety Communications Europe – PSCE) [2-15], Cybersecurity (European Cyber Security Organisation – ECSO) [2-18], Automotive (5G Automotive Association – 5GAA) [2-16], Transportation (European Road Transport Telematics Implementation Co-ordination Organisation – ERTICO) [2-17] sectors and others are underway in the Industry, eHealth and media domains. In [2-19] a large list of stakeholder groups that have to be involved in a realistic and business viable offering of 5G solutions for the vertical industries has been created (c.f. Figure 2.4).

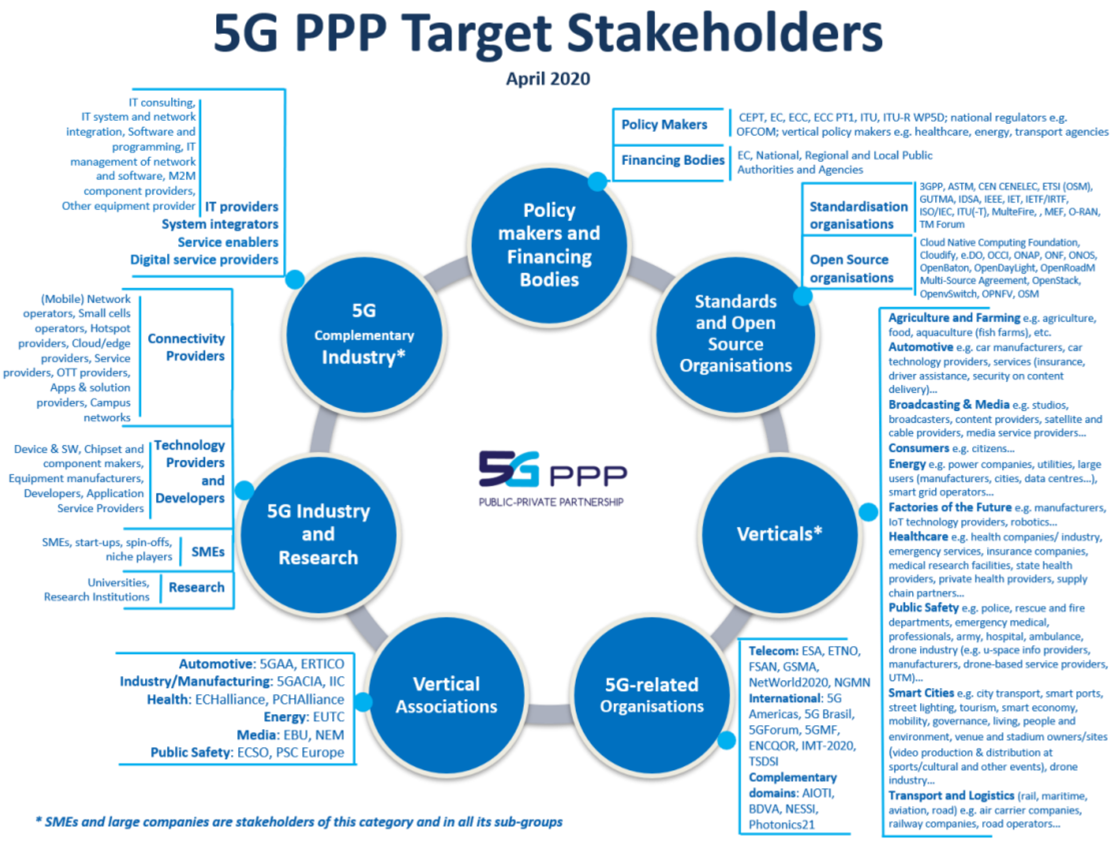


**Figure 2.4 5G PPP Target Stakeholder groups and Stakeholders**

The building of sustainable business cases is based on the identification of the problems verticals are facing worthwhile to be solved and through the validation of solutions based on distinctive 5G capabilities. The aforementioned projects have suggested robust hypotheses about business and societal benefits and are validating the sustainability of their use cases.

The benefits from 5G are usually assessed from five stakeholder type perspectives, a list neither exhaustive nor mutually exclusive. These perspectives are illustrated in Figure 2.5, indicating five stakeholder types and the categories of benefits they may achieve. The Mobile Network Operators (MNOs) assess the viability of 5G infrastructure investments as general services and localized opportunities along e.g. highways. Alternative infrastructure stakeholders, e.g. railways, assess their opportunities by investing in 5G infrastructure. Entities in verticals are validating how 5G enabled services may benefit the running of their businesses and operations; these can be both private and public stakeholders such as factories, health entities, agricultural firms and public safety agencies. There is a plethora of so-called third parties, which explore how they can integrate and take advantage of 5G in their offerings; third parties can be both SMEs and large firms specific to certain verticals. Finally, the consumer perspective is a part of benefit assessment of 5G, on how service experience may increase.

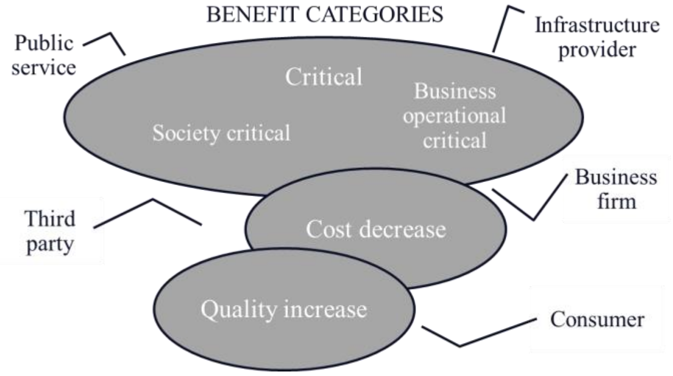


**Figure 2.5 Stakeholder types & benefit categories**

5G PPP projects validate the benefits from their use cases in two main ways. Firstly, having stakeholders as participants in the projects provides a *qualitative* and well-informed assessment of pain points to be addressed and potential benefits to be accrued. Secondly, in many projects, *quantitative* techno-economic analyses are important when assessing the financial sustainability for infrastructure providers. Indeed, it is easy to come up with initially interesting and relevant use cases; however, projects do find it challenging to confirm promising value propositions upon which to build their business models and cases [2-20]. The challenge is twofold: to actually be able to identify a service where there is willingness to pay, and to have sufficient methodological tools to increase the probability of success.

**Table 1: Benefit examples drawn from verticals and categorized**

| Benefit categories | Benefit examples drawn from verticals |
|---|---|
| **Society critical** | **Automotive**: Boost road safety, e.g. avoid collisions at intersections; Allow enhanced traffic management, reduce environmental impact by road traffic; Increase the efficiency of mobility.<br><br>**Health/Media**: Enable fully and connected digitized emergency ambulance operations, ambulance teleguidance, ambulance routing; Save lives through e.g. smart wearables; Life-saving applications, e.g. wireless operating room calling on remote experts; Video application for health purposes.<br><br>**Energy**: Support self-healing protocols that are required for avoidance of failure/power interruption; Support crew in energy outages with on-site assessment and mitigation tools.<br><br>**Public safety**: Enhanced information exchange, mobility and coverage, situation awareness, and collaboration. |
| **Business operational critical** | **Factories**: Digital twins for risk assessment and avoidance.<br><br>**Ports/Airports**: Safety. |
| **Cost decrease** | **Automotive, Railway**: Reduce infrastructure capital expenditure (CAPEX).<br><br>**Media**: Cost savings in production.<br><br>**Public safety**: Cost savings using commercially available services.<br><br>**Agriculture**: Operational cost efficiency. |

| | |
|---|---|
| | **Ports/Airports**: Operational efficiency and reduced logistic costs, also decrease air pollution. |
| **Quality increase** | **Smart cities**: Develop cloud infrastructures, based on existing passive infrastructure, e.g. waste management, traffic lights control, parking detection and optimizing, air monitoring, personalized information to citizens, movement tracking, navigation services.<br>**Automotive**: Increase the efficiency of mobility, improve traffic safety.<br>**Automotive, Media**: Enable video/game consumer consumption with higher quality, more interaction; Enable (live) video production with higher quality and speed, distributed production; Improve passenger experience with infotainment services.<br>**Factories**: Automation and vehicle automation in warehouses, for assembly lines and seaports.<br>**Health**: Smart wearables for health monitoring, emergency localization, and secure access to patient records.<br>**Agriculture**: Monitor and manage sites in order to optimize production and animal welfare.<br>**Tourism**: Enhanced tourist experience, virtual museum visits, robot-enabled museum guidance. |

Drawing on verticals described in Section 4, we find examples of benefits in all categories, as presented in Table 1. These are all elaborated upon in more details in Section 4, and also connected to which role 5G capabilities play in delivering these benefits. After further validation, the next step for verticals and 5G providers is starting to assess the aggregated market potential. As an example, in [2-21], the three automated “straddle trucks” in the harbour of Herøya, Norway, may prove to deliver benefits on safety and around-the-clock operation. Considering that in Europe about 130.000 construction machines are purchased each year [2-22], the business opportunities for 5G providers in the construction sector can be explored. In the same way, 16 million cars sold in Europe each year [2-23] indicates the business potential that may come from successful validation of 5G capabilities in the automotive sector. To this regard, a business plan has been carried out by the 5G PPP Automotive Working Group to assess the economic viability of a Connected Automated Mobility (CAM) scenario on a European highway corridor, tested in the context of the Connected Europe Facility (CEF) program at cross border level in Europe [2-8]. Yet another business case in Section 4.1.9 provided a techno-economic analysis for 5G deployments in ports, finding operational benefits from increased capacity and cost improvements. This constitutes a positive business case for providers of 5G mobile services at the port. Societal benefits such as lower $CO_2$ emissions can be extracted from intelligent transport systems; however, in order to kick off investments, it is necessary to initiate public-private partnerships. Both this, and knowledge gained from the CAM sector [2-24], point at the complex business models in 5G markets with many stakeholders where the so called “chicken-and-egg” dilemma exists; a potentially positive business case is not realized because different interdependent stakeholders are uncertain about their role and share, and wait to invest.

No matter how large a market currently is, new 5G enabled services still have to prove their real value and feasibility. Furthermore, clear roadmaps of business model innovation must appear to lower the uncertainties and increase willingness to invest. Thus, the current and continued validation of specific use cases in 5G PPP projects, in both business and technological contexts, is pivotal to address stumbling blocks, business model innovation complexities and the anticipated 5G market growth.

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# 3 Architectural considerations for the verticals

## 3.1 Architectural enhancements

The support of the vertical industries (from now on abbreviated to verticals in this document), requires various architectural enhancements as it has been described in detail in [3-1] and [3-2]. These are needed to enable the enhanced performance of mobile networks, as well as the required flexibility to adapt to diverse requirements imposed by the verticals. The key findings are discussed below.

The development of the 5G networks has been supported by a number of architectural enablers that capitalize on network softwarization, where Virtualized Network Functions (VNFs) can be deployed in edge clouds (e.g., within the framework of multi-access edge computing-MEC) and in central clouds (e.g., core network VNFs). Moreover, these enablers, have been shown to improve considerably the operation and performance of the mobile networks to serve a multitude of vertical applications that use the same physical infrastructure. An indicative list of these enablers spans from **network slicing, MEC, adoption of service-based architecture (SBA), functional split in Radio Access Network (RAN), security intelligence, smart network management, support of location services and context awareness**. It is worth noting that although architectural enablers have been emphasized herein, numerous lower-layer enablers have been adopted by the 5G networks to substantially enhance the link-layer and system-level performances, e.g., flexible air interface design, beam-based communication, data duplication, configured grant, and a new more flexible Quality of Service (QoS) enforcement.

As the verticals have different service requirements in terms of Key Performance Indicators (KPIs) such as throughput, delay and reliability, and network requirements such as isolation and special authentication, the mechanism of **network slicing** is one of the key enablers for 5G networks [3-3]. For this reason, four types of network slices have been specified by 3GPP so far, namely eMBB, URLLC, mMTC, and Vehicle-to-Everything (V2X) services [3-4], where up to 256 such slice types can be allocated in the current 3GPP Release 16 specification [3-5]. In addition to the slice type, each network slice can be further categorized via a slice differentiator, which can significantly widen the support for different verticals. These network slices are essentially logical networks operating on top of the same physical infrastructure. Network slices may operate in total isolation among them or they may share resources and network functions. A vertical service may require the use of one or more network slices, which may be controlled or operated by more than one stakeholder, e.g., a mobile network operator and the vertical itself. The deployment and management of the network slices are performed in a standardized as well as implementation-specific way ([3-6], [3-7]). It is worth noting that network slicing is an end-to-end concept; therefore, slicing support for different verticals may require modifications and extensions in the access, transport and core network domains.

Considering the end-to-end notion of network slicing, each network slice may use its own extensions in various parts of the network. For instance, extensions may be needed in the RAN for energy utilities to realize new methods for Internet of Things (IoT) device identification and optimization of data routing. At the resources and functional level, application-specific VNFs may require deployment at the edge. Similar modification will be required for the V2X communication and Industrial Internet of Things (IIoT), where the low delay and the high reliability also require extensions at the edge of the network. The use of MEC is expected to address some of these requirements.

The extensions needed by a network slice supporting a target vertical can be in the form of slice-specific network functions. For example, at the core network, new functions may be needed to support specific requirements for content delivery. That is, for live video streaming, mission critical communications, and information dissemination in IoT and V2X domains, specialized functions for content delivery of unicast and multicast data need to be placed in the core as well as the access parts of the network. To support such extensions, the core network adopts the principles of **SBA**, where the rather rigid reference point interactions between the network functions are replaced by a service-based interface approach. Within the SBA framework, any network function in the core network can register and discover services utilizing the well-established Hypertext Transfer Protocol Secure HTTP(s). The SBA paradigm enables an easy addition of slice-specific network functions and interactions with the vertical domains through network exposure mechanisms. On the RAN side, the **functional split** based on central-unit / distributed unit (CU/DU) enables a virtualized implementation of the higher-layer RAN protocols of a CU, and thus easy integration of VNFs in the RAN.

Moreover, Function-as-a-Service (FaaS) should be an integral part of cloud services. The FaaS addresses use cases that require the immediate setup of an elastic communication service. A very nice example of these kind of services is described in [3-1] about the media production and delivery. Such solutions require extensions and modifications for **smart network management** by providing automated mechanisms that will allow the fast and easy deployment of network slices along with the necessary network and computing resources, their dynamic adaptation during the lifetime of a service and their eventual release when these are no longer needed. To this end, the network management interfaces with orchestration (e.g., ETSI Management and Orchestration – MANO) to handle the network slice instantiation in the physical infrastructure.

As the support of vertical industries involves multiple stakeholders, **security** aspects should be re-examined so that efficient end-to-end security solutions are integrated in the network infrastructure at various levels (e.g., end device, edge computing, core network and vertical application servers). For example, security at the mobile edge has the advantage of being far more scalable and selective to the needs of end users and would typically act as a first line of defence in a security architecture performing tasks such as Scanning Security, Denial of Service Security and Sniffing Security.

Finally, a rather important enabler for 5G networks is related to **context awareness.** One main example for context awareness is the knowledge about the exact location of a terminal. This is essential for a variety of existing and emerging vertical sectors requiring continuous (indoor/outdoor) **high-accuracy localization** to not only fulfil the demanding QoS of 5G and beyond 5G new services but also enhance the intelligence of user applications. The positional information of network nodes is encapsulated by soft information, the ensemble of positional and environmental information, respectively, associated with measurements and contextual data [3-8]. This can be used for example for location-based data access as well as user monitoring and guiding in diverse indoor scenarios such as in museums, supermarkets, train tunnels, emergencies within buildings as well as in outdoor scenarios such as large venues and dense urban environments. It can also be used to guide network management decisions such as load balancing as well as provide co-localisation information in the event of social distancing in health epidemics/pandemic. Since not everyone may be equipped with a smartphone, imaging the environment for the detection of the location of other people using backscattering from radio transmission is important for a more nuanced context awareness.

Section 4 provides details for a subset of Phase 2 and Phase 3 5G PPP project solutions that have been validated or are planned for 11 different vertical sectors. The indicative list in Table 2 is a compilation of key 5G features used in the specific projects. The number of 5G features depends on the number of projects that have been active in a specific vertical area. Although in principle all 5G features can be used to support a vertical sector, the following list provides a snapshot of what the most important 5G features could be at this moment.

**Table 2: Demonstrated and planned 5G functionalities in verticals**

| 5G Features | Automotive Section 4.1.1 | Transportation Section 4.1.2 | Media Section 4.1.3 | Smart City Section 4.1.4 | Healthcare Section 4.1.5 | Smart Factories Section 4.1.6 | Energy Section 4.1.7 | Public Safety Section 4.1.8 | (Air)Ports Section 4.1.9 | Tourism Section 4.1.10 | Agrifood Section 4.1.11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Network Slicing** | X | X | X | X | X | X | X | X | X | X | X |
| **Mobile Edge Computing** | X | X | X | X | X | | | | X | X | X |
| **Functional Split in RAN** | | X | X | | | | | | | | |
| **Advanced Security** | X | | | X | | | | | X | | |
| **Smart network management** | | | X | X | X | | X | X | | | |
| **Location services & Context Awareness** | X | X | X | | X | X | | X | X | | |
| **5G NR capabilities** | X | X | X | X | X | X | X | X | X | X | X |
| **Softwarization** | X | | X | | X | | | | X | | |
| **Service chaining** | | X | X | | X | | | | | | |
| **Traffic steering** | | | X | | | | | | | | |
| **Spectrum and Coverage** | X | X | X | | | | | | | | |
| **Guaranteed QoS** | X | X | | X | X | X | X | | | | |

Section 5 discusses in detail a list of enablers that can serve multiple verticals. These enablers span from network slicing (c.f., Sections 5.9 and 5.10), security (c.f., Section 5.2), advanced traffic steering over multiple Radio Access Technologies (RATs – c.f., Section 5.1) and use of location (c.f., Sections 5.3 up to 5.8). This list is an indicative list of the successful solutions produced in the context of 5G PPP Initiative to cover a diverse set of verticals.

## 3.2 Validating the 5G specifications

As the 5G architecture is very ambitious to support a significant number of different vertical uses, considerable improvements have been targeting a wide set of networking KPIs (e.g., delay, throughput, reliability, density, etc.). All these requirements have been motivated by a thorough use case description and analysis. A significant part of the definition and the analysis have been performed in the context of 5G PPP, starting with projects like METIS and continued with the 5G PPP Phase 2 projects. A multitude of the technological solutions for 5G networks that have been produced in the context of 5G PPP projects, have been communicated to Standards Developing Organizations (SDOs), e.g., 3GPP and ETSI (c.f. [3-1] for details). To evaluate the overall performance of 5G networks and verify that indeed they meet the requirements specified by International Telecommunication Union-Radiocommunication (ITU-R) WP5D (Working Party 5D International Mobile Telecommunications – IMT Systems), an Independent Evaluation Group (IEG) has been created and supported by the 5G PPP.

The 5G PPP IMT-2020 IEG was organized under the umbrella of the 5G IA, with participants from active 5G PPP projects and 5G IA members, to perform an independent evaluation of IMT-2020 proposals to support ITU-R WP5D for the finalization of the IMT-2020 recommendation in 2020. This evaluation group has been recognized by ITU-R as a contributor of an independent second opinion on the Radio Interface Technologies, which have been submitted by SDOs to ITU-R to be recognized as member of the IMT family of systems for mobile and wireless communications.

In December 2019, the 5G IA IMT-2020 evaluation group submitted the interim evaluation report to the ITU-R evaluation workshop in Geneva on December 10 and 11, 2019. The report contains a detailed analysis of the analytical, inspection and simulation characteristics defined in ITU-R Reports [3-9], [3-10], [3-11]. The final evaluation report was submitted to ITU-R in February 2020.

The final evaluation reports, including the considered scenarios, the main configuration settings and further information for the validation of KPIs, are available as follows [3-12]:

- Report: 5G IA Final Evaluation Reports for different SDO submissions February 2020
- System-level calibration results:
    - Whitepaper with description of calibration activities
    - Matlab calibration files
    - Calibration procedure performed

**As can be seen from the results, a 5G network is able to deliver the demanding KPIs under the target scenarios (e.g., use of Multiple-Input/Multiple-Output (MIMO) antennas and Carrier Aggregation, using make-before-break handovers etc.). This is a very important milestone to validate that indeed 5G system can support the vertical industries.** This however is the first step. The full industry digitization of the vertical industries and the support of new emerging services require further technological solutions. At the level of SDOs, work is underway to provide such solutions. Moreover, at a European level, a new Smart Networks and Services (SNS) Partnership proposal is under preparation (c.f., section 10) to provide those breakthroughs that will enable the full digitization of the vertical industries.

## 3.3 References


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# 4 Supporting the Verticals in the context of the 5G PPP

## 4.1 Indicative Use Cases for the Vertical Sectors

This section provides an indicative list of use cases where solutions have been developed for 11 different vertical sectors. Several of these solutions have been implemented, tested and validated through large-scale trials and pilots, while others are still in their implementation phase.

These solutions present the high level of innovation on how 5G networks can be used to provide useful services that will change our way of living, open new business opportunities for Europe and create new jobs across all the vertical sectors. Although one may consider that some of the described functionalities could be supported by 4G networks, a closer look in the following subsections clarifies why 5G networks are needed to transform the vertical industries and support emerging applications. The key 5G features anticipated to be adopted to serve the vertical sectors, have already been discussed in section 3 and as such they will be presented using specific examples in the following sub-sections.

A key lesson learned from the trials performed in the context of 5G PPP projects is that 5G networks are not only about faster and more reliable networks. 5G is bringing on a level of flexibility in the deployment of new services, which have a diverse set of characteristics, for which 4G networks would not be able to support. This has enabled researchers to create rather novel services, parts of which can be even implemented over different network slices. 5G networks have been designed to be fully modular and allow the dynamic chaining of virtual functions and allocation of resources. These characteristics are the catalyst for the creation of an innovation ecosystem that is expected to shape the full digitization of vertical industries. The following examples from 5G PPP projects are based on a selection of current achievements and expected future results.

### 4.1.1 Automotive

Even though automated driving for individual vehicles can be implemented without connectivity, there is no doubt that for circulation with other traffic participants (ideally in an altruistic manner), communication among vehicles, road infrastructure, and vulnerable road users, such as pedestrians, can boost the capabilities of automated driving at all levels of driving automation, from driver assistance to high or full driving automation [4-1]. The success of high degrees of connected and automated driving has the potential to boost road safety, increase the efficiency of mobility, allow enhanced traffic management, reduce environmental impact of road traffic, and improve passenger experience through infotainment services.

Connectivity offers a good complement to the on-board sensors by extending vision and detection range even when visual line-of-sight is not available. In addition, connectivity is key to cooperative functions that will allow vehicles, infrastructure and other road users to share information that can help the vehicles to coordinate their actions and finally to take the right collective decisions and adapt to the traffic situation. Cooperative, Connected and Automated Mobility (CCAM) refers exactly to this vision where cooperation, connectivity, and automation as complementary technologies can be jointly used to increase safety and efficiency of mobility of future vehicles.

For these reasons and for the innovative business potentials that promise to have a dramatic positive impact into society and economy, the 5G PPP portfolio includes a number of projects which have contributed or are actually contributing to developing and testing 5G features for the automotive vertical.

Cellular Vehicle-to-Everything (C-V2X) communications is considered one of the key enablers of CCAM. C-V2X communications encompasses both short-range (PC5 interface, also called side-link) and wide-area (Uu interface) communications, designed specifically for use by vehicles and associated road infrastructure. C-V2X is an umbrella term, which encapsulates all 3GPP V2X technologies (New Radio – NR-V2X and Long Term Evolution – LTE-V2X). It should be noted that LTE-V2X side-link/direct relates to 3GPP Rel. 14 or 15 specifications (LTE based), whereas NR-V2X side-link/direct relates to 3GPP Rel. 16 and beyond specifications (NR based). A 5G-V2X vehicle can combine LTE-V2X and NR-V2X, where LTE-V2X side-link (PC5) is used for broadcast safety messages such as CAM messages or distributed environment notification messages (DENM) for basic safety services and NR-V2X side-link (PC5) is used for delivering advanced driving functionalities.

One of the 5G PPP phase 2 projects [4-2], had as a goal to evaluate and propose radio access network and system architecture enhancements aiming at supporting the strict requirements of V2X use cases. It defined five Use Case Classes (UCCs) taking into consideration the different sets of operations required by cooperative and automated vehicles [4-3]: a) Cooperative manoeuvres, b) Cooperative perception, c) Cooperative safety, d) Intelligent autonomous navigation, e) Remote driving. Each UCC enables a different functionality and consists of various use cases. 5GCAR selected one relevant and representative use case from each of the UCCs taking into account their impact (e.g., societal, safety purposes, business opportunities), their frequent occurrence in future highways or urban environments and the challenges that they set for the communication system (Figure 4.1): a) lane merge, b) see-through, c) network-assisted vulnerable road-user protection, d) high definition local map acquisition, and e) remote driving for automated parking. For each of them, studies based on KPIs have been made focusing on three categories: automotive requirements, network requirements and qualitative requirements.

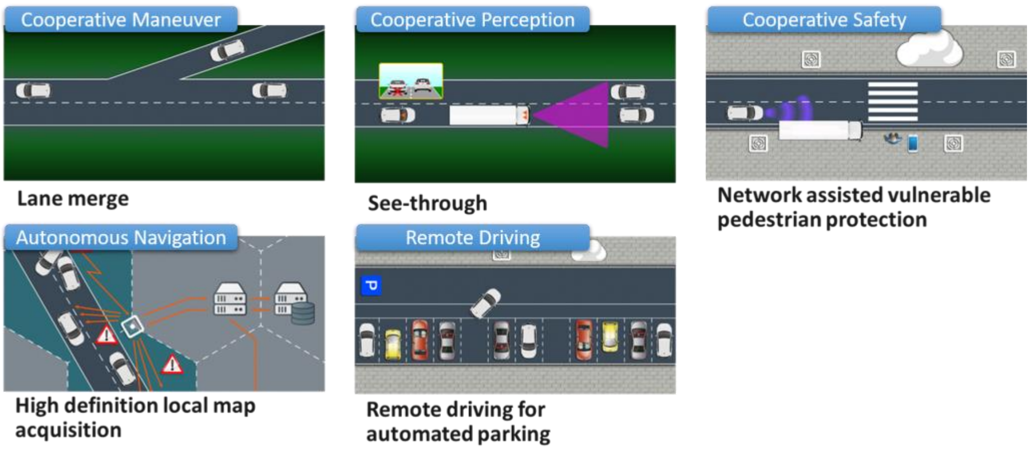



**Figure 4.1 5GCAR project Use Cases [4-4]**

The project designed 5G solutions that can be applied to improve the identified challenges and KPIs in terms of capacity, latency, reliability, and positioning accuracy for future autonomous driving [4-4], [4-5]. Some of these solutions are the following:

- Multi-antenna techniques: predictor antenna, beam management for unicast/multicast/broadcast communications, and optimal antenna design for V2X communications including both vehicle and infrastructure antennas.
- Radio resource allocation and management: efficient radio resource management for both Uu and side-link in either centralized and/or distributed way.

- Sidelink design: basic design for side-link (discovery, synchronization signal and reference signal design).
- Full duplex: cognitive resource usage for Vehicle-to-Vehicle (V2V) communication and collision detection/avoidance.
- Reliability enhancements: trade-off between reliability, latency and capacity for reliability enhancement to both data and control channels.
- Positioning Enhancement: real-time positioning, trajectory estimation and tracking.
- Multi-connectivity Cooperation: improved service availability by jointly using several communication modes or technologies instead of relying only on one mode/technology (i.e., only Uu or only side-link) that might not be able to support some use cases.
- Multi-operator communication: enhancements are required for dealing with the proper (in terms of delay and reliability) communication of the vehicles belonging to different operators or in cross-border scenarios.
- Edge Computing Enhancements: availability of computing capabilities at the edge of the network (i.e., edge computing) opens potential for several improvements in mobile networks to support vehicular use cases. Enhancements are needed from a core network perspective as well as from an access network point of view.
- Network orchestration and management: improved orchestration capabilities able to cope with the unique requirements of vehicular use cases and with improved network management and re-configurability capabilities to cope with the dynamicity in terms of traffic demand in vehicular scenarios.

The project demonstrated three different use cases using 5G technologies, namely: a) Lane merge coordination, b) Cooperative perception for manoeuvres of connected vehicles, c) Vulnerable road user protection [4-6].

Three further 5G PPP projects are working on large-scale trials for CCAM, with particular emphasis on cross-border operation [4-7], [4-8], [4-9]. The trials are conducted along cross-border corridors between different European countries, with the ultimate target to build the foundations to deploy 5G infrastructure providing pan-European transportation paths with 5G connectivity and uninterrupted services, which can facilitate high levels of driving automation.

The first one [4-7] focuses its trials on:

1) **Tele-Operated Driving**, which consists in driving a vehicle from a remote driving and control centre by a human being, by either actuating directly on the car steering wheel and pedals, or by sending trajectories that the vehicle must follow.
2) **High Definition Mapping**, which consists in exchanging information to dynamically generate high-definition maps, with very high accuracy to detect both dynamic and static objects, which allow high levels of automated driving.
3) **Anticipated Cooperative Collision Avoidance**, which consists in allowing the exchange of information between vehicles to reduce the probability of accident or collision due to obstacles that they may have come across on the road; e.g. traffic jams, sudden braking of a vehicle or unexpected manoeuvring of a vehicle ahead, or cut-in anticipation when a car suddenly comes in from another lane.

The second one [4-8] focuses its trials on:

1) **Cooperative Manoeuvring**, which aims at coordinating the trajectories of a group of vehicles in close proximity by i) sharing information produced locally by a vehicle, e.g., from radar, Light Detection and Ranging (LIDAR), and on-board cameras, in a privacy-aware and secure fashion with other vehicles, and ii) combining vehicles' information with precise positioning and traffic information. The specific cooperative manoeuvre that

will be implemented is the Cooperative Lane Merging depicted in Figure 4.2, which was previously tested by the 5GCAR project [4-2].

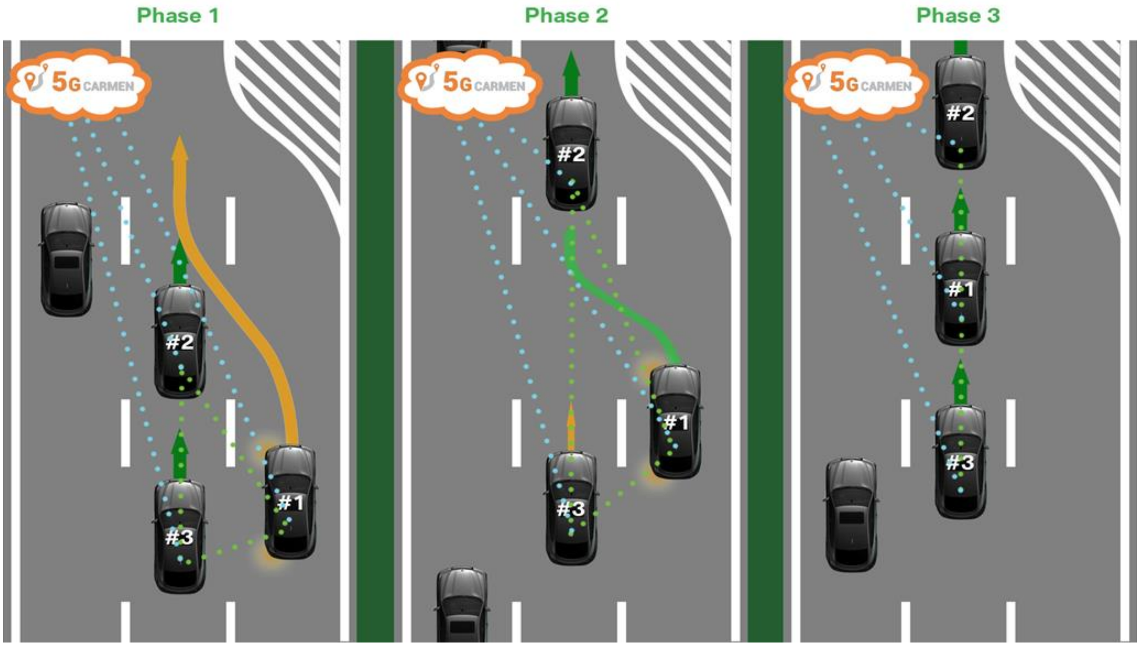



**Figure 4.2 Cooperative Lane Merging – Automotive Use Case**

2) **Situation awareness**, which aims at detecting dangerous conditions (e.g. fog, icy roads, traffic jam) by sensors in Roadside Units (RSU) or vehicles on the road and communicate them to nearby vehicles through direct V2V communication (bypassing the base station), and to incoming vehicles through 5G connectivity. Similarly, emergency vehicles can inform nearby vehicles of their arrival through direct V2V communication, and far away vehicles through 5G connectivity thus giving them enough time to take relevant actions to create a clear corridor for the emergency vehicle.

3) **Video streaming for infotainment**, which aims at using predictive QoS capabilities to grant a more pleasant experience on board to passengers, controlling the proactive adaptation of streaming applications (e.g. increasing buffering) to minimize the impact of predicted interruptions of service or low data-rate conditions, thus allowing higher and more stable Quality of Experience (QoE) in the fruition of multimedia content on-board.

4) **Green Driving**, which aims at yielding increased sustainability of mobility, suggesting driving behaviour based on the environmental and traffic characteristics based on information collected from road side sensors of the motorway section that is being traversed, while crossing country borders (i.e., multi-domain service orchestration is needed) (see Figure 4.3).

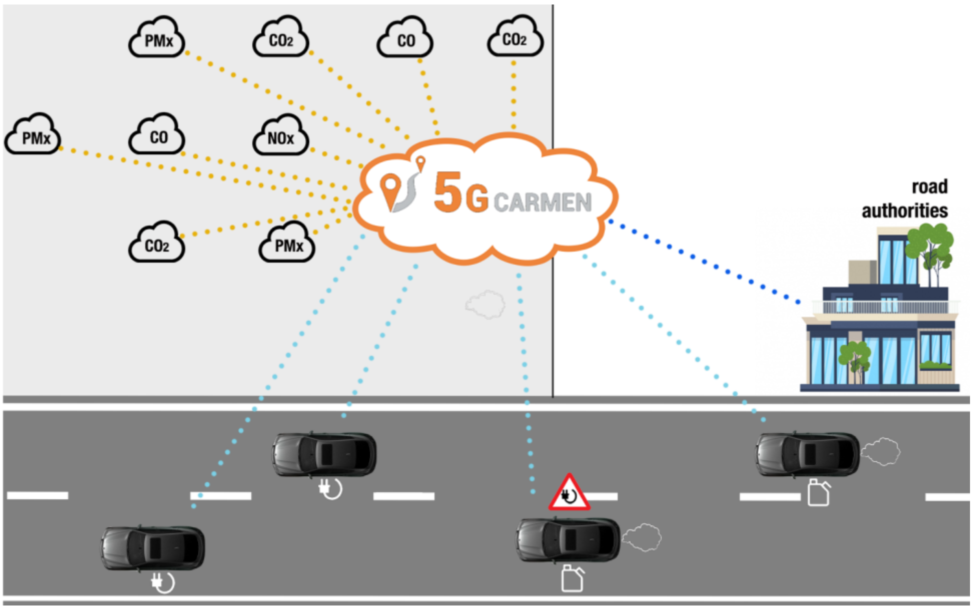



**Figure 4.3 Green Driving Use Case**

The third one [4-9] focuses its trials on:

1) **Advanced Driving** enables semi-automated or fully automated driving. Each vehicle and each RSU shares data obtained from its local sensors with vehicles in proximity, thus allowing vehicles to coordinate their trajectories or manoeuvres. In addition, each vehicle shares its driving intention with other vehicles in proximity. The benefits of this use case group are safer travelling, collision avoidance, and improved traffic efficiency.

2) **Platooning** enables vehicles to dynamically form a group travelling together. All vehicles in the platoon receive periodic data from the leading vehicle, in order to carry out platoon operations. This information allows the distance between vehicles to become extremely small. Platooning applications allow vehicles following to be operated autonomously.

3) **Extended sensors**, which enables the exchange of raw or processed data gathered through local sensors or live video data among vehicles, RSUs, devices of pedestrians and V2X application servers. The vehicles can enhance the perception of their environment beyond what their own sensors can detect and have a more holistic view of the local situation.

4) **Remote driving**, which enables a remote driver or a V2X application to operate a remote vehicle for those passengers who cannot drive themselves or a remote vehicle located in dangerous environments. For a case where variation is limited, and routes are predictable, such as public transportation, driving based on cloud computing can be used.

5) **Quality of Service support**, which enables a V2X application to be timely notified of expected or estimated change of quality of service before actual change occurs and to enable the system to modify the quality of service in line with V2X application's quality of service needs. Based on the quality of service information, the V2X application can adapt its behaviour to system's conditions. The benefits of this use case group are offerings of smoother user experience of service.

These are examples of use cases that will help demonstrate the potential of 5G to boost the true realization of highly automated driving. V2X communication will provide a longer line of sight, up to several kilometres, and a better field of view, up to 360°, and allowing exchange of information thereby boosting the concept of collective group intelligence and group perception for driving.

4G-LTE connectivity is capable of meeting some of the automotive industry's requirements; however, 5G offers substantial advantages and new capabilities that 4G-LTE is not offering. Besides the **huge advantage of additional bandwidth brought by 5G** and the **expected wide coverage facilitated by the use of different parts of the frequency spectrum**, 5G also offers advanced features, which will improve customer mobility and customer experience through support for **URLLC** and **mMTC** communications.

A key advantage of 5G is the enhanced notion of **guaranteed QoS** which results in improved reliability and service continuity, while enabling **customized service provisioning** for automotive services via dedicated network slices. Built-in QoS functionality also ensures guaranteed bandwidth and latency meeting the more stringent requirements. Additionally, *Predictive QoS* including coverage prediction explained also in [4-10], will assist services like tele-operated driving, planning of map or software updates and many others. **Precise Positioning** will make advanced high-precision localization available, along with correction data for Global Navigation Satellite Systems (GNSS). Finally, the capability for **direct communication** with other vehicles, and the digital infrastructure along the road, enhances existing LTE-V2X solutions with higher bandwidth, unicast and multi-cast capabilities.

A 5G-guaranteed high throughput and low latency service instantiated via **network slices**, combined with **enhanced caching**, will be capable of meeting the automotive requirements. Among other things, 5G will allow resource-hungry applications to be offloaded to the Cloud or MEC to enable among others the vehicle as a gaming platform, in-vehicle streaming of 4K video and high-quality video conferences.

The new frequencies available for 5G, combined with New Radio (NR) technology, will provide very wide coverage, a higher throughput and reduced delay making it possible to enhance vehicle Original Equipment Manufacturers' (OEM) services like software updates. The **computation power** available next to the road with the **introduction of MEC** will enable among others **computational and distributed offloading, reduced response times and analysis of cyber security threats** next to the location where they are occurring.

5G will be able to provide eMBB services respecting the constraints of the other use case groups previously indicated, thanks to **network slicing** and **network function virtualization**.

In order to evaluate how well 5G will perform against the needs of the automotive sector, it is necessary to identify the KPIs that will drive the evaluation. Across the different 5G PPP projects contributing to this domain, it is possible to identify:

- **Reliability and availability**: when functional safety is involved, high levels of reliability and availability are needed. For example, tele-operated driving or situation awareness would require a 99% of both availability and reliability [4-11]. However, when safety is not directly involved, more relaxed, yet high levels of reliability and availability are required; for example, video streaming for infotainment or green driving could accept a range of reliability between 90% and 95%.

- **Low latency**: when safety functions are involved, fast response from the communication network is needed. In this area, the automotive vertical calls for low latencies with stable performance. Guaranteed and stable low values of latency will ensure the fulfilment of functional safety requirements.

- **Seamless connectivity**: mobility and seamless connectivity must be guaranteed. This becomes particularly important when safety applications are being used for automated or highly automated driving; communication must not be interrupted when changing the serving base station. Therefore, end-to-end (E2E) communication links must be guaranteed, with very high levels of reliability and low latency.

- **Real-Time Communication**: for high definition (HD) mapping, it is necessary that information is transmitted in real-time, since out-of-date information may generate wrong map information which, in the case of automated driving, could compromise the functional safety on the road.
- **High throughput**: ensuring high throughput is necessary for infotainment services and for functions which rely on the exchange of video images between cars such as see-through applications where the vehicle ahead exchanges real-time video of its sight view with the cars following, so that overtaking can be performed under safer conditions. This use case was previously tested [4-2] with successful results demonstrating the capability of 5G to become a true enabler for this type of use cases.

The trial for *Extended Virtual Sensing (EVS)* [4-12] showed that adding networked functionality to cars that, together with entities deployed in the network, give extended sensing capabilities to cars for improving road safety. In this case, the goal was to avoid collisions at intersections by exploiting ETSI Intelligent Transportation Systems (ITS)-based Cooperative Awareness services [4-13]. During the trial two real cars generate Cooperative Awareness Messages (CAM) that are processed by the EVS service and receive DENM that can be alerts. The Proof-of-Concept (PoC) showcased that the car equipped with an Automatic Emergency Braking system brakes upon receiving alerts, thus avoiding collision. The PoC demonstrated the capability of the network to provide round trip delays **below 20 ms together with the required network reliability.** In addition, the performance of the EVS service was evaluated through simulations as a function of speed and density of cars. Finally, the PoC showed **how vertical services are arbitrated and prioritized as a function of their criticality and Service Level Agreements (SLA).** In this case, video streaming and EVS services were deployed over a heterogeneous computing and transport infrastructure and it was shown how the video service was scaled down when not enough resources for the high priority EVS were available. Figure 4.4 shows the scenario setup for this automotive demonstration [4-14].

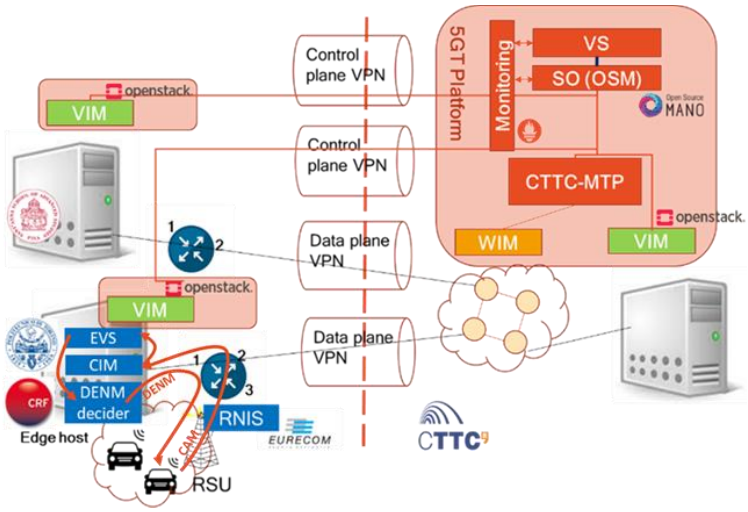



**Figure 4.4: Scenario setup for automotive EVS demonstration**

The measurement campaigns carried out resulted in **latency** from the transmission of the CAM to the reception of the corresponding DENM with an average value of 8.870 ms (standard deviation: 1.447 ms, maximum value: 11.637 ms, minimum value: 5.050 ms). This fulfils the vertical requirement for latency below 20 ms.

Simulation with several cars also showed that **reliability** of DENM messages is always above 99% on average for all combinations of speeds and densities. As for the **mobility** KPI (i.e., EVS service availability at varying speeds), EVS was able to predict 100% of collisions at 50Km/h (urban mobility) for which it was designed, hence trigger the actions to avoid them. In summary, for the simulated urban scenario and for a variety of realistic urban **densities** and speeds, the algorithm is capable to avoid all collisions. In summary, this work demonstrated the compliance of 5G with stringent automotive requirements in real and simulated scenarios for scalability [4-15].

Across the different trials that are planned in the near future, one open technical question is the nature and amount of validation with respect to functional safety requirements that will be necessary before connected automated vehicles will be allowed on public roads by the governing authorities. Industry associations like the 5G Automotive Association (5GAA) [4-16] have begun to form working groups to liaise with the committees developing the relevant standards and specifications like International Standards Organization (ISO) 26262 [4-17] and ISO Publicly Available Specification (PAS) 21448 [4-18] which focus on issues of situational awareness and practical approaches to validating the myriad scenarios that present themselves in connected and automated driving.

Another important technical subject for the automotive vertical is **cyber security and data privacy**. An overview of potential attack scenarios of the connected mobility is shown in Figure 4.5.


**Figure 4.5: Overview of the attack surface of the Connected Mobility**

For the cooperative and connected mobility domain, amongst the top priorities is to ensure the integrity and authenticity of the exchanged information. Some of the most important security threats of this domain are listed in Table 3.

**Table 3: Overview of attacks in the connected mobility domain**

| # | Description of attack |
|---|---|
| **1.** | Attacks on backend server. An attacker can compromise a backend server and use it to attack the connected cars. An attacker may launch a Denial-of-Service (DoS) attack on backend servers to disrupt the services. An attacker may target sensitive data at the server or information in other parts of the cloud. For example, mobile apps are used to allow a user to query the status and control the car from his/her smartphone. Insecure application programming interfaces (APIs) at the backend allow an attacker to interact with the car using falsified API requests. |
| **2.** | Attacking a car using V2X communication channels. An attacker may spoof V2X messages, tamper with transmitted data or code, attack data integrity, exploit the trust |

| | |
|---|---|
| | relation, gain unauthorized access to data, jam the communication channel on the protocol or radio frequency level and inject malware or malicious V2X messages. For example, non-secure protocols such as HTTP are sometimes used for V2X communications. Even when secure communication protocols such as Transport Layer Security/Secure Socket Layer (TLS/SSL) are used, if the client software does not properly check the server certificate, an attacker can launch a Man-in-the-Middle attack to steal the user's credentials to further control the car. |
| **3.** | Attacking a car by exploiting software update. An attacker may compromise the over-the-air updates or local and physical software update process, manipulate the software before the update process, or even steal cryptographic keys to compromise code signing. For example, the 2014 Jeep Cherokee was remotely hacked by updating the Renesas V850 firmware to allow the compromised telematics unit to send messages directly to the electronic control units on the Controller Area Network (CAN) bus. |
| **4.** | Social engineering exploits vulnerabilities and weaknesses introduced by human errors. An attacker may trick an owner, operator, or maintenance engineer to unintentionally install malware or change the setting to enable an attack. An attacker may also exploit errors in system configuration or usage. |
| **5.** | Attacking vehicle interfaces and functions for external connectivity. An attacker may access and manipulate functions designed to remotely operate systems or provide telematics data, short range wireless systems and sensors, and applications with poor software security. An attacker may also utilize physical interfaces such as Universal Serial Bus (USB) or diagnostic port, or even media connected to the car as a point of attack. For example, connected cars rely on network devices with Transport Control Protocol/User Datagram Protocol (TCP/UDP) ports to interact with the outside world. Even the Internet Protocol (IP) address of a connected car is protected by network separation provided by network operator, since open ports and services with weak or no authentication pose security risks. An attacker can remotely scan and access the open ports and exploit the services as an entry point to the on-board system. In addition, the CAN bus can be accessed physically through the on-board diagnostics port, charging station, or a mechanic's computer. |
| **6.** | Attacks on in-vehicle network or software of on-board systems. An attacker may extract data and code, manipulate vehicle data, erase data and code, inject malware, inject or overwrite existing software, disrupt system operation, and manipulate vehicle parameters. |
| **7.** | Attacks that exploit security flaws in system design. An attacker may break the encryption due to insecure cryptographic design such as lack of encryption, weak key strength, or the use of deprecated cryptographic algorithms. Bugs in software and hardware may provide the attacker exploitable vulnerabilities and means of access or privilege escalation. Poor network design such as weakness in internet-facing ports and internal network separation also pose security risks. Crypto systems in the car should last for a long period of time. Lack of crypto agility, i.e. not being able to upgrade broken or obsolete cryptographic systems over time, may affect the whole security status. |
| **8.** | Attacks on privacy or data loss and leakage. V2X communication packets may contain identifiable information. Some of the information may be anonymized or pseudonymized. However, an attacker may still be able to intercept the V2X packets, footprint and track a car's movement over a certain period and area and re-identify the user. Personal data may be transferred to third-party service providers in V2X |

| | |
|---|---|
| | communications. Sensitive data from cars may be lost or leaked due to physical damage, failure of Information Technology (IT) components, or change of ownership. |
| **9.** | Physical manipulation of on-board systems to enable an attack. Manipulation of OEM hardware or adding unauthorized devices may enable a remote attack afterwards. |

A project in 5G PPP Phase 3 [4-19], will address security aspects of 5G, including the automotive vertical among its main areas of work. Other research projects outside the 5G PPP (e.g. [4-20]) are also working towards a safe 5G technology for connected and automated mobility.

Beyond pure technical aspects of 5G, projects are also working on identifying and assessing new business models and understanding the implications in regulations and standards. A techno-economic analysis for three different automotive use cases: (i) assisted, (ii) cooperative, and (iii) tele-operated driving can be found in [4-21] and [4-22]. The analyses conclude that all three use cases actually do require a 5G network at least from a latency point of view. The question investigated was which architecture with which functional split was most suitable from a cost point of view. The study outcome complements the information provided by the 5G PPP Automotive Working Group in its whitepapers [4-23] and [4-24].

Other projects have also contributed to the business implications of the use of 5G for the automotive vertical. Still many open questions need an answer, such as what cooperation models can be put in place to ensure a network deployment that can help leverage the potential of 5G-enabled automated driving.

In summary, 5G PPP trials are demonstrating that 5G characteristics such as 5G NR, network slicing, edge computing, location services and context awareness, softwarization, guaranteed QoS, additional spectrum and coverage and intelligent security solutions will be key enablers for autonomous driving.

### 4.1.2 Transportation

Transportation is another vertical industry that will benefit greatly from 5G networks. For example, a study for the European Commission (EC) [4-25] that provided fundamental quantitative socio-economic bases for the stakeholders to plan the critical phases for the introduction of 5G concluded that the annual benefits arising from 5G capabilities for the road transport industry are in excess of 8 billion Euro. This sector deals with the mobility of goods and people. In this section we discuss the reported progress and the planned activities by 5G PPP projects for the railway systems and the transportation with buses.

For the rail transport, it is expected that adopting the traditional model of separate dedicated network infrastructures to support rail related services, will be very inefficient and of high cost. Dedicated purpose cellular deployments installed along railway tracks suffer the following shortcomings:

- For extended geographical areas there will be low or no traffic from other demands to share the network capacity and associated cost.
- Traffic demands from trains are instantly high but moving fast between cells, creating many inefficient handovers.
- The total cost of deploying and maintaining the traditional copper wire cables is significant.

A multi-tenant 5G network model was demonstrated [4-26] that supports the needs of railways, among other tenants, deploying **converged wireless-optical network domains**. Through the proposed approach the railway industry will take advantage of the multi-tenant capabilities

**exploiting network slicing** that 5G offers, enabling the support of both traditional telecom services available to the passengers and operational services required by the train operator. The approach taken provides **service continuity and guaranteed QoS** along the tracks. In cases that various RANs operated by different mobile network providers co-exist along a route, the solution offers a unified network that can be deployed **addressing service fragmentation** issues, meaning that mobile network providers are able to share assets between them, or they are provided resources from different infrastructure providers [4-26].

A high-performance network model was trialled based on moving wireless access nodes on-board trains connected to track via different vehicle to infrastructure (V2I) technology options [4-27]. The trial showed **high-bandwidth internet access** for infotainment and video streaming to the passengers on the move, while providing train operators with driver-to-control connectivity and access to on-board surveillance cameras applications. The project considered 20 - 100 Mbps throughput per user and a radio network capacity of 1 - 3.5 Gbps. During the trials, the overall system achieved data rates between 223 and 993 Mbps, a mean one-way latency of 2.35 ms (with a minimum of 0.36 ms and a maximum of 17.4 ms), a residual packet loss rate (measured on TCP retransmissions) of 0.06%. The supported mobility was 90 km/h and the power used was 199.5 W/km.

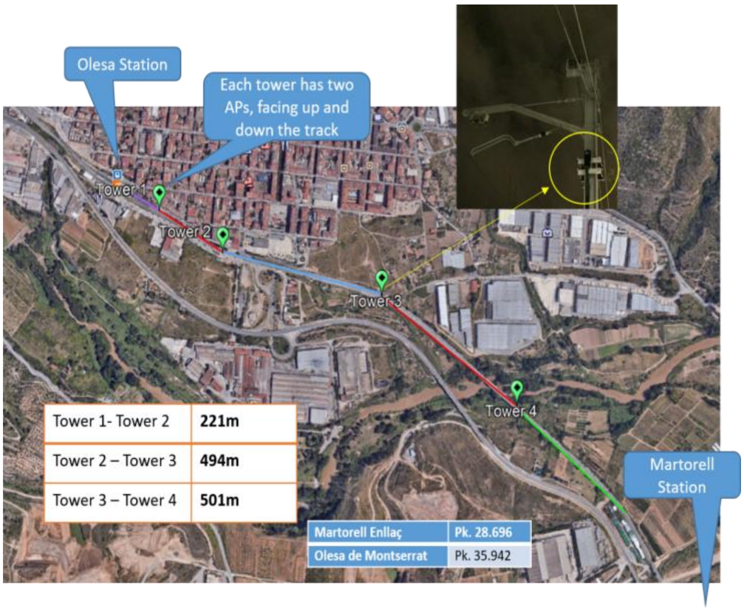



**Figure 4.6: Demonstration configuration for railway services**

A diagram of the demonstration configuration and components is shown in Figure 4.6 illustrating a track segment located behind Olesa de Monserrat station in Spain. The trial was based on mmWave technology to provide V2I connectivity. Four stations equipped with mmWave access points are interconnected through fibre links forming a telecommunications infrastructure that connects a set of on-board devices mounted on a train that passes by this section, while Martorell station is simulating the operations control centre. A network on-board the train was connected to the track-side infrastructure via electronic self-directed beams. Session continuity is controlled by a mobility server. The wireless infrastructure on the track-side was connected to the core railways' or operator network via a low-cost optical G.metro network [4-27], [4-28] including:

- A network with automatic provisioning of multiple 10 Gbps services.
- Remote passive nodes, since laser pluggables are integrated inside mmWave equipment.
- An outdoor cabinet designed and developed during the project for all non-mmWave components at mmWave poles: G.metro/Wavelength Division Multiplexing (WDM) filters, power switch, patch panel.

- A 100 Gigabit Ethernet (GE) aggregation network to protect and aggregate traffic between mmWave poles and the core network.
- A network that can be implemented with full redundancy to support railway's stringent availability requirements.

5G PPP phase 3 projects [4-29] plan to demonstrate the use of 5G communications in railway safety critical communications, between the level crossing train detector activation points and the Level Crossing (LX) controller, as illustrated in Figure 4.7. In the presence of an approaching train, messages indicating axle detection and axle count information are sent to the LX controller, to inform that a train is approaching the level crossing as well to transmit the status of the equipment on the track. The LX controller then starts a set of actions to assure safe conditions for the train, cars and people. After detecting that the train has left LX, the peripheral devices must return to normal state. Therefore, **the LX controller gets the sensors' information to automatically define the position of the half-barriers, the traffic lights and the protection signal**. In this case, all communication between all LX equipment must be guaranteed. 5G is a viable alternative to replace traditional copper wire cables and deploy safety communications protocols to comply with railway signalling safety communications standards, ensuring Reliability, Availability, Maintenance and Safety.

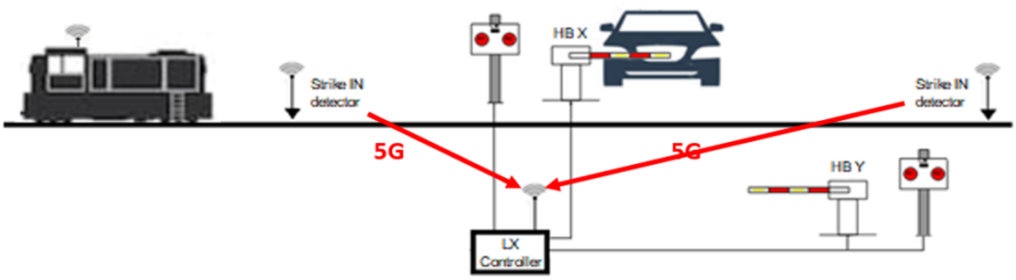



**Figure 4.7: Safety critical communications for the train Level Crossing signalling system**

Since this type of communication is considered critical, the most relevant requirements are related to **reliability, availability and low latency** in order to support railway signalling operations meeting railway level crossing communication requirements for safety critical communications from approaching train detectors to the level crossing controllers.

The main requirement on 5G is low latency (<10ms) for ensuring timely train detection, and high availability and reliability of 99.99% of the system to ensure all safety conditions and to ensure that train rails and car roads are always mutually protected [4-30] [4-31].

In one of the recent 5G PPP projects [4-32], **a joint use case is being designed and implemented with the objective to increase safety and comfort** for the citizens who travel by bus. The use case provides the following main services to be implemented in the buses supported by a 5G ready infrastructure:

- **Infotainment services** - displaying municipality information of public interest (e.g., surveys, alerts, tourist information, etc.). Video cameras and displays will be connected to the traffic management centre of the private operator over 5G networks where input from various stakeholders will be collected and transferred to the public transportation passengers.
- **Public safety critical service** – all the buses will be equipped with surveillance cameras identifying public threats (thefts/healthcare emergency/lost items) and allocating on the spot the appropriate requested resources. Special attention will be given to the transportation of children via school buses where additional services will be offered (e.g.,

face recognition to identify that a child is on board the bus, identification of unusual behaviour, etc.)

The infotainment and public safety critical services will be supported by two different slices, the slice for emergency will be created automatically by an event triggered by the driver or an external event. **Immediate service triggered instantiation** must be achieved, the latency being a critical metric for experimentation (5ms target), the **low latency** will provide the proper traffic delivery for analytic processing at the **5G MEC**, including also the needed device data rate to ensure the video quality to the C&C centre, at 20 Mbps per device. The full list of KPIs is depicted [4-33].

All the above-mentioned examples from successful 5G PPP trials identify that the transport section will benefit considerably from the use of advanced 5G solutions that indicatively include: mobile edge computing, 5G NR (including RAN functional split), location services and context awareness, guaranteed QoS and additional spectrum and coverage capabilities.

### 4.1.3 Media

The Media sector is one of the most promising consumer sectors which can benefit from 5G networks as it is expected that 5G solutions will drastically increase bandwidth and reduce latency thus increase media usage. The average monthly traffic per 5G subscriber will grow from 11.7 Gigabyte (GB) in 2019 to 84.4 GB per month in 2028, at which point video will account for 90% of all 5G traffic [4-34].

Numerous market research reports forecast a rapid growth of video, often together with breath-taking predictions for the rollout of next-generation wireless broadband. Ericsson's Mobility Report [4-35], predicts annual video traffic growth of 35% until 2024 – increasing from 27 exabytes (EB) per month in 2018 to 136 EB in 2024. Video's share of the global mobile traffic will rise to 74% from 60% today "as 5G establishes itself as the fastest generation of cellular technology to be rolled out on a global scale" the reports states.

The European Technology Platforms, New Electronic Media and NetWorld2020 issued a joint position paper [4-36], which considers nine use cases, covering a broad range of existing and future media services. The paper identifies 12 KPIs, among others **latency, reliability, data rate, mobility, user density, positioning and user equipment speed** that should be used to adapt the network to the application requirements. The use cases identified by the position papers are:

1. Ultrahigh fidelity imaging for medical applications
2. Immersive and interactive media
3. Audio streaming in live productions
4. Remote, cooperative and smart media production incorporating user generated content
5. Professional content production
6. Machine generated content
7. Collaborative design including immersive communication
8. Dynamic and flexible ultra-high definition content distribution over 5G content delivery networks
9. Smart education

Analysing the 5G network capabilities and KPIs that are needed to meet the requirements of the listed use cases, the position paper concludes that two network slices with complementary capabilities are needed. The reason for this is that the media production and delivery chain encompass functionalities and operations such as content creation, service composition, service aggregation, content distribution, devices capacities, user interaction and user interfaces, which require very diverse network capabilities. As an example, content production mostly needs high uplink capacity, while media distribution typically needs high downlink capacity.

The 5G media slices can be defined as subtypes of the eMBB slice type, which is meant for applications requiring large capacity. However, elements of the other two slice types – latency from URLLC and density from mMTC – must be taken into account, when required by the specific media use cases.

In the context of the 5G PPP several projects have designed and validated solutions for the media sector or are currently designing innovative services.

A solution for immersive on-site live experience (matching service 4 above) [4-12] targeted large-scale event sites to provide better experience to fans (e.g., re-play, choose a specific camera, language, add information through augmented reality etc.), including HD video. End-users were able to request Ultra High Definition (UHD) in their media consumption through their user devices. UHD media experience was available for linear (e.g. live programming, streaming) and non-linear (e.g. on-demand) content.

The key service requirements were latency, data rate, and service creation time. The solution demonstrated the use of 5G to deliver a **high data rate streaming service** to the fans, and the capability to **deploy the service at the network edge near the fans**. Furthermore, it demonstrated **the instantiation and scaling of the service on demand** with low service creation time.

The capability to **deploy at the network edge**, reduces the probability of a bottleneck in the transport network and reduces the latency perceived by the fan. The capability to store content locally at the network edge is critical to provide an immersive experience.

The solution was demonstrated on-site live at the golf event Mutuactivos Open España in October 2019 in Madrid. The trial illustrated in Figure 4.8 provided a 360° live video in a mobile player with the capability to switch between two different streams provided by two 360° cameras placed in two different locations of the training area. The player was able to see the 360° videos in Virtual Reality (VR) mode using a Google  Daydream View head mounted device.


**Figure 4.8: Demonstration at the public golf tournament in Madrid in October 2019**

The solution achieves latency of 40 ms on average for the client requesting the different video segments. The measured data rate range between 19.27 Mbps and 35.23 Mbps, sufficient for UHD experience. The total service creation time (i.e., the time required to provision a service, measured since a new service deployment is requested until the overall orchestration system provides a response of the service successfully provisioned) is in the range of a few minutes [4-15].

In a further project, Video Acquisition and Production for Live Events was tested and validated [4-37]. It is common practice today for people to point their smartphones during events to the stage recording it in video for later play and share. The broadcasting and live event production world is aware that to achieve optimal user experience in an event, and increase its potential revenues, platforms must be agile and designed to provide support for massive user engagement meeting the experience provided by Facebook or YouTube. A mobile application was designed and implemented that is capable of acquiring high quality video in an event (c.f. Figure 4.9) and **stream the acquired video and audio flows through a/the 5G Neutral Host platform** [4-38], to a designated central acquisition service capable of receiving multiple streams and dynamically switching different video inputs based on the producer/director commands. The three core components of this vertical application include a *Media Controller* which **configures the various media flows**, a *Media Switcher*, which allows to select the main flow to stream in production, and multiple *Media Transcoders*, which allow to homogenize encoding from variable sources and to implement high quality media acquisition and subsequent transmission, adapted to the number of attached devices. Target KPIs which make the scenario viable for an actual media production in live events are reported in Table 4, together with the final measurement values.

**Table 4: Video Acquisition & Production KPIs**

| KPI | Description | Target | Measured |
|---|---|---|---|
| **User Experienced Data Rate** | Average network throughput used per mobile device. As each mobile device sends data at different levels, this value is an average between all of them. | **2-8 Mbps per mobile device** | **≈ 2.2 Mbps** |
| **Service latency** | Delay between the camera filming the event and the switcher output feed used to feed YouTube. | **<= 2.5 s** | **2.32 s** |
| **Service Instantiation Time** | Amount of time (seconds) needed to have the entire use case up and running. | **<= 120 s** | **84.04 s** |
| **Transcoder Scaling Time** | Time required to instantiate one Transcoder VNF after the scaling strategy. | **<= 60 s** | **30.59 s** |

The scenario has been trialled in Barcelona district @22 and in Bristol Millennium Square. Dedicated network slices were configured through an orchestration platform which automatically deployed the media service chain and regulated scale-out/-in of transcoders across the edge and core virtual infrastructures. The dedicated network slice included an isolated RAN, made of Wi-Fi and virtualised LTE-A radios. The key 5G functionalities for this use case are **automatic orchestration and scaling of virtualized network functions offered by the Network Function Virtualisation (NFV) MANO framework** [4-39].

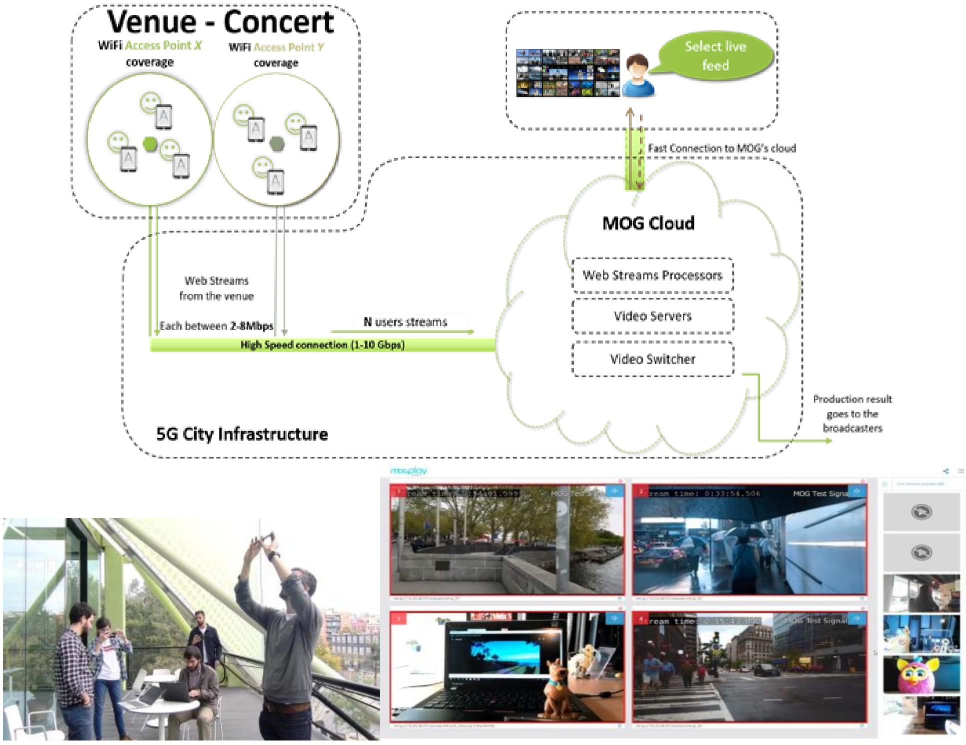



**Figure 4.9: Video Acquisition and Production in Barcelona**

In a further project of 5G PPP phase 3 [4-40] the objective is to analyse how 5G networks could support various scenarios where high quality video (e.g., in 4K, HD High Dynamic Range –HDR or 360º video) is generated and transmitted [4-41], [4-42]. Video content could be delivered from cameras located at places where an event is taking place to a television (TV) studio in the broadcasting centre or to a remote studio facility at the event location itself. Such video contents could be used both for **immediate live broadcasting** of the event or recorded to be further edited and used in TV programmes to be broadcasted later on. This use case requires the use of two 5G services, namely: **URLLC and eMBB**. Extremely low latency – below 5 ms – is required between remote locations and the central location to keep the different content providers synchronized. A minimum reliability level of 99.99% is required to generate combined high-quality A/V content. The functionalities and assets that will be developed include 5G-enabled camera backpacks for live recording of the itinerant musicians as well as applications for synchronizing and mixing the different video streams needed for remote video production.

Another project of 5G PPP phase 2 [4-43] provided two **media related solutions for home environments** [4-44] [4-45]. The first solution is related to 4K/8K streaming of media, because quality of video content is increasing to meet consumers' demands. Traditional TV broadcasting is the preference of home residents to enjoy high quality contents on large screen TVs (c.f. Table 5). This trend is set to continue with larger screens, with wider colour palettes and greater bit depth resolutions at faster frame rates. However, home networks may not be suitable for distributing video programs with such high quality around the home. The **requirement for high capacity becomes even more challenging** if multiple video streams are transmitted such as for picture-in-picture video, 360° video or a bouquet of video streams transmitted to a property.

**Table 5: Video Formats, Codecs, frame rates and bitrates**

| Resolution | Compression | Frame Rate (fps) | Network Bandwidth (Mb/s) |
|---|---|---|---|
| UHD 8k (8192x4320) | H.265/HEVC | 120 | 280 |

| | | | |
|---|---|---|---|
| UHD 4K(3840 x 2160) | H.265 HEVC | 60 | 26.8 |
| UHD 4K(3840 x 2160) | H.264 | 60 | 36.2 |

**5G is required for providing sufficiently high capacity to stream 4k/8k content** to TVs in the home, because existing TV streaming technologies such as digital video broadcast – second generation terrestrial (DVB-T2) do not meet the capacity requirements. **MEC capabilities introduce intelligence** in the streaming service that takes into account the knowledge about the network state and residents' context at the home gateway. Besides, MEC capabilities facilitate additional service innovations to be provided by third party service providers. The main performance indicators of this home use case are the delay and the video quality. In order to meet these requirements, a web-based TV application is developed for Linux based 4K UHD TVs. Using this application, TV users are able to display streaming video contents transmitted by a Visible Light Communication (VLC) sender. Integration of the TV is handled by a VLC receiver which is connected to the TV via an Ethernet port as shown in Figure 4.10.

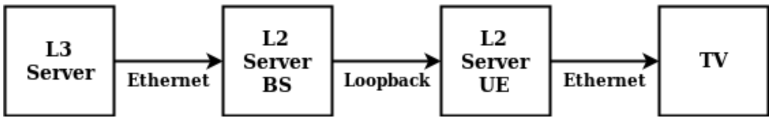



**Figure 4.10: TV interface in home UHD TV system**

In order to display more than one stream simultaneously, a native application was developed for Android based 4K UHD TVs. It is possible to display two videos such as picture-in-picture by listening on two different IP ports. With the help of this use case, TV users have the ability to watch the high-quality video content transmitted on the home network. **Due to the binary nature of VLC and mmWave radio channels, the demonstration setup consists of a network of Remote Radio Light Head (RRLH) Controllers on a 10 Gbit/sec Ethernet network in a home ring network**, provisioning a cluster of four or more RRLHs per room with each cluster providing 732.16 Mbits/sec/room, which can provide up to a total of 10 Gbit/sec for the whole home [4-46]. The setup exhibits **a latency of less than 1 ms on the air interface**.

The second solution is related to VR multiplayer gaming. Within this use case, a VR user is interacting with multiple users in a single environment. Every action involves transmitting and receiving media information simultaneously between each user and the host via a relay server as illustrated in Figure 4.11.

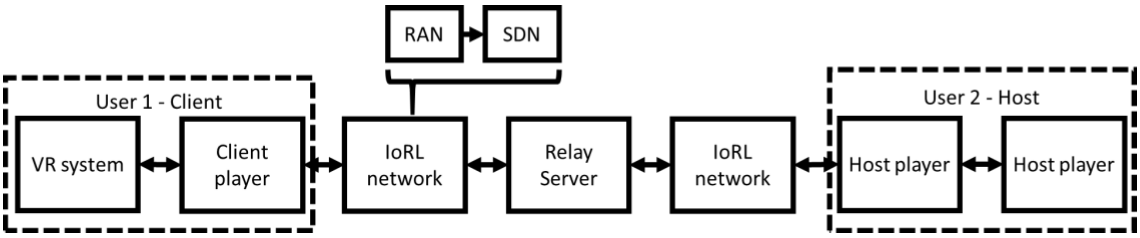



**Figure 4.11: Multiplayer data transfer between two users**

**5G is needed to provide a combination of high capacity to stream two HD videos to the two VR video screens,** with latency lower than 5 ms and high location accuracy to the VR headset. The used VR headset uses a 1080×1200 pixels resolution screen per eye and requires a very low latency to avoid motion sickness. Hence, latency and throughput are critical criteria for this use case. As suggested in [4-47] the project results have the potential for a novel VR headset tracking method that requires high location estimation accuracy, precision and latency to meet current VR standards.

Bit rate, tracking response and latency vary between VR headsets, applications and can be subjective to individual users. Proposals for entry level VR, 2K*2K at 30 fps, would demand 100 Mbps and 30 ms latency, while advanced VR with 4K*4K at 60 fps would require 400 Mbps with a maximum latency of 20 ms. Current tracking systems work with precision and accuracy in the sub-millimetre range. Although the system supports latency of less than 1 ms on the air interface, the position accuracy is 10 cm which is insufficient for the requirements of a VR headset and needs improvement to less than 1mm.

Another 5G PPP Phase 2 project [4-48] investigated a use case about the "Remote and Smart Production Pilot". Project partners made a live event field test, by supporting the broadcast via streaming from Cineteca de Matadero (Madrid) of the radio show La Radio es Sueño, organized by Radio 3. The pilot took advantage of edge computing technology for live content production. 5G-MEDIA developments in terms of architecture and virtual network functions were able to provide **real-time bandwidth and low latency (10 frames) to support remote audio-visual production.** Three cameras, connected to the edge of Telefónica, by its current fibre network from Matadero, captured the experience in situ while a technical team was responsible for the realization from the Radio Televisión Española facilities in Torrespaña (Madrid) using a remote interface for the realization of the content, and thus avoiding the displacement of a mobile unit and the realization equipment.

The pilot showed the viability of new models of events coverage. **The virtualized service improved the current processes of television production,** making them simpler and speeds up response times to cover events. This is achieved by replacing the usual technical and human deployment that television production entails through mobile units with the simple connection of cameras and sound equipment directly to the edge. The solution maintains the optimum quality and latency that conventional production requires, a very important factor, for example, in the retransmission of sporting events. In this way, production is greatly simplified by making it possible to perform it from a remote centralized point, thus avoiding large technical and human deployments and achieving savings of more than 30%.

One of 5G PPP phase 3 projects [4-53] is currently investigating enhanced smart campus facilities for innovative education experiences. The use of 5G mobile technologies can help to achieve personalized education, with attractive, updated, and available content at any time and place. Tactile applications with VR and Augmented Reality (AR) will play a crucial role in the quality of education allowing immersive learning based on independent exploration. Mapping student groups to different multimedia contents in a smart campus can dramatically increase the network load. In this use case, the project LOCUS is focusing on the **network management aspects relying on localization**. Location information and data analytics can be employed to achieve smart network management, demonstrating dynamic allocation of resources (e.g., based on usage, number of people in regions of interest) and/or improving network resilience (e.g., intelligent fault detection and diagnosis, as well as actionable analytics and detection of problematic areas where network events occur).

Last but not least, [4-54] is currently developing mechanisms to cope with **increasing demand in terms of data rates, number of simultaneous users connected and/or more stringent QoS requirements**. High quality and high-resolution audio-visual services are important drivers for increased downlink data rates, where 5G promises to provide cost-effective alternatives to today's **Content Delivery Network (CDN) approaches**. The main use cases identified in this project are the following:

- Ultra High-Fidelity Media;
- User & Machine Generated Content;
- Multi CDN selection;

- Immersive and Integrated Media and Gaming;
- On-site Live Event Experience;
- Cooperative Media Production.

Media is another vertical industry where 5G capabilities are expected to provide a paradigm shift on the production of new services both for indoor and outdoor environments. As already proven by 5G PPP projects, network slicing, edge computing, traffic steering, smart network management, location and context awareness, the enhanced 5G NR capabilities and the ability to use multiple new radio access technologies, the dynamic chaining of virtual functions are expected to revolutionize this sector.

### 4.1.4 Smart City

Cities are a flourishing business ecosystem for 5G. In fact, cities can host thousands of 5G Small Cells in order to guarantee deep coverage and advanced performance to end-users/citizens. Municipalities often own passive infrastructures (i.e. cabinets, lampposts, power, ducts and sometimes fibre infrastructure) and can equip these spaces at edge with computing and storage resources at affordable costs to serve locally many application requests for city services and requesting verticals. Therefore, it is a largely discussed business case that cities can easily become themselves huge distributed cloud infrastructures, or hyper-connected fabrics, which can be used as open environments for service deployment. From a business perspective, **pushing cloud architectures to the edge of the network makes economic sense**, since it extends one of the main benefits of the cloud paradigm – i.e. elasticity - to a new peripherical area – i.e. the edge – where data sources (e.g., video cameras, traffic and proximity sensors, temperature and humidity sensors) are deployed and tighter control loops can be implemented between sensors and actuators such as traffic lights; or where data consumers (i.e. end-users) are located and may request high responsiveness and throughput for their connectivity workloads.

[4-55] has built a common, multi-tenant, open platform that **extended the centralized cloud model to the edge of the network**, with live demonstrations and trials in Barcelona, Spain, Bristol, UK and Lucca, Italy. Among the various use cases deployed in the cities, one is specifically related to the operation of a detection service for unauthorized waste dumping. 5G City developed a smart system for real-time survey of violations related to the illegal ways of waste dumping in the collection areas.

The video stream acquired from an HD camera placed in the monitored area (c.f. Figure 4.12 top-right), was processed by a machine learning-based Infringement Recognition Server. When a potential violation was detected, a notification was sent to the Central Infringement Notification Service. Each notification contained the video frames of the detected violation, the timestamp when it was detected and the identification code of the area. At this stage, an Operator in the City Control Centre was able to check the notification and, displaying the frames, determine whether it was a true violation or not. In case of infringement, the Operator forwarded the notification to the Infringement Visualization Service and sent a message to the Police Officers, who can access photographic details of the analysis on their smartphones attached to a dedicated 5GCity radio network (sliced LTE-A on Neutral Host platform). This use case has been deployed and tested in the city of Lucca, Italy.

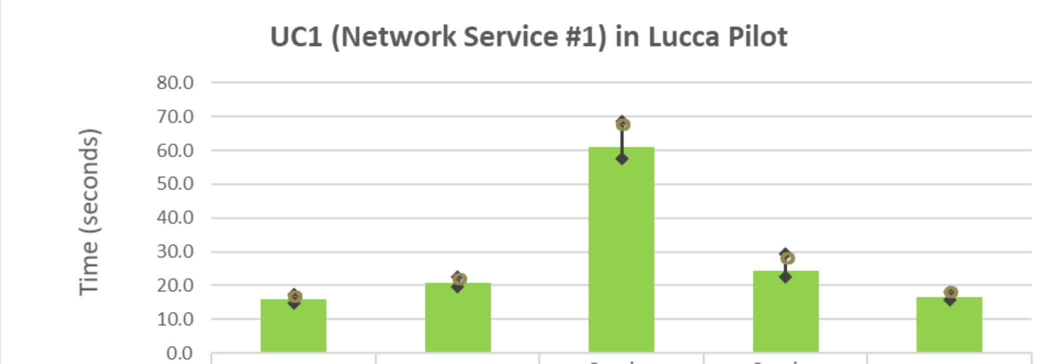

**Figure 4.12: Unauthorized Waste Dumping Prevention via 5GCity in Lucca, Italy**

**Table 6: Unauthorised Waste Dumping Prevention KPIs**

| KPI | Description | Target | Measured |
|---|---|---|---|
| **User Experienced Data Rate** | Average network throughput used per HD camera. | **4-10 Mbps per camera** | **≈ 4.04 Mbps per camera** |
| **Service Instantiation Time** | Amount of time (seconds) needed to have the entire use case up and running. | **<= 120 s** | **60.93 s** |
| **Accuracy (ACC)** | Ratio of the correctly classified subjects to the whole pool of subjects.<br><br>ACC = (True Positives + True Negatives) / Quantity of test data | **> 80%** | **≈83.3%** |
| **F1 Score** | Harmonic mean of the precision and recall:<br><br>F1Score = 2 * (Recall * Precision) / (Recall * Precision)<br><br>Precision is the ratio of correctly predicted positive observations to the total predicted positive observations.<br><br>Recall is the ratio of correctly predicted positive observations to the all observations in that class | **> 90%** | **≈90.9%** |
| **Time to detect infringement** | Total amount of time to detect the infringement and notify it | **< 2 mins** | **≈62.07 s** |

A key 5G functionality deployed by this use case was the **automatic orchestration of resources at the edge** and the possibility to **allocate on the fly the various network services** required for the service within a City Security **slice** upon a shared virtualization infrastructure spanning from sliced radio networks up to edge and core data centre.

Figure 4.13 presents details on all the time measurements for Slice Creation, Slice Activation, Service Instantiation and Service and Slice Removal) that have been collected in the trial.




| | Slice Creation | Slice Activation | Service Instantiation | Service Removal | Slice Removal |
|---|---|---|---|---|---|
| AVG | 15.82 | 20.86 | 60.93 | 24.50 | 16.73 |
| MIN | 14.80 | 19.69 | 57.71 | 22.51 | 15.62 |
| MAX | 17.30 | 22.46 | 68.60 | 29.31 | 18.18 |
| 90-PERCENTILE | 16.46 | 21.74 | 67.46 | 28.04 | 17.65 |

**Figure 4.13: Indicative Service Management Measurements**

Another 5G PPP Phase 2 project [4-56] provided a solution for the lighting of a smart city [4-57]. In a smart city, an intelligent public lighting system is expected to be deployed to enable secure remote control of every single lighting in real time, in order to adjust the lighting intensity and efficiently manage energy consumption with a target to reduce energy costs of up to 80%. Moreover, the system should allow real-time and history-based energy consumption measurements. Furthermore, the network service provider should be able to proactively spot the malfunctions in the physical and/or virtual communication infrastructure.

For smart cities based on IoT, the **5G mMTC capabilities are typically required**, demanding highly scalable solutions to meet the 5G PPP KPI in terms of supporting 1 million devices per square kilo meters. This smart city lighting use case focuses on deploying network slices to protect the control traffic of the lighting system, and **scalable security management** for smart city applications based on large-scale IoT/mMTC. The developed solution was based on E2E **network slicing** covering both RAN and core network to ensure that the lighting control communications are delivered in a timely, robust and secure way. Moreover, the security solution is based on software switches and implemented by extending the open source Open Virtual Switch (OVS). The solution supports various security management tasks such as firewalling, intrusion detection, intrusion prevention, service confinement, data leak prevention, and law enforcement through traffic control rules.

Two experimental sets of validation tests have been conducted. The first set of experiments have been conducted in a real-world operational environment. More than 50 lighting poles have been deployed in a university campus in Bucharest, Romania, where the effectiveness of E2E network slicing was validated, and the control of the lighting system through an application was demonstrated. The second set of experiments has been performed in a lab-based setting. Experimental results have shown high scalability of the solution in a very demanding scenario where over a quarter of a million emulated Narrow-Band (NB)-IoT devices were sending a total of 3 Gbps traffic through one OVS machine where over a quarter of million firewall rules were installed. As shown in Figure 4.14, the system with one OVS machine only experienced a minimal delay of less than 3 ms and minimal packet loss ratio of 2.5% for up to 262,144 devices. Therefore, only four such OVS machines are required per square kilo meter to deal with 1 million devices [4-58], fulfilling the requirements of the corresponding 5G mMTC KPI mentioned above.

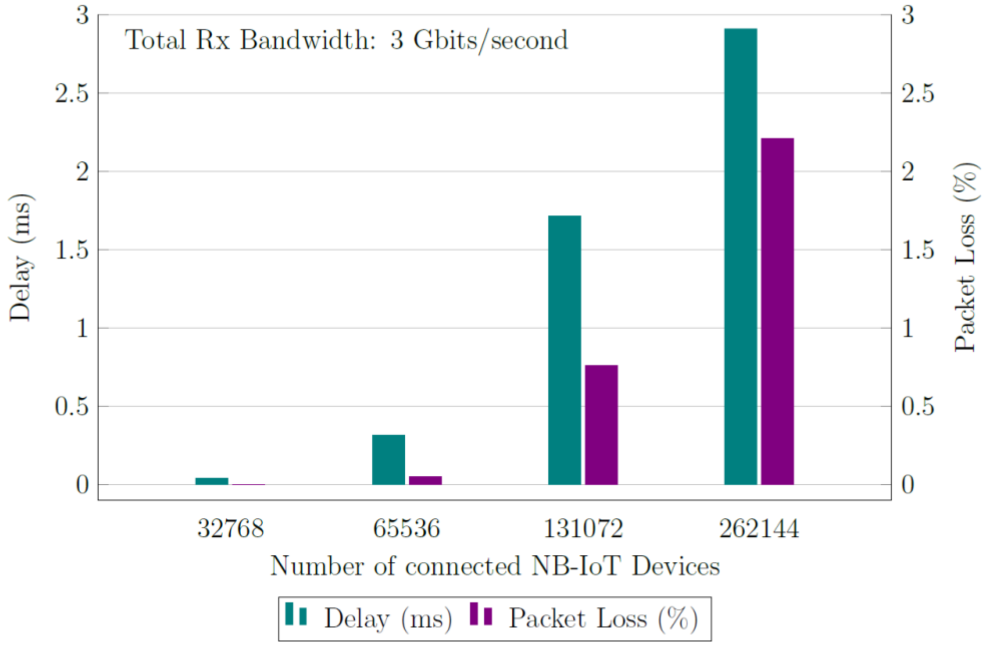



**Figure 4.14: Empirical results of an IoT-based smart city use case**

The key achievements in this use case include the demonstration of **guaranteed QoS in IoT applications** through network slicing, and the contribution to the open source OVS project in enabling 5G-aware scalable software-based network slicing in the data plane and scalable firewall solutions to mMTC use cases such as IoT. In addition, this use case has achieved a machine-learning-based noisy neighbour mitigation algorithm to further improve the availability and performance of the 5G virtual communication infrastructure.

[4-53] is currently investigating solutions for people's mobility and flow monitoring in smart environments in a city. The project is leveraging location and context information in smart environments (e.g., personalized recommendations in shopping malls) through advanced localization solutions and ability to support eMBB 5G services. **Context information and physical analytics** will be inferred not only for terminals/devices but also for device-free objects/bodies using radar solutions.

Airports and malls host some of the most dynamic indoor traffic in the world, as well as mobile traffic hotspots. **Embedded location services** will help track the movement of visitors in the venue. This will not only help mobile operators to optimize network resources; in both airports and shopping malls the localization and mobility pattern analysis can be used for pushing information or advertisement. According to [4-59], "the 5G system shall be able to provide positioning service to support AR applications with 3 m horizontal position accuracy, 90% availability". [4-53] will explore a vertical application related to the retail sector, which involves the combination of the advanced localization solutions and the ability to support eMBB 5G services and machine learning/artificial intelligence (ML/AI)–powered vertical services. The main service offered will include real-time AI-powered personalized shop recommendations through an application, based on both user/shop locations, as well as user's profile and preferences. Other complementary services may include navigation instructions, video sharing on promotions and so on. A set of smaller scale simulations will take place for algorithmic design and model training with offline data prior to demonstration.

As for most of the verticals, it is always important to evaluate the business case apart from the technological one. [4-60] has provided a techno-economic analysis on the smart city scenario with a focus on non-real-time-critical processes and logistics for dense urban and suburban areas management. The applications are numerous, from traffic management, waste collection and management, parking detection and information, to air monitoring. They are characterized by small payloads and light constraints on latency.

The analysis on smart city IoT networks takes the 3GPP Release 15 NB-IoT and mMTC networks as a baseline and looks into the cost elements for upgrading to Release 16. The software upgrade needed is deemed to be free of deployment costs and also the existing macro cell network is assumed sufficient to cover a large city like Paris.

The costs in terms of the required number of Physical Resource Blocks for this Release 16 IoT network were calculated using traffic assumptions for 2020 and 2030, considering different Inter Site Distances for the macro cells and focusing on the 700 MHz frequency band. The spectrum requirement of roughly 1 MHz that represents about 5% of the total bandwidth allocated in the 700 MHz band for the macro cells. Medium frequency bands (between 2 and 6 GHz) should also be allocated to 5G mMTC services. Considering the fact that 5G macro cells in Release 16 will be supported by a dense underlay of small cells for eMBB 5G applications, releasing this amount of spectrum is seen as manageable and also as a potential to increase the operator revenues by better utilization of spectrum.

So, the project concluded that an upgrade for the NB-IoT and mMTC network from 3GPP Release15 to Release 16 is viable, from a cost point of view since it will require only a software upgrade and also from a spectrum point of view with roughly 5% of the total spectrum allocated to mMTC services [4-21], [4-22].

Smart cities are expected to make significant use of the 5G capabilities to improve the life of the citizens. 5G PPP projects have already demonstrated that there are viable business opportunities that rely on network slicing, edge computing, advanced security schemes, the evolved NR capabilities, the use of contextual information (e.g., location) and the provision of guaranteed QoS.

## 4.1.5 Healthcare

The healthcare sector has undeniably a lot to benefit from 5G networks as these will enable a number of innovative applications. As a first example, the [4-56] has designed, developed and successfully demonstrated how the operation of an ambulance can be improved using 5G networks. A 5G-connected eHealth ambulance can act as a high-speed mobile connection hub for the emergency medical force comprising both paramedics staff and their on-board equipment and wearables such as head cameras to allow on-board real-time video streaming of the patients to the awaiting accident and emergency department team at the destination hospital, and optionally shared with other specialists out of the hospital to help timely diagnosis and treatment on the route. This use case will advance the emergency ambulance services by developing a 5G-enabled collaborative ecosystem involving different healthcare stakeholders to save lives and help create improved eHealth experiences and outcomes for both healthcare personnel including paramedics and their colleagues, and also patients on the move.

This 5G eHealth Ambulance use case **leverages network slicing** with video optimizer **VNFs** and machine learning based Telestroke VNFs as a service for the on-board real-time video streaming and in-network optimization from a 5G-enabled ambulance to the hospital. The Telestroke VNFs are deployed in the **edge of 5G networks** to allow timely diagnosis of potential stroke at a MEC platform. The diagnosis results are communicated to the hospital, together with real-time video streaming to allow effective remote treatment guidance for on-board patients in critical conditions. In this use case, paramedics wear or hold a 5G user device to stream video to a doctor in the hospital to perform a real-time patient assessment, assisted by the Telestroke VNF. In addition, a set of videos can be simultaneously streamed and optimized by several video optimizer VNFs deployed in the data plane of the 5G networks including the edge to ensure the quality of the mission-critical video streaming.

This eHealth ambulance use case can be aligned with the 5G eMBB use case and thus, requires **broadband mobile communications**. The KPIs defined for this use case include **guaranteed Quality of Experience** of the streamed video for the remote doctors through network slicing, and also significant bandwidth savings for numerous parallel video streams whilst maintaining the QoE through video optimization VNFs.

Accordingly, two experimental sets of validation tests have been conducted in a lab-based setting. In the first set of tests, the effectiveness of network slicing as provided in [4-56] in the data plane was assessed [4-61]. Firstly, no network slicing was applied, and the video was streamed in a best effort mode. When background traffic was increasing, the quality of the video streaming was compromised and distortions were observed. Secondly, in this same situation, when E2E network slicing was enabled for the video streaming, the perceived quality of the video was assured even if the competing background traffic was still in place. This comparison as shown in Figure 4.15 has validated that this solution is able to meet the required QoE.

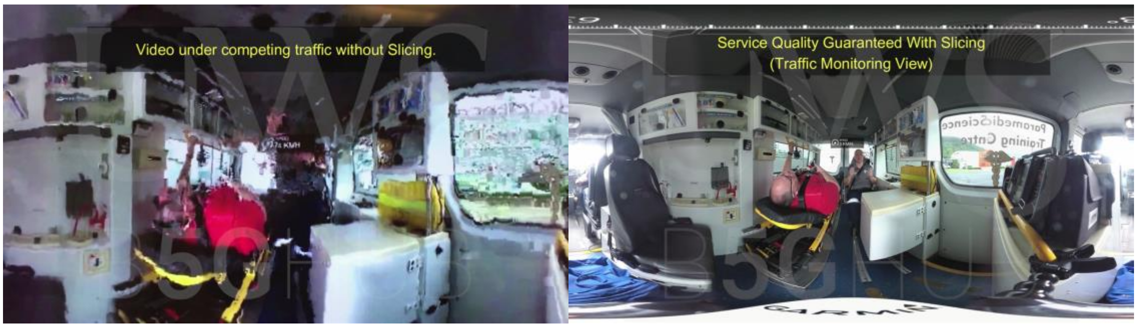



**Figure 4.15: Empirical results on QoE in a video-based eHealth ambulance a) without network slicing (left side) and b) with network slicing(right side)**

In the second set of experiments, the capabilities of the video optimizer VNFs have been validated [4-62]. As shown in Figure 4.16, empirical results have demonstrated the ability to reduce the total bandwidth consumed by using these tailored VNFs, which are able to optimize the real-time video transmissions, and consequently alleviate the whole network traffic in terms of network capacity. In particular, this figure shows the results obtained when 1,536 video flows were simultaneously being streamed, representing a large-scale deployment of this use case. Each flow has 3.8 Megabyte (MB) traffic and was sent at 1 Mbps during a stream duration of 30.57s and thus a total of about 6 GB for the whole transmission. This experiment has automatically deployed 12 VNFs (each one able to handle up to 128 video flows) to yield close to 3 GB bandwidth saving at the end of the transmission without compromising the perceived video quality for the doctor at the hospital. In addition, this use case has developed a machine learning based handover trigger algorithm able to predict forthcoming anomaly in the RAN and thus trigger handovers for the ambulance to continue operating in an optimal way.

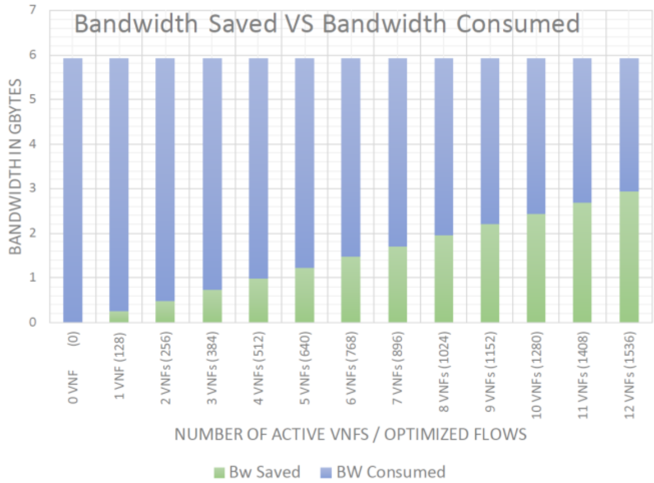



**Figure 4.16: Empirical results on video optimization for bandwidth saving in a video-based eHealth ambulance use case through VNFs**

Another interesting example of an innovative health service has been developed and validated by [4-12]. The use case is composed of users wearing a smart wearable device (e.g., smart shirt or smart watch) with 5G connectivity (either directly or via a mobile phone) that can detect a potential health issue (e.g., heart-attack, high blood pressure, etc.). The wearable periodically reports the health status to a central server running on the cloud/edge. If the monitoring data shows a potential issue/accident of the user, the central server issues an alarm to the wearable device so the user can mark it as a false alarm, or the issue will be confirmed if there is no feedback within a certain interval.

When an alarm is detected, the central server requests for an emergency team to be deployed at the location of the user. This is possible because the Global Positioning System (GPS) location of the user that had an accident is known, as well as the **location** of all available emergency teams. Actually, since a lot of information is known about the accident (e.g., the recent story of medical information from the user), the system can decide which is the best emergency team to deploy (not only considering location, but also the needs of the accident). Note that this cannot be done today, and much less **in a fully automated way** (i.e., with no human intervention). This cannot be done with 4G either: (i) the **mMTC and low power consumption** characteristics of 5G are required to assume the availability of remote monitoring capabilities, (ii) **very low latencies** requiring dynamic deployment of services at the edge are needed to support the use of Augmented Reality tools (described next).

Once an emergency is detected/predicted, an emergency team is sent to the location of the emergency, automatically by the centralized eHealth server. In addition to this, the centralized server also requests **deployment of an edge service** closer to the user (c.f. Figure 4.17). The edge service is deployed to lower the latency and provide features to ambulances or patients (e.g., patient history, remote consultation, video streaming, AR/VR features etc.). Once the edge service is deployed (on computing resources closer to the accident, meeting the required latency and bandwidth constraints), the edge application establishes a connection to the user's hospital, obtaining the health records and establishes a connection with the emergency teams that are involved in the emergency response. These teams can obtain the records from the edge service or, in case it is needed, the paramedics can establish video stream connection to a medical specialist (e.g., surgeon) located at a remote site (e.g., hospital far away from the emergency location) to perform remote surgery or consultation through the edge service. The edge service can also be used as video streaming hub to enable AR/VR applications supporting the emergency personnel deployed (e.g., to guide the team to the actual location of the accident when it is not directly reachable by vehicle and to show medical information in real time while treating the patient, thus making the process more efficient and less error-prone).

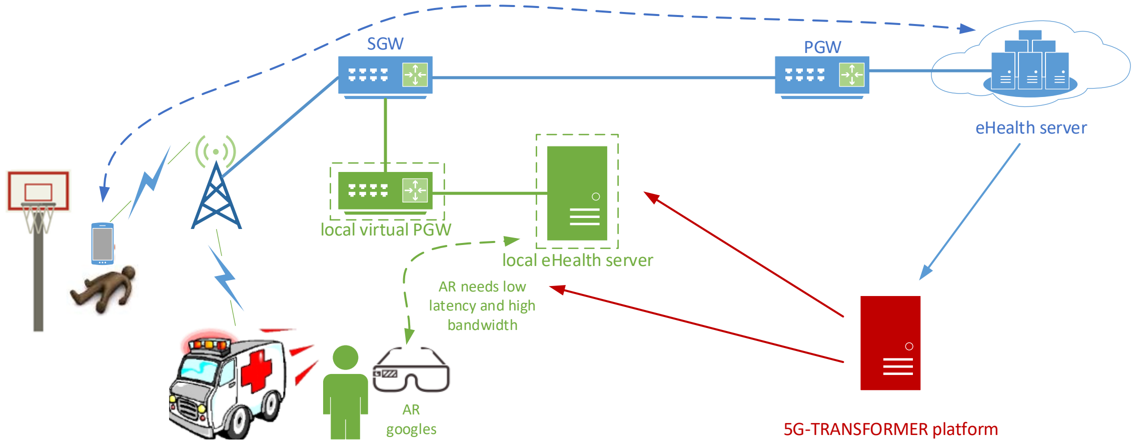



**Figure 4.17 Scenario triggered by an accident**

This has demonstrated the benefits of deploying low-latency communication services at the edge of the network with the goal to lower the door-to-balloon time (i.e., delay between the arrival of a patient at the hospital, and the re-opening of the blocked artery) and can potentially increase the probability of saving people's life. With this technology, the project achieved reducing the latency from 120 ms to 35 ms.

For this use case, the main KPI considered was the **service creation time, including federation between different administrative domains**. The project achieved to deploy emergency NFV-Network Service (NS) over two different domains at around 270 seconds. Compared to the 5G PPP expected service creation time this improvement is in the order of magnitude (significantly less than 90 min). Note that for this, a non-standalone system was used, which means that a 4G virtual Evolved Packet Core (vEPC) was used.

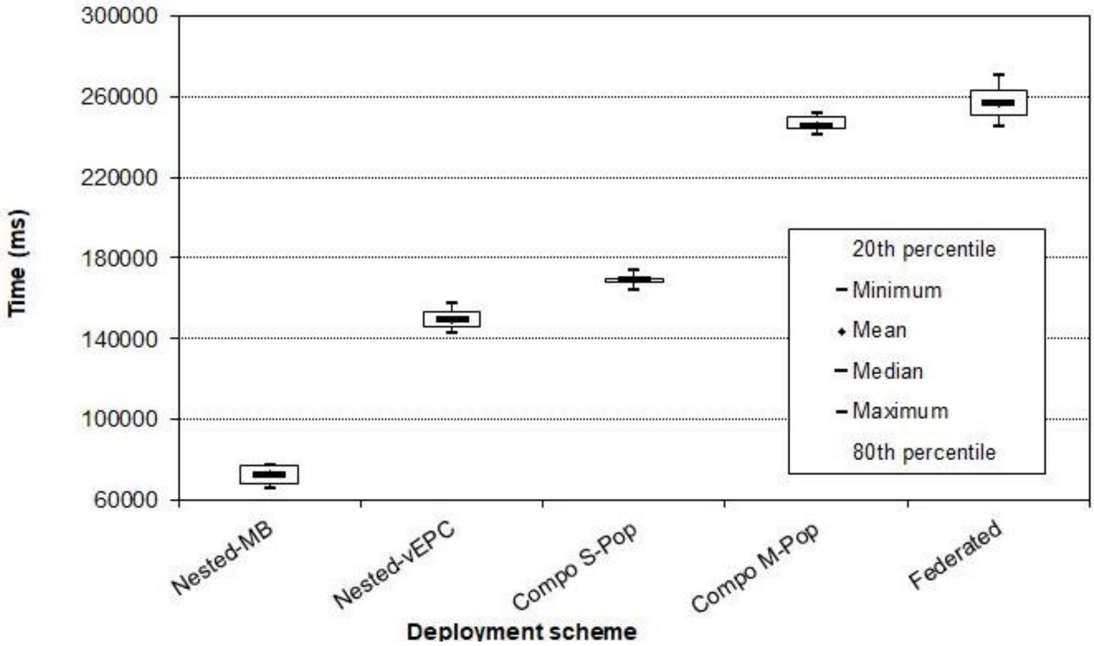



**Figure 4.18: E-Health Composite service creation time using Federation**

The results in Figure 4.18 are derived from measuring the instantiation time (from left to right): 1) & 2) for each single nested NFV-NSs of the eHealth composite NFV-NS (e.g., the nested-Monitoring Backend and the nested-vEPC); 3) the eHealth composite NFV-NS instantiated in a single NFV Infrastructure Point of Presence (NFVI-PoP); 4) the eHealth composite NFV-NS instantiated over multiple NFVI-PoPs; 5) the eHealth composite NFV-NS instantiated using service federation.

In addition to the quantitative evaluation, an actual demonstration of this full use case took place on Nov. 27th at 5TONIC premises in Madrid. Real ambulances (from SAMUR_PC service of Madrid City Hall) and firefighters (from Madrid City Hall) were involved using real 5G equipment. The central eHealth server and the Packet Data Network Gateway (PGW) are deployed at Centre Tecnològic Telecomunicacions Catalunya (CTTC) in Barcelona, while the Signalling Gateway (SGW), radio access and the local virtual PGW and local eHealth server are automatically deployed at 5TONIC in Madrid (i.e., at the edge, very close to the location of the emergency), as triggered by the accident. A video of the demonstration event is available at [4-64]. Additionally, an exploitation workshop, organized by the Emergency services of the City Hall of Madrid took place on March 2nd, 2020.

Additional use cases for medical services are under development in 5G PPP as described at [4-41] and [4-63]. The first one considers the presence of at least one doctor in the ambulance, who is required to make a call to a regulator in the emergency care centre to discuss patient status and decide on clinical interventions. In addition, a medical specialist such as a cardiologist may be consulted in specific cases. The ambulance doctor may be able to correctly position the probe to acquire echocardiograms of sufficient diagnostic quality. However, he may still be dependent on an additional medical specialist (e.g., Cardiologist) to assist in diagnosing the data properly. This use case requires specific settings that will be provided by 5G network. **High reliability and low latency communication** will be required for eye-hand coordination in case of tele-sonography examinations based on video, AR/VR and/or remotely controlled robotic ultrasound probes. Bandwidth requirements are also foreseen to support 4K video streaming for remote (doctors at hospital site) patient monitoring. In addition to that, interaction with vertical providers require a 5G network. The project provides a solution for teleguidance of a paramedic in the ambulance to support diagnosis and intervention for medical emergencies. Furthermore, it provides the Xperteye smart-glass solution, enabling the sharing of first-person point-of-view camera feeds with the medical personnel at the hospital. Speeds above 100 Km/h, 2 Gbit/s for UHD multi-camera video streams from hospital to paramedic treating the patient and high-resolution streaming from the ultrasound probe at the paramedic to the remote expert(s) in the hospital will be supported. The target for latency is below 10 ms and the target for reliability will be greater than 99.999%.

The second use case is related to the operation of an ambulance by providing an optimal ambulance routing. While optimal ambulance positioning and routing has been addressed extensively from a decision-making perspective, the emergence of technologies such as 5G actually enable the fast and reliable acquisition of data. This is of significant importance with respect to the changing factors of an urban or sub-urban environment such as traffic flow, changing road graph, population mobility, and hospital capabilities and availability as well 5G coverage to be exploited by AI powered decision making for dynamic optimal ambulance routing.

**Latency** problems may affect the decision of the Hospital Operations Centre in which hospital's dispatch centre should be selected in order to send the ambulance based on the patient's condition, as well as other parameters such as traffic, 5G coverage, road closures etc. As the ambulance is moving with high speed it is essential to support these mobility requirements in order to provide as seamless service as possible. Last but not least, **location accuracy** could also affect the routing as well as the ambulance driver's perception of the location and where to head based on the system recommendations. This could also affect the time to reach the destination which is a crucial parameter when carrying a patient that needs to be transported in a hospital immediately. Reliability, latency and location accuracy related KPIs are of utmost importance in this scenario.

More specifically, the main requirements to be validated for this use case are: (i) low latency (<10ms E2E), (ii) Mobility (up to 100Km/h), and (iii) reliability and availability (above 99.99%).

A third use case is related to health monitoring and emergency situation notification. This use case addresses solutions for remote health monitoring of people, especially when already diagnosed with a critical disease. Such a solution includes consultation with remote medical attendants, collaboration between remote and local medical personnel and leveraging advanced technology to detect medical conditions that require immediate attention. The main features offered by this use case involve (a) remote health monitoring services leveraging a variety of data sources, and (b) quick, reliable notifications to nearby ambulances, medical professionals and family members. The use case will leverage wearable devices and patches tracking a person's vital signs and having them aggregated inside an IoT-based platform; Figure 4.19 outlines the planned architecture.

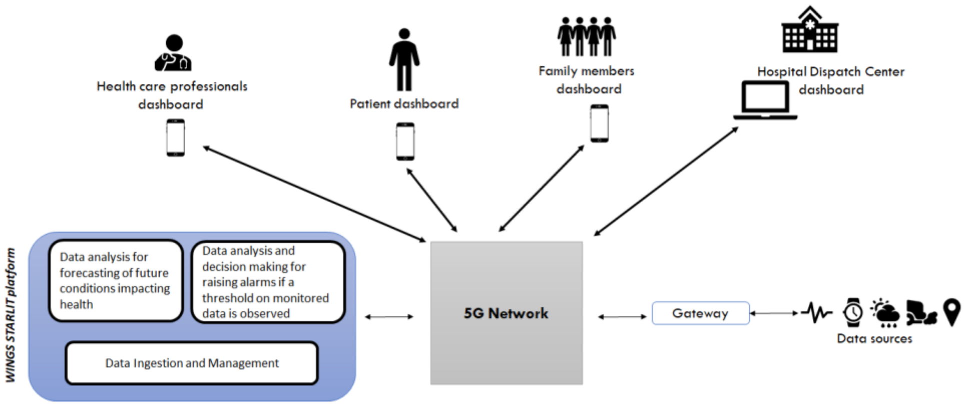



**Figure 4.19: health monitoring and emergency situation notification**

**Latency** problems may impact the real-time monitoring service as measurements may be displayed later than originally received. **Reliability, latency and location accuracy** related KPIs are of utmost importance in a remote health monitoring scenario. More specifically, the main requirements to be validated are: (i) low latency (<10 ms E2E), (ii) Mobility (up to 100Km/h), and (iii) reliability and availability (above 99.99%).

Last but not least, 5G networks are expected to support wirelessly advanced life-saving applications, that could not be supported before. [4-40] is studying the use case of a wireless operating room. This use case addresses a more flexible operating room thanks to the use of wireless communications based on 5G. This use case requires the use of **two types of slices** with stringent requirement that can be met using 5G networks. The URLLC slice is needed for surgeon guidance and unplanned procedures whereas the eMBB slice is needed for high quality video streaming and augmented reality applications. These slices are used to serve the verticals needed for the demonstration of the use case. An Operating Room, partially dedicated to research project, is available for extension with 5G equipment and advanced AR applications. For this use case **latency below 5 ms**, **reliability above 99.9999% and aggregate data rate of 10Gbps** resulting from three simultaneous HD uncompressed video for AR application.

Innovative healthcare applications are expected to provide important services to citizens. Their operational environment has however some demanding requirements. 5G networks can meet these requirements with the use of network slicing, edge computing, advanced 5G NR capabilities, smart network management and accurate location awareness, dynamic service chaining and guaranteed QoS.

### 4.1.6 Factory of the future

In case of smart factories, 5G networks and their services can improve the effectiveness of the workforce and bring down the production costs. The manufacturing industry has taken concrete steps to embrace the potential of 5G as a complement to their needs. The 5G Alliance for Connected Industries and Automation (5G-ACIA), launched in April 2018 [4-65], aims to firstly, establish a common language between OT (operational technology) and ICT (information and communications technology) and secondly, to ensure that the requirements [4-66] of the industrial domain are considered in 5G standardization, ultimately paving the way for a 5G ecosystem for the industrial domain.

In the context of the 5G PPP [4-29] is designing the following advanced services. The first one is called the "Digital Twin" and is a virtual representation of a production line (c.f. Figure 4.20). If something unexpected happens in the production flow for instance a component is delivered out of sequence, several alternative scenarios can be simulated in parallel in the virtual environment of the digital twin and the most appropriate alternative can be applied to the "real" twin. To make this possible, the real machinery is outfitted with a **massive number of sensors** that continuously send status data. This service requires a **huge throughput and very low latency** to avoid delays in the digital twin representation. The low latency requirement of 15 ms is imposed by the need to read data from PLCs. The broadband connectivity is required because cameras are also used to shape the twin (250 Mbps). Finally, the device density refers to the cumulative number of connected devices which is dominated by a plethora of sparse sensors (50 Mbps/m2 are required). Reliability- and latency-related KPIs are of utmost importance in this Industry 4.0 scenario. More specifically, the requirements are: (i) Availability/Reliability of 99.9999%; (ii) Latency (E2E) < 15 ms ; (iii) Bandwidth up to 250 Mbps ; (iv) Connection Density up to 5000devices/km2 ; (v) Mobility 3-50 km/h ; and (vi) Wide-Area Coverage of 5 km$_2$.


**Figure 4.20 Digital Twin Application**

The second service is aiming to develop new functionalities for a zero-defect manufacturing system. One of the desired use cases is to allow the operator to make remote configuration of the Coordinate Measuring Machine (CMM), as shown in Figure 4.21. The CMM can measure autonomously, but it must be programmed previously by an operator measuring a hardware piece with the same sizes. In this use case, the operator programs the CMM remotely using a virtual joystick in a mobile device, which at the same moment, displays a live video of the CMM to the operator to provide direct feedback. The use case will be composed of **two non-permanent slices**, one is an eMBB slice for transmitting the video streaming and the other is a URLLC slice to control the synchronization of the video stream and the virtual joystick. This service requires the use of network slicing capabilities and **very low latencies and high reliability** for data transmission. For the eMBB slice, the key requirement for 5G is a bandwidth of 10 Mbps. For the URLLC slice the critical parameter is to provide high reliability of 99.99%, while the latency requirement of 5 ms will also play an important role between the synchronization of the video stream and the virtual joystick.

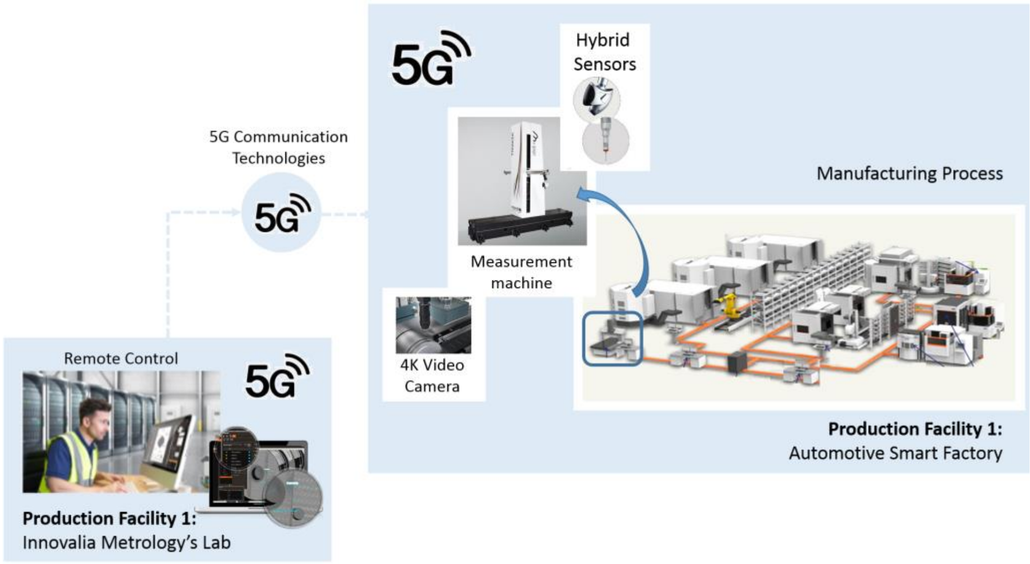



**Figure 4.21 Connected Worker Remote Operation of Quality Control Equipment**

[4-49] aims at demonstrating, evaluating and validating the use of 5G for manufacturing applications in real environments. It focuses on seven different use cases that are considered for the evaluation and validation at three trials sites, namely the Ericsson smart factory in Kista, the Fraunhofer Institute for Production Technology (IPT) shop floor in Aachen and the Bosch semiconductor factory in Reutlingen. The selected use cases cover a wide range of application areas for 5G in smart manufacturing. These application areas include process automation, human-machine interfaces and production IT, and logistic and warehousing. Furthermore, six new forward-looking use cases have been identified which go beyond what is currently being considered for the evaluation and validation in 5G trials. A detailed description of the use cases, requirements and KPIs can be found in [4-50].

The considered use cases in this project can be categorized in three groups:

1. Use case targeting time-critical process optimization inside a factory.
2. Use cases targeting non-real-time critical in-factory communication for large number of devices.
3. Use cases targeting remote operation and massive information exchanges.

At the Fraunhofer IPT shop floor in Aachen two use cases are implemented. These include the validation of a 5G versatile multi-sensor platform for a digital twin as well as a 5G-based wireless acoustic emission sensor that is integrated into a milling machine and is used to monitor the milling process of a jet engine component. At the Kista trial site the first use case focuses on a factory floor collaboration between stationary robots and a mobile robot via 5G. The second use case complements the first by considering an interaction between the mobile robot and a human. The third use case to be trialled at the Kista trial site considers AR-based visualization of information from the factory floor. At the Bosch semiconductor factory, the project is working towards the realization of two use cases: cloud-based mobile robotics and Time Sensitive Networking (TSN)/industrial Local Area Network (LAN) over 5G. The 5G deployment at the trial sites is completed for the Aachen and Kista trial site ([4-51]).

The stringent requirements on the wireless infrastructure are explained further in the following using the use case of the acoustic emission sensor system and the TSN/industrial LAN over 5G as an example: The wireless Acoustic Emission (AE) sensor system is a system where a machine is being monitored and controlled based on smart AE sensors mounted on the machine table that are sending raw or pre-processed data over 5G to applications hosted in the edge cloud as shown in Figure 4.22. Requirements of AE traffic streams are depicted in Table 7. These data streams impose high uplink bandwidth requirements on the communication link. In addition to this, the 5G system also needs to provide deterministic low latency to react in a timely manner on the detection of critical events, such as, e.g. tool break. Additionally, time synchronization is required between the AE sensor and the machine it is operated in, in order to align the sensor data to, e.g. a certain position on the workpiece for advanced process diagnostics.

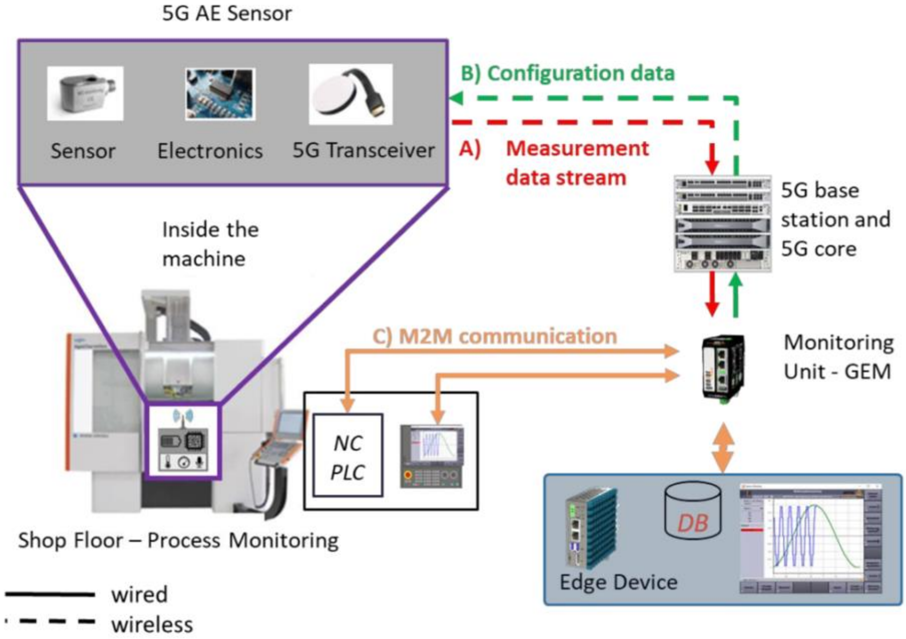



**Figure 4.22: 5G based wireless acoustic emission system design**

**Table 7: Requirement of AE traffic streams [4-51]**

| Communication | Data rate [Mbit/s] | Latency [ms] | Jitter [ms] | Time Synchronization Error [ms] | Communication Service Reliability |
|---|---|---|---|---|---|
| **A) Measurement data** | ≥ 8 | < 10 | < 1 | < 0.1 | ≥ 99.999 % |
| **B) Configuration data** | Low | < 1.000 | Not relevant | Not relevant | ≥ 99.999 % |

For the TSN/industrial LAN use case periodic and symmetric data traffic is observed between industrial controllers. One of the key features here is to have network slicing to support transporting multiple TSN streams with different QoS requirements over the same communication platform. Considering different requirements of the TSN streams of high availability and security, network slicing features is more suitable compared to LTE QoS classes.

Looking at the wide applications areas covered by these use cases, it is observed that the performance, functional and operational requirements imposed on the 5G system vary widely, which cannot be fully satisfied by the LTE. For example, most of the use case requires deterministic latency along with time synchronization which only 5G can support. Moreover, edge cloud and network slicing are also essential enablers.

[4-53] is currently investigating many use cases for the factory of the future. One of these is related on the flexibility required by production in Industry 4.0 and deep automation of seaport activities that require the massive introduction of Automated Guided Vehicles (AGVs) that depend on **accurate and real-time localization** to achieve high accurate navigation (centimetric in some scenarios). In particular, in factory 4.0 the position accuracy required for AGV can range from some dozens of centimetres, when moving between work cells, to a few centimetres when the AGV has to interact with precision robotic arms. In seaport outdoor logistics (c.f. Figure 4.23), the position accuracy required by AGVs shuttling freights between storage and loading areas is less than 1 meter. 5G features together with multi-RAT integration can provide such accurate location analytics to replace magnetic floor tapes, LIDAR, and camera sensors used nowadays for AGV navigation. After analysis of the results and data obtained by relevant studies and test activities, the behaviour of a simulated AGV in industrial logistics cases will be analysed to evaluate the accuracy required by the different cases and the sensitivity to the 5G positioning system accuracy tolerance. The use cases that will be simulated will be (i) a warehouse where the AGV will shuttle materials between different locations, and (ii) an assembly line where the AGV will replace a conveyor.

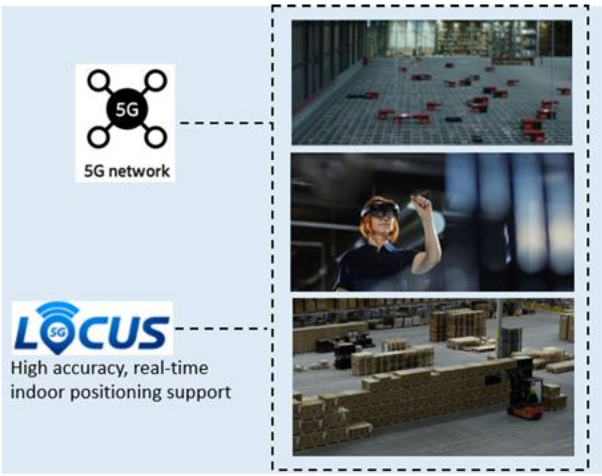



**Figure 4.23: Automated guided vehicles in smart factories**

5G networks can increase the productivity in smart factories. The currently active projects are developing solutions that among other 5G features are relying in smart slicing, edge computing, the enhanced 5G NR capabilities, advanced security, location and context awareness mechanisms as well guaranteed QoS.

### 4.1.7 Energy

Power distribution networks oversee transporting high-voltage power lines from the power generation plants to the power substations, located closer to the consumers, where high-voltage power lines are transformed to low-voltage lines. These are critical infrastructures providing the electricity that we all consume at home every day. Any failure along the transportation network will cause an imminent power interruption. Thus, automated solutions or real-time support of operators and crews dispatched in the field are of paramount importance.

[4-56] has dealt with the support of sophisticated self-healing protocols that are already present in the power distribution network in order to avoid any power interruption caused by short-circuits, malfunctions, natural disasters, animals and so on. These mission-critical self-healing protocols rely on high-quality underlying communication infrastructure to function in a reliable and real-time manner. The self-healing capabilities are based on the detection of the malfunction in a given segment of the power line and the automatic reconfiguration of the power network to

redirect the power to other routes not affected. Thus, assuming that power is transported close to speed of light and that our current power lines are working at 50-60 Hz on alternate electricity. It means that a complete alternate cycle is happening 50 times in a second, i.e., 16-20 msec. In order to detect problems in the network, a solution needs to perform 4 different measurements along a given cycle, leading to very **strict URLLC requirements** around 4-5 ms, and these values need to be transmitted to the next hop of the power grid before the next cycle reading, to allow the self-healing capabilities to be enforced, leading to an effective maximum 4-5 ms delay. To address such demanding requirements, hardware-accelerated **network slicing technologies** over the 5G **edge** and core network segments have been provided to demonstrate the feasibility of using the 5G network to truly isolate the critical traffic used for the Smart Grid from the traffic that is being generated for other users of the public network.

This smart grid self-healing use case can be aligned with the 5G URLLC use case and thus, requires ultra-reliable low-latency communication. The KPIs defined for this use case include guaranteed **low latency and low packet loss ratio through hardware-accelerated network slicing** [4-67]. To validate the solution in respect to the above URLLC requirements, experimental tests have been carried out in a lab setting. Figure 4.24 shows empirical results where four different slices were deployed over the same physical infrastructure in the network segment between the edges of the 5G network and the core network. Slices are ordered by priority. Thus, the first slice, with the least priority, has background user traffic corresponding to final users of the 5G network. The second slice is for the Smart Grid management traffic used to send information from the power distribution network to the Supervisory Control and Data Acquisition (SCADA) systems. The data is used to control and monitor in real time the status of the network. The third slice is for the ultra-reliable Smart Grid control traffic used to implement the self-healing capabilities of the power grid. And finally, the fourth slice, with the highest priority, is used to deliver the 5G infrastructure control traffic ensuring that the control of the 5G communication network is already protected. The first slice is the traffic of 32 simulations users, the second and third slices correspond to the traffic of 32 power distribution units and the fourth slices corresponds to 32 simulations communication devices. A total of 28.8 Gbps was sent over a 10 Gbp network link creating high stressed conditions to demonstrate the suitability of network slicing to protect the self-healing capabilities of the power grid. The rest is traffic coming from the final users of the 5G network. As highlighted in the inset of the results, all the **three prioritized slices guaranteed the quality** of the corresponding services in terms of both low delay of under 0.3 ms and low packet loss ratio of under 0.3% in this saturation traffic condition.

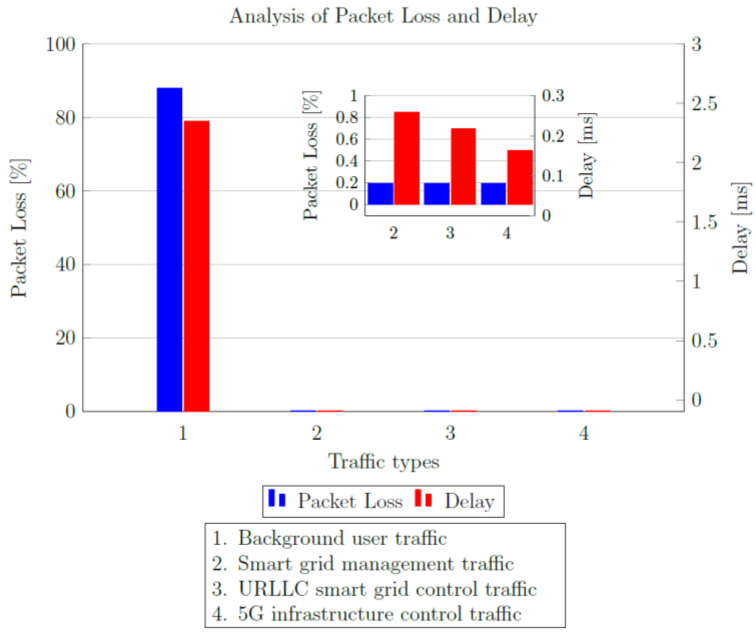



**Figure 4.24: Empirical results of guaranteed QoS in a smart grid use case through network slicing**

[4-56] has successfully demonstrated guaranteed QoS in terms of low latency and high reliability for mission-critical applications through hardware-accelerated network slicing. In addition, it has developed a machine learning-based network failure/faults prediction algorithm to further improve the reliability of the 5G communication infrastructure.

One of the new 5G PPP projects [4-30] targets to assist the remote operator and the crews dispatched in the field to better assess the severity and the impact of the outage they are facing while heading to the substation and once on-site. From the local surveillance systems available in the secondary substation, an HD video signal must be streamed, and monitoring assets, i.e., sensors and meters, should communicate in nearly real-time to the control centre and to the mobile devices of the maintenance crew. These data will be incorporated into an Augmented Reality application running in the mobile devices of the crew. Sensors and meters will monitor the status of fuses or low voltage feeders. Furthermore, the Low Voltage substation controller will aggregate transformer measures and will concentrate all the information from the substation and low voltage network. Once again the requirements of this critical infrastructure from the underlying 5G networks are related to low latency (Round-trip Time – RTT< 5 ms) to ensure the timely collection of energy monitoring data, and the high bandwidth at high Data Rate (mobility) (100 Mbps at 120 Km/h) required to ensure that high quality video can be streamed to the maintenance staff when travelling using a car. Reliability and availability should be above 99.99%.

Last but not least, in another 5G PPP Phase 3 project [4-32] Orange Romania develops together with Alba Iulia Municipality a joint use case for smart energy metering solution exploiting 5G **mMTC capability**. The solution will be able to collect real-time data from relevant end points scattered across the city of Alba Iulia, providing several key capabilities:

- Faster power reconnection after outages, and more cost-effective measures across smart metering Alba Iulia Municipality facilities;
- Electric power quality monitoring for fault management and SLA infringement;
- Predictive and proactive maintenance;
- On-the-fly reporting and analysis for both consumption and generation.

An e2e service framework will be developed over a 5G infrastructure assuring the **E2E management, control and orchestration of the slice**. The scenario assumes metering data collection from endpoints connected over LTE-M/5G-NR access layer, scattered across a city having up to 10k devices per km2 as it is an mMTC use case. The collected measurements will be transferred to the central cloud facilities that will be responsible for hosting, processing and analysing the collected measurements. The use case also implements advanced analytics capabilities in order to predict future demands and create incentives for citizens to reduce overall power consumption. Besides the high density of endpoints envisioned, the full list of KPIs can be found in [4-33].

In the context of the 5G PPP several solutions have demonstrated or are in the process to be validated in the vertical domain of energy. 5G networks appear to provide significant enhancements with the use of network slicing, the enhanced 5G NR capabilities, smart network management solutions and guaranteed QoS of services.

### 4.1.8 Public Safety

Public Protection and Disaster Relief (PPDR) composes the most critical societal impact and life-affecting vertical use case for 5G, with the most demanding requirements in terms of reliability, availability and scaled quality. PPDR has been commonly deployed using Private Mobile Radio (PMR) networks, in order to provide assurances that would otherwise be impractical on public networks. 5G networks offer shared resources with other verticals and so PPDR users are faced with this new sharing paradigm where security and resilience are offered under a virtualized separation rather than a physical isolation. Two important papers from PCSE and the GSM Association (GSMA) provide information about Critical Communications of this type [4-68] [4-69].

Within the 2025-30 timeframe, European countries will begin to deploy mission critical mobile broadband technology, allowing for greater capacity for information exchange, improved situational awareness and especially enabling improved cross border collaboration. Approximately 3.5 million first responders in Europe will be presented with new secure and reliable broadband devices that they can carry and use anywhere in Europe. The lower cost of this new technology compared to existing and costly narrowband technologies is expected to increase this volume 2-3-fold, also allowing additional supporting staff to join these mission critical mobile networks.

A Pre-Commercial Procurement (PCP) project [4-70], is currently checking solutions to a common challenge which seeks to allow Public Safety First Responders to become operationally mobile across Europe (and even beyond). Responders will be equipped with up to date mobile communication technologies which should allow them to carry out response operations wherever they are, whenever they need to, and allow secure information exchange with whoever they need to share information to cooperate with. The BroadWay Group of Procurers consists of 11 Ministries of Interior, or their delegated agencies, in 11 member states that are responsible for mobile communication for Public Safety-First Responders in their country. They collectively provide mobile communication services to 1.4 million of the total 3.5 million First Responders across Europe. A pilot at technology readiness level 8 is due for trial and evaluation in 2022 [4-71].

In the context of 5G PPP, one of the Phase 3 projects [4-40] is investigating an emergency airport evacuation scenario [4-41] [4-72]. This aims to showcase how airports and other large-scale public infrastructures, can exploit 5G capabilities to bring in place an effective evacuation plan, where personalized, dynamic and smart instructions can be provided in a reliable, instantaneous and massive-scale manner. The airport’s objective is to process the crowd in the terminal (travellers, airport staff etc.) in an efficient and safe manner, while at the same time have in place the relevant plans, tools and processes required to mitigate any emergency. Efficient and effective evacuation is one of the mitigation measures that are of particular importance in security incidents or even in the case of fire, gas leakage, etc.

The evacuation use case is in principle a representative example that falls within URLLC service type. In this case there are strict requirements to ensure a high reliability level. A more powerful **RAN is expected to achieve high reliability,** with diversity mechanism considered in frequency or in spatial domain. This is because the **strict requirements in latency** enforce that a URLLC transmission should be localized in time. Generally, URLLC service type differs a lot from eMBB in terms of target specifications and this heterogeneity imposes the need for a fundamental re-design of traditional network components and architectures.

The **localization** capabilities offered by 5G will assist in obtaining real-time data from the emergency environment which is to be evacuated, such as numbers of occupants within the area, persons trapped in isolated areas of building and in regard to the real-time flow management of evacuees. In addition to the cost reductions that the 5G network can bring to verticals, reliability, latency and location accuracy related KPIs are of utmost importance in an evacuation scenario. More specifically, the main requirements are: (i) low latency (<10 ms E2E), (ii) Location accuracy (<1 m), and (iii) reliability and availability (above 99.99%).

The deployment of such systems needs also their evaluation in terms of the expected cost. [4-60] has performed a techno-economic analysis for ad-hoc airborne (e.g., drones 0.5 - 1km) and/or high-altitude platforms (8 - 20km) for disaster and emergencies. In this study different cases were considered either with only drones or drones complemented by a high-altitude platform (HAP).

While the emergency services can be deployed using LTE, they can benefit hugely from the advanced capabilities that 5G networks are promising to unleash, from the **very high data rates** in eMBB services to the ultra-reliability and **extreme low latencies** in URLLC services. 5G offers new opportunities for the development of innovative communication, surveillance and remotely operable robotic solutions in this domain.

The expected services from these air-borne platforms can be defined under the categories below— where the system parameters and KPIs are presented in [4-73]:

1. Low data rate broadcast messaging from HAPs (Down-Link – DL)
2. Low data rate response messaging, voice calls from a very large number of User Equipment – UEs (Up-Link – UL)
3. Some basic URLLC and eMBB direct support from the HAPs.
4. UHD/AR/VR maps, videos from/to emergency service personnel in drone communications (UL/DL)

The techno-economic analysis was assuming a drone network in single or multi-hop configuration: the drones provide the network access links while using existing public networks for backhaul, occupying part of the public spectrum for some time.

The study contains a cost sensitivity analysis for the optimum number of drones per wireless link, taking into consideration parameters like the drone unit cost and the link capacity factor. These cost sensitivity analyses provided different 'sweet spots' in terms of the number of drones RRHs to be operated per wireless link for the different drone unit costs and capacity levels considered.

The spectrum analysis on the impact of **allocating 25% of the commercial spectrum 'on demand'** for this emergency deployment looked at the likely proliferation of 5G small cells in the early stages (up to 5 years). The impact on the commercial network is found to be minimal in the commercial (business) areas, while the residential areas see more impact, but the capacity penalty is seen as highly manageable. The results of the techno-economic evaluation are publicly available [4-21] [4-22].

Public protection and disaster relief application and services require the fast and dynamic re-configuration of network resources along with higher capacities that only 5G NR can offer. For public safety, 5G PPP projects have also explored the benefits that novel security and advanced localization schemes could bring in this vertical sector.

### 4.1.9 Ports - Airports

Ports are complex systems involving a wide number of stakeholders, such as port operators, authorities and shipping companies. As global trade is expanding, ship sizes and cargo volumes are increasing, placing additional pressure on ship berths and yards. Ports are therefore becoming increasingly interested in smart solutions to help optimize and improve their operational efficiency and reduce logistics costs.

One of the 5G PPP phase 2 projects implemented a GSMA Global Mobility (GLOBO)-award-winning 5G testbed in the Port of Hamburg [4-75] and, based on the testbed results and additional stakeholder interaction, developed reliable techno-economic cost benefit methods to quantify costs and benefits of 5G deployments, which are then applied to the setting of the Port of Hamburg (c.f. Figure 4.25). The testbed has employed three fundamental types of network slices (i.e., eMBB, URLLC, and mMTC) to address the needed **flexible deployment of network services** in a **secure** and private environment. Current network infrastructures are difficult to deploy, manage and maintain, and the flexibility of the 5G network along with its supported **network performance** is the perfect solution for these environments. In addition to the deployed testbed, the project also developed reliable techno-economic cost benefit methods to quantify costs and benefits of 5G deployments in port environments, with the Port of Hamburg use cases as baseline. Among the key findings [4-76] it was concluded that:

- Reliable wireless services in ports can have tangible and significant operational benefits. For example, it was estimated for the analysed scenario that by 2030, automation of container terminals could generate undiscounted operational benefits per year of €140 million (due to protection of market share via increased capacity and improvements in operational costs).
- For the range of the examined port services (e.g., environmental monitoring, intelligent road traffic control, eMBB hotspots for cruise ship terminals, and the enhancement of these services towards smart city environments) the extra cost of providing resilient and reliable services via **network slicing** from the existing wide area public mobile network ranged up to 10% (assessed from 2020 to 2030 in terms of CAPEX and OPEX).
- Translating the above operational benefits of port services to potential revenues for mobile service providers and combining these with the extra costs of delivering these services gave a positive business case for all port services analysed with return on investment improvements of up to 20%.
- Reliable wireless services can be a key enabler for smart port and smart city services such as ITS, which include connected traffic lights and traffic monitoring. These services deliver high socio-economic benefits via reductions in wasted driver time, lower $CO_2$ emissions etc. However, historic investments by cities for ITS indicate a bad cost-benefit-ratio for mobile service providers thus, implying the need for public private partnerships to realize such services.

- The flexibility of virtualized 5G network architectures means that network resources can be used more efficiently, reducing network over-dimensioning. The analysis for the Steinwerder cruise ship terminal showed that the costs of providing a dedicated small cell network to serve temporary hotspots for passengers could be reduced by between 38% and 68% due to this flexibility.

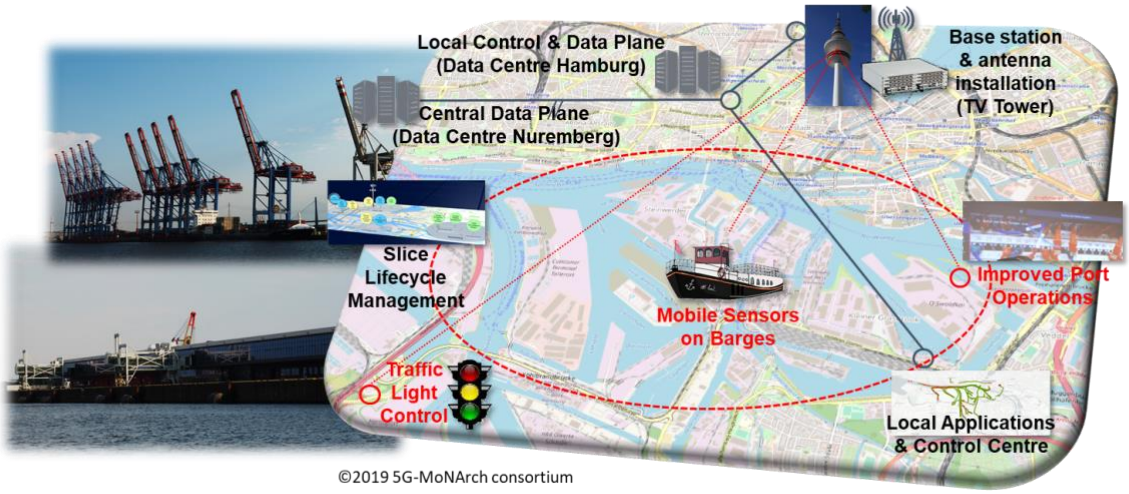



**Figure 4.25: Hamburg Smart Sea Port testbed schematic setup, Tollerort container Terminal and Steinwerder cruise ship terminal**

A Phase 3 5G PPP project, is currently developing solutions for airports ([4-41] [4-72]). Already such a solution for an emergency airport evacuation has been described in subsection 4.1.8 (Public safety). Additionally, a smart parking management application and a video-enhanced ground-based moving vehicles service is being developed.

For the first application the Athens International Airport parking areas will be equipped with 5G-supporting parking occupancy sensors providing a real view on the parking availability status of the overall area. The main objective of this use case is to provide a solution that will enable the airport car park users to quickly identify a suitable parking place, saving time and energy, reducing emission and increasing passenger satisfaction. Covering a pre-defined parking area with low-rate sensors that generate small payloads in the UL is the way to go. The sporadic nature in UL/DL communication and the operators' requirement for **quick machine type communications network deployment** and expansion make the 5G network as a suitable core network for such use case. **Reliability** and **location accuracy** related KPIs are of utmost importance in this scenario. More specifically, the main requirements are: Reliability 99,999% and location accuracy <5 m.

As for the second use case, working with the airport authorities it was identified that the operations of the Airport's Apron need to be efficient and effective towards providing Follow-Me service to an aircraft, responding to emergencies, as well as maintaining a safe environment for all concerned users of the Apron. 5G technologies are provided via the installation of HD cameras on the Follow-Me vehicles with live video feeds to not only the airport services operations centre but also to other concerned third parties and stakeholders. This will most certainly expedite the response to aircraft during arrival and departure from parking positions, which will avoid flight delays, for emergencies as they occur, and when responding to such matters as fuel spillages. Overall this will positively benefit the safety of the Apron Area.

Within the context of this use case, the airport's Follow-Me vehicles will be enhanced with mobile units equipped with HD cameras; the scenario will demonstrate how live video feeds sent to the

AOCs (Airport Operations Centre) and other stakeholders improve both day-to-day airport operations and response activities to emergencies.

This use case falls within eMBB service type. eMBB is a natural evolution to existing 4G networks that aims to provide Gbps data rates, and therefore a better user experience than current mobile broadband services. The demanding scenario of sharing live video feeds with high rate (and resolution), while moving with moderate speed makes the trial even more challenging and hence offers the opportunity to draw useful conclusions. Indicative QoS parameters to be considered are video quality, video disruption statistics, start-up delay (the duration elapsed from making the content request and the start time of the video playback), and latency in live streaming that refers to the time gap between the true progress of the event being streamed and what is being played back at the user device side.

Ports and airports are complex operational environments where multiple stakeholders execute complex tasks. 5G features such edge computing and location accuracy services enable the development of innovative applications and services, network slicing enables the coexistence of these innovative applications on the same network infrastructure with different QoS, thus, invoking the economies of scale, and flexible deployment of network functions enables the efficient use of network computing, communication and memory storage resources. It has been already demonstrated and proved that the deployment of 5G networks will be an enabler for cost reduction and service performance enhancements.

### 4.1.10 Tourism

Tourism is a very important economic sector in Europe. Several European cities are among the most visited cities in the world. 5G as a disruptive technology will be one of the new technologies that will change global tourism's development. In order to demonstrate how 5G can affect tourism, a phase 3 5G PPP project [4-40] will demonstrate 5 use cases under the touristic city node. The touristic city node is based in the beautiful Italian city of Turin. It comprises a set of use cases that aim at improving the touristic experience at a city by providing visitors with (i) added value services within the visited touristic attractions, and (ii) media applications to complement their visit. In particular, some of the use cases addressed under this theme are centred on a museum, providing AR/VR applications as well as a robot that serves as a guide and allows for remote visits. An additional use case addresses media distribution and production, providing visitors with digital content to complement their visit and improve the visitors' experience. More specifically 5G-TOURS will deal with the following use cases [4-41] [4-42]:

1. Augmented tourism experience: It will provide museum visitors with an improved experience based on Extended Reality. Extended Reality (XR) is the umbrella term that includes VR, AR, and Mixed Reality (MR).The goal is to use all these technologies in a seamless way to provide users with the best possible experience, according to each user's hardware, location, network capacity, and needs.
2. Telepresence: The main application of this use case is to enable a visit to the museum by a visitor located at a remote station or the surveillance of the museum by an operator external to the museum. For this service a robot located inside the museum will be used.
3. Robot-assisted museum guide and monitoring: In this use case, a robot is deployed inside the museum and has a map of the environment enriched with the location of the main attractions. Visitors interact with the robot, asking information on what they can see and where. The robot can physically guide the visitors to the required attraction.
4. High quality video distribution: This use case targets the distribution of enhanced high-quality video services for tourists providing immersivity functionalities to the user

experience. Immersivity lies in providing the user with additional content related to the surrounding environment (in the form of text, pictures and video on the monuments, objects in a museum, etc.) by using smartphones and/or HoloLens-like devices. These can be automatically retrieved for example from TV archives. In order to support such a user experience, images of the city captured by the users' device cameras are sent to a remote server (via the 5G network infrastructure).

These use cases need a combination of **network slices** with specific network requirements. For example, the first use case requires all three slice types (i.e., eMBB, URLLC and mMTC) as it requires implementing new XR applications using VR glasses, MR headsets and haptic gloves on top of 5G. These applications will be implemented by Samsung media and ATOS media, and the solutions provided will be integrated with Samsung's mobile terminals.

For the second use case, eMBB and URLLC slices are required. Novel software integrating a VR headset with hand trackers will be developed, which will both be used to control the movements and vision of the robot. The communication between the remote visitor and the robot will take place over a 5G network. The application will be developed using Ericsson's infrastructure, and will be used towards future robotic products.

The third use case requires the development of software applications for exploiting the use of robots at the museum. In particular, the robots will need to be provided with enhanced intelligence to respond to visitors' queries, guide them, and warn them when a safety violation happens. The latency needed for such applications can be provided by 5G networks.

The last use case requires the use of service type eMBB provided by 5G networks. It also requires edge computing equipment for fast server processing. The use case will generate broadcasting applications for distributing immersive contents to a large number of users, where part of the content needs to be personalized and there is also information being delivered by the user in the uplink.

All the above use cases require network services only 5G networks can offer. For example, the **latency** for most of them should be less than 10 ms which may also require the usage of **edge computing**. As for the **throughput,** the requirements of the services vary from 25 to 500 Mbps. These rates cannot be easily supported for a significant number of end users like the visitors of a museum.

Applications and services related to tourism have also a lot to benefit from the usage of 5G networks. Edge computing and location accuracy services enable the development of innovative applications and services that cannot be supported by legacy cellular networks, whilst network slicing enables the coexistence of these innovative applications on the same network infrastructure with different QoS, thus, invoking the economies of scale, and flexible deployment of network functions enables the efficient use of network computing, communication and memory storage resources.

### 4.1.11 Agrifood

The Food sector is expected to benefit a lot from the introduction of new Information and Communication Technologies (ICT) and especially the services offered by 5G networks. For example, aquaculture production is strongly characterized by the need for continuous monitoring and management of the site with the goal of optimizing production and fish welfare. There is an increasing trend for continuously including new technologies to cover these needs, including multi-sensor monitoring of water quality as well as image/video footage to monitor the infrastructure and the fish stocks themselves for extracting information that traditionally comes from manual observations or not at all, due to insufficient network solutions. Additionally, technological state-of-the-art solutions like remote and autonomous operations including controlling underwater drone and/or remotely operated vehicles, as well as edge computing and on-site communication could enhance in a great manner the way that aquaculture production works nowadays. This topic is currently under investigation in one of the 5G PPP Phase 3 projects [4-74]. The target is to include multiple HD/4K camera streams that **require high broadband connection**. Their feed is to be used at the **edge** of the network. Moreover, **low latency** (i.e., <5 ms) networks support is needed for services like remote operation of underwater drones for monitoring and management of the infrastructure facilities.

The main motivation of the overall use case that is going to be studied during the trials is to establish an extensive solution including two different pilots, in Greece and Norway, bringing to market a new and cost-effective, networked solution to optimize the aquaculture producers' activity, through successful deployment and operation, from both the network operator and the E2E user-experienced perspectives. Specifically, two different software platforms are used to validate the 5G solutions through a series of test cases **including operations that require all mMTC, eMBB and URLLC services**.

The Agrifood sector is also expected to be greatly benefited from 5G networks either through the use of the advanced 5G NR capabilities (e.g., higher throughput for HD cameras, low latency for remote operation of devices). Based on the needs of the sector it is also anticipated that edge computing will be an important asset to support the aggregation and further processing of the collected information. Network slicing will be again a key technology as more than one network slice types are expected to be used in this vertical sector.

## 4.2 Platforms to support Verticals

Whilst 5G is currently being deployed mainly in commercial networks for eMBB services, extended pilot trials are being executed to validate 5G also for other use cases. To that end, the three research projects 5G EVE [4-77], 5GENESIS [4-78] and 5G-VINNI [4-79] are working in the context of the 5G PPP Programme providing end-to-end testing capabilities to vertical industries to validate a wide variety of use cases on a 5G network.

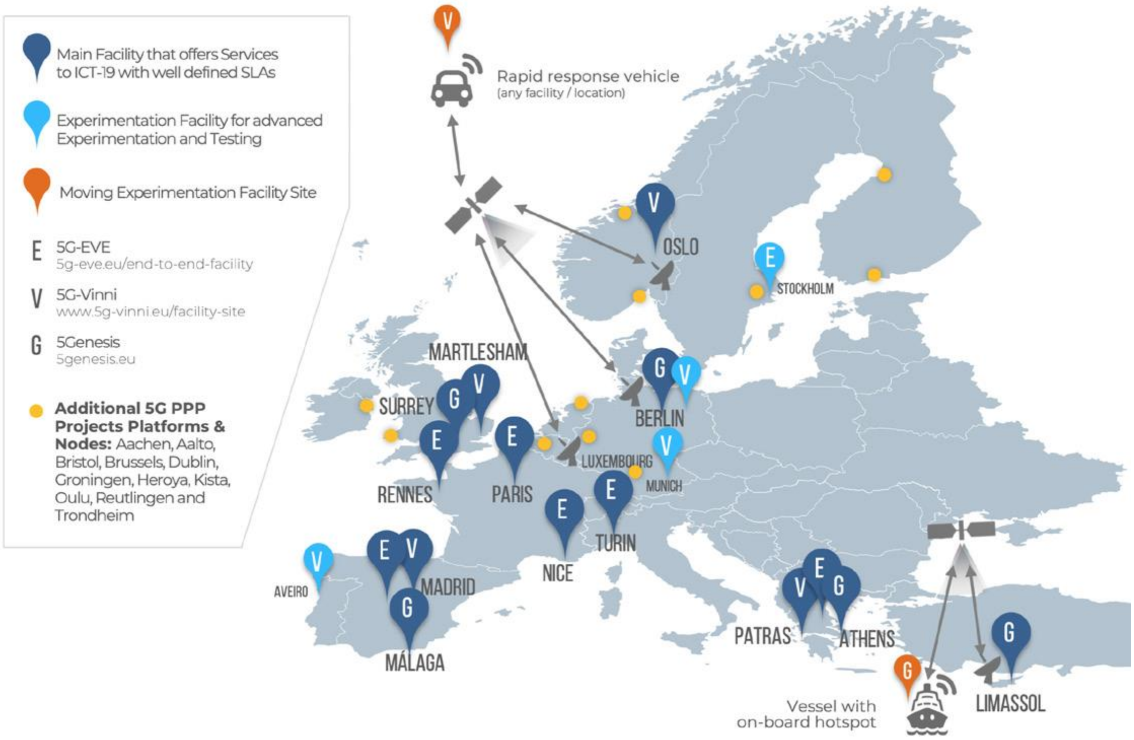



**Figure 4.26 5G PPP Platforms Geography**

The three platform projects will provide the capabilities to test vertical use cases in particular coming from the 5G vertical industries' related projects shown in Figure 4.27.

| Platform Projects | Vertical Projects | Verticals URL |
|---|---|---|
| 5G EVE | 5G!Drones | https://5gdrones.eu/ |
| | 5G HEART | https://5gheart.org/ |
| | 5GROWTH | http://5growth.eu/ |
| 5Genesis | 5G smart | https://5gsmart.eu/ |
| | 5G Solutions | https://www.5gsolutionsproject.eu/ |
| 5G-VINNI | 5G-TOURS | http://5gtours.eu/ |
| | 5G VICTORI | https://www.5g-victori-project.eu/ |

| | |
|---|---|
| 5G-EVE | 5G!Drones, 5G HEART, 5GROWTH, 5G SMART, 5G-SOLUTIONS, 5G-TOURS, 5G VICTORY |
| 5GENESIS | 5G!Drones, 5G HEART, 5G VICTORY |
| 5G-VINNI | 5G HEART, 5GROWTH, 5G-SOLUTIONS, 5G VICTORY |

**Figure 4.27 Support of vertical related projects by the three platform projects**

The key capabilities, the provided services, the corresponding locations per project and the timeline of the trials are highlighted in Table 8. Note that the exact support and timing for each individual capability may vary from one site to another.

**Table 8: Capabilities and services offered by 5G PPP platform projects**

| Vertical Sector & Supported Capabilities and Services | | | 5G PPP PLATFORMS | | |
|---|---|---|---|---|---|
| **Vertical** | **Capability / Service** | **REFERENCE STANDARDS** | **5G EVE** | **5G-VINNI** | **5GENESIS** |
| **ARCHITECTURE** | Non Standalone 5G | 3GPP Release15&16:<br>- 3GPP TS 23.501 | Turin, Madrid, Paris, Athens<br>2020 (Rel15)<br>2021 (Rel16) | Oslo, Martlesham, Patras, Madrid,<br>2020 (Rel15)<br>2021 (Rel16) | Athens, Berlin, Limassol, Malaga, Surrey<br>2020 (Rel15)<br>2021 (Rel16) |
| | Standalone 5G | 3GPP Release15&16:<br>- 3GPP TS 23.501 | Turin, Madrid, Paris, Athens<br>2020 (Rel15)<br>2021 (Rel16) | Oslo, Martlesham, Patras, Madrid, Aveiro.<br>2020 (Rel15)<br>2021 (Rel16) | Athens, Berlin, Malaga, Surrey<br>2020 (Rel15)<br>2021 (Rel16) |
| **ACCESS AND SPECTRUM** | Sub-6 GHz 5G NR | 3GPP Release 15:<br>-3GPP TS 38.401 | Turin, Madrid, Paris, Athens<br>2020 | Oslo, Martlesham, Patras, Madrid,<br>2020 | Athens, Berlin, Limassol, Malaga, Surrey<br>2020 |
| | mmWave 5G NR | 3GPP Release 15:<br>-3GPP TS 38.401 | Paris, Rennes and Nice<br>2020 | Oslo, Martlesham.<br>2020 | Malaga<br>2020 |
| | Virtualized RAN 5GNR | Multiple SDOs | Paris, Rennes and Nice<br>2020 | Patras<br>2020 | |
| | NB-IoT and LTE-M support | 3GPP Release 14, 15 | Turin, Madrid, Paris, Athens, Rennes and Nice<br>2019 | Oslo, Patras<br>2020 | Surrey 2020 |

| | | | | | |
|---|---|---|---|---|---|
| | Ability to integrate additional RAN nodes | 3GPP: TS 38.300, TS 23.501, TS 23.502 | Turin, Madrid, Paris, Athens, Rennes and Nice 2020 | Oslo, Martlesham, Patras, Madrid 2020 | Athens, Berlin, Limassol, Malaga, Surrey 2020 |
| **SLICING** | Slicing for 5G NSA | 3GPP Release 15:<br>- 3GPP TS 28.530<br>- 3GPP TS 28.533<br>ETSI NFV MANO<br>- ETSI GS NFVMAN 001 | Turin, Madrid, Paris, Athens<br>2020 | Oslo, Martlesham, Patras, Madrid<br>2020 | Athens, Malaga, Surrey<br>2020 |
| | Slicing for 5G SA | 3GPP Release 15:<br>-3GPP TS 28.530<br>-3GPP TS 28.533<br>ITU-T Y.3100 | Turin, Madrid, Paris, Athens<br>2021 | Oslo, Patras, Martlesham, Madrid, Aveiro<br>2021 | Athens, Malaga, Surrey<br>2021 |
| | Customized Slicing | Multiple SDOs and open source community | Turin, Madrid, Paris, Athens<br>2020 | Oslo, Patras, Martlesham, Madrid, Aveiro<br>2020 | Athens, Berlin, Limassol, Malaga, Surrey<br>2020 |
| **INTERWORKING** | Interworking with other Projects | Builds upon ETSI NFV principles | Turin, Madrid, Paris, Athens<br>2020 | Oslo, Martlesham, Patras, Madrid<br>2020 in phases | Athens, Malaga, Surrey<br>2020 |

| | | | | | |
|---|---|---|---|---|---|
| **EDGE COMPUTING** | Edge Computing | 3GPP Release 16:<br>TS 23.501, TS 23.502 | Turin, Madrid, Paris, Athens, Rennes and Nice 2020 | Oslo, Patras, Madrid, Aveiro, Martlesham (TBD) 2020 | Athens, Berlin, Limassol, Malaga, Surrey 2020 |
| **BACKHAUL** | Millimeter wave for Backhaul | IEEE 802.11ad or IEEE 802.11ay | TBD | Patras 2020 | Berlin, Surrey 2020 |
| | Satellite for Backhaul | 3GPP: TS 22.261, TR 22.819, TR 22.822, TR 23.737, TR 28.808, TR 38.811, TR 38.821 / ETSI: TR 103 611 / ECC Report 280 / ITU-R: M.2460-0 | N/A | Luxembourg, Nomadic (Rapid Response Vehicle – RRV), Oslo 2020 | Surrey 2019, Limassol 2020 |
| **VALIDATION** | Automatic Testing Framework for KPI Validation | ITU-R M.2083-0<br>ITU-R M.2410-0<br>3GPP TS 28.51<br>5G PPP Test Monitoring and Validation Work Group | Turin, Madrid, Paris, Athens, Rennes and Nice 2020 | Oslo, Martlesham, Patras, Madrid 2020 | Athens, Berlin, Limassol, Malaga, Surrey 2020 |

Note that slice customization refers to different features (e.g. customized service function chaining, security, enhanced cloud access, monitoring as a service, hosting 3rd party VNF, specialized data analytics for IoT, etc.). Also, Interworking refers to the capability to execute one service E2E, involving at least two different infrastructures or platforms.

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# 5 Enablers to support verticals

In this section, an indicative list of enablers is presented that have been designed, implemented and evaluated in 5G PPP projects. Since these enablers are located in the MEC they can be developed by 3rd party service providers to sometimes support the specific requirements of a particular vertical or sometimes be applicable across multiple verticals.

## 5.1 Smart Management of Streaming Services

Future high definition streaming services will require high throughput and low latency support from the network to deliver the required QoE to the end users. As 5G networks will support multiple different RAT the network needs sophisticated mechanisms to select the most appropriate RAT.

5G networks have been enabled to support dual-connectivity through LTE and New Radio (NR). However, it is important to remember that the overall 5G network architecture enables the tight interworking of multiple RATs. The co-existence of these RATs provides the opportunity to take advantage of more than two RATs at a time. Also, together with the deployment of Multi-Access Edge Computing using VNFs, the network is able to provide enhanced and sophisticated traffic steering solutions, that apply splitting and combination of streaming flows as well as load balancing schemes.

The flexibility of the 5G network architecture supports the introduction of enablers for the intelligent control of traffic to achieve low latency, high bandwidth and high accuracy localization.

A set of solutions to tackle the abovementioned requirements has been developed for all vertical use cases where high definition streaming media are needed. They rely on intelligent control of traffic at the Multi-Access Edge Computing cloud using Virtual Network Functions. This project has applied these solutions in a 5G environment where the RATs from a set of RRLHs that incorporate mmWave and VLC access, and WiFi.

The first solution is the Follow Me Service (FMS) which is a multimedia service, designed to enhance UE's QoE, by enabling the network to push media contents from UE to the nearest TV device based on UE location. It thereby enables UEs to continue watching the contents on various TV devices without the need for resynchronising or media requesting on each platform.

FMS consists of end user application installed on smart phone, Software Defined Network (SDN) controller, Follow ME Application (FMA) written in Python running on top of the SDN controller, and proxy/cache server. The main focus of FMA is to enable the SDN controller to update the Open Virtual Switch (OvS) forwarding tables with the correct TV destination. FMA utilizes UE location information, to ensure real time traffic switching instructions to be sent via SDN controller.

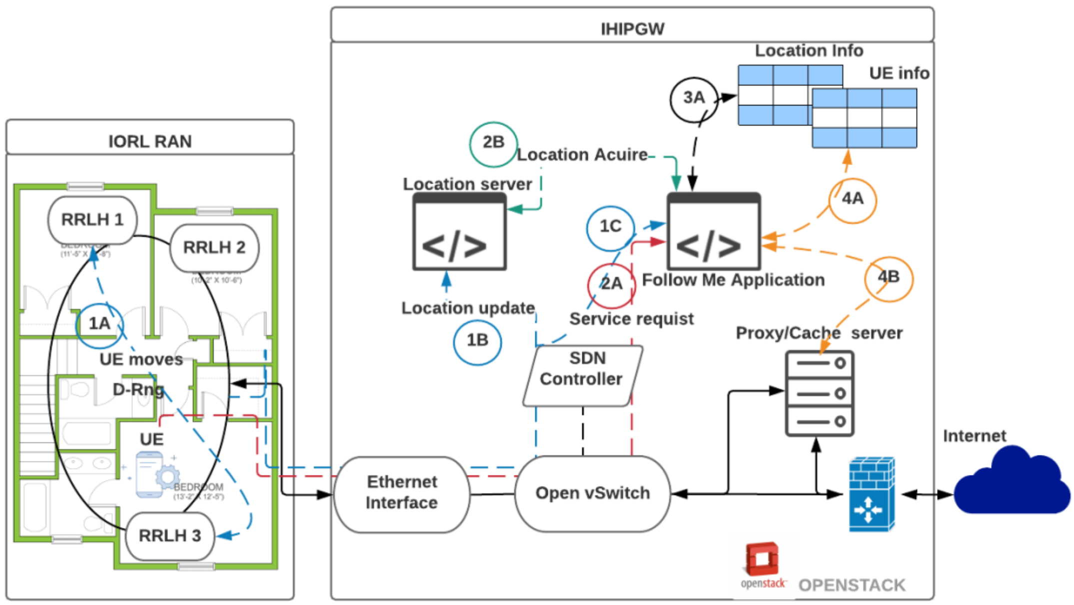


**Figure 5.1 Follow Me Service Architecture**

FMS relies on 5G compatible indoor radio-light network resources to achieve the required performance, where radio-light air interface exploits VLC to gain very high bandwidth. In addition, combining two location estimation mechanisms achieves sub-meter accuracy. So far FMS has passed the preliminary test for the service mechanism and is awaiting further deployment with fully functional radio-light platform. The system testing showed high QoS performance parameters (zero packet loss due to route switching, very high throughput, and 0.03 ms jitter) [5-1], [5-2].

A second solution is related to the provision of an innovative Load Balancer (LB) that implements a paradigm shift in handling heterogeneous user requests due to two key achievements. First, it is one of the very few LB solutions to coordinate each data flow packet among three (instead of two) co-existing network paths, the benefit of which is a reduced likelihood of congestion. Second, it is the first scheme to perform the processes of LB and Access Point Assignment (APA) jointly and in mathematically optimal manner considering not only the per-network throughput threshold criteria, but also the per-user QoS demands and priorities. In this respect, we derived joint LB-APA optimal solution (in terms of final formulas) and implemented its pseudo-code as Virtual Network Function into the SDN/NFV environment, which sits on the OpenFlow protocol for establishing the communication between a Ryu controller [5-3], the VLC/mmWave/WiFi network elements and the home users.

Using laboratory equipment, the developed scheme has been demonstrated, which can monitor five main indicators to support maximising throughput for a 0.3 Gbit/sec experience per user and minimising latency when switching networks. (i) The user requests on per-minute basis, which provides a view into how well the load is being balanced across the system. (ii) The averaged and maximum active connections and flow counts, which helps to understand if the right level of system scaling is in place and, if the traffic load is being appropriately spread across the three co-existing networks. (iii) The error rates over time to provide a view into how well the LB-APA service is running. (iv) The latency measured as the amount of time between the load balancer receiving a request and returning a response, which is one of the top metrics as its value has been directly linked to users' QoE. (v) The rejected/failed connection count, which reveals which of the three co-existing networks has reached capacity, either because of being overwhelmed by sheer number of requests, or because the LB-APA does not monitor the number of failed/rejected connections appropriately [5-4].

With respect to the runtime results of these five monitoring indicators, the constrained LB-APA optimisation problem converges towards maximising the overall system throughput (maximum of 5 Gbit/sec), user QoE (15 users of minimum QoS of 0.3 Gbit/sec experience >5 msec delay when switching networks) and fairness index (an average of 0.97 Jain's index, where absolute fairness is achieved when index reaches the value of 1).

Moreover, innovative solutions have been provided for multiple-source streaming over remote radio light heads. This is essentially a multiple-path streaming system that has been implemented increasing both reliability and QoE of the streaming sessions. In this system, the client is used to retrieve video packets in high quality through a VLC/mmWave network and simultaneously in low quality through a Wireless LAN (WLAN) access to provide reliability in case of an interruption in the data transmission. When retrieved, the requested sub-streams are merged in order to reconstruct and display the original requested content quality. In the event of sub-streams loss or outdated delivery, content playback continuity is not affected, only image quality. Additionally, if the considered network paths experience outages or throughput degradation, the Maximum Segment Size (MSS)/RRLH client relies on multiple paths content-adaptation mechanisms to avoid QoE degradation.

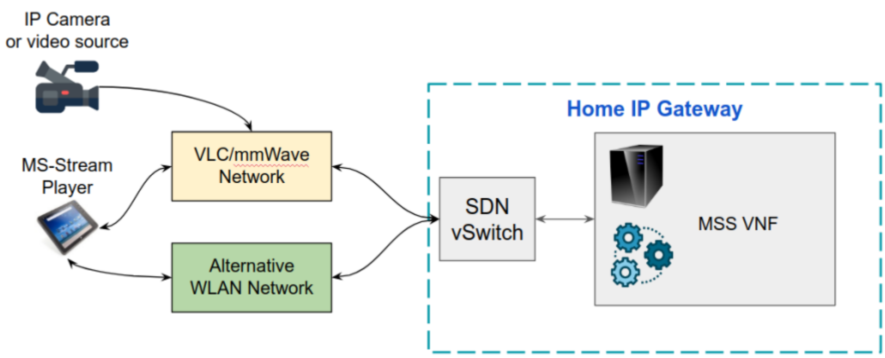


**Figure 5.2 Multisource Streaming Architecture**

Although the work is still ongoing, the proposed system target to support live video streaming in 4K with less than 3 seconds end-to-end delay and with a low number of stalling events. The MSS/RRLH VNF has been successfully tested on a 5G compatible indoor radio-light platform with WiFi access to UEs and MEC security VNFs, whilst the 5G home RAN is being constructed. This VNF has also been evaluated in a lab environment against a State of the Art (SotA) single-path player by following different scenarios where the networks are unreliable or obstructed. A summary of the results is available on the following Table 9.

**Table 9: MSS Performance Metric Results**

| **Video streaming systems** | *Average live latency (in seconds)* | *Average duration of stalling events in case of occultation (in seconds)* | *Average video bitrate (in Mbps)* |
|---|---|---|---|
| **SotA Single-Path Player** | 3 to 10 | 5 | 4.8 |
| **MSS/RRLH Player** | 3 to 5 | <1 | 7.8 |

The results show that MSS/RRLH can reliably support a live stream within a 3-5 seconds end-to-end delay with a higher average video bitrate and significantly less stalling events than other players.

## 5.2 Distributed Network Security

5G is capable of providing intelligent monitoring of traffic from the mobile edge cloud using VNFs. Security monitoring in the MEC provides the basis of a distributed security monitoring system that is more able to scale with increasing network size. Security at the mobile edge has the advantage of being far more scalable and selective to the needs of end users and would typically act as a first line of defence in a security architecture performing tasks such as Scanning Security, Denial of Service Security and Sniffing Security. As an example, three security monitoring services have been developed that provide this benefit, namely: Scanning, Denial of Service and Sniffing as VNFs on the MEC.

**Scanning:** The developed security VNF is implementing the scanning protection functions by tracking the state of each TCP connection handled by the switch. When a client attempts to initiate a TCP connection the controller creates a description object (IPv4 addresses, ports) and sets its state to "pending". This state will not change until a full TCP handshake is completed, in which case the status of this connection changes to "connected". When the connection is closed the description, the object is removed. By counting the number of "pending" connections per client IP address we are be able to distinguish a scanning machine from a benign one and thus eliminate the attacker [5-5].

To realize this, network services use listening TCP or UDP sockets on the specified ports in order to accept incoming network connections from the clients. This functionality can be exploited by a rogue transmitter, which can scan the entire network in search for open listening sockets in order to enumerate available services. The results of this scan can be used to perform further exploitation of the target. Therefore, detection of the scanning activities is an important task for every security system.

**Denial of Service:** In networking environments, an attacker can perform many types of DoS or Distributed DoS attacks to disrupt the targeted service, a network or a device. One type of this attack is called *Dynamic Host Configuration Protocol (DHCP) pool exhaustion* or *DHCP starvation attack*. It utilizes the specifics of the DHCP protocol as the time required for exchanging four DHCP messages to complete the transaction, in order to successfully obtain IP address, is rather short (ca. 1-3 ms) thus the address pool can be exhausted quite quickly. In effect, the communication of the entities that depends on DHCP IP addresses allocation is completely paralyzed. This is especially the case for dynamic and scalable environments (like clouds or public networks with open access).

To mitigate DoS attacks, the developed security VNF limits the number of IP addresses that can be leased from the DHCP server. It relies on intentionally dropping initial DHCP Discovery messages and measure the delay between the original DHCP message and the retransmitted one. Then it is verified whether this value is in the range of accepted values and the decision is made whether to block or accept the DHCP traffic [5-6].

**Sniffing:** An intruder tries to gather as much information as possible on the devices, protocols and applications residing within the targeted network in order to discover their vulnerabilities. It is typically performed using dedicated software called sniffers and it is based on passively analysing the traffic exchanged within the network. Due to its passive nature such malicious actions are challenging to be discovered.

The security VNF was deployed to discover machines that are sniffing in the network (i.e., they have NICs set to the promiscuous mode). Our approach is based on the *macof* and *ping* tools and it relies on inflicting artificial load on the investigated machine and measuring its RTT with and without the load. The performed experimental evaluation proved that such an approach is effective [5-7].

## 5.3 Indoor Location Services

5G can provide location monitoring and recording of user equipment in indoor RAN coverage area at the Mobile Edge Cloud using Virtual Network Functions for use by network and application layer services. Providing location data from a location database in the cloud for network and application layer services allows intelligent location-based security, data access streaming services to be developed.

Indoor location services have been developed which use VLC/ mmWave remote radio-light head (RRLH) in a priori known locations within a 5G RAN to produce location-based measurement data. Each VLC RRLH successively issues reference signals every 1.0 ms in unique sub-carriers within the VLC Transport Block (TB) and the Received Signal Strength (RSS) is measured in the UE to estimate the distance travelled from each of the four RRLHs, which are used to compute location of a UE to an accuracy of about 10 cm [5-8]. Furthermore, each mmWave RRLH successively measures the Time Difference of Arrival (TDoA) of Pseudorandom Noise (PN) sequences issued by UEs every 2.5 ms in unique uplink sub-carrier transmissions within the mmWave TB and TDoA is measured at each of the four RRLHs successively, which are also used to measure the location of the UEs to an accuracy of about 10 cm [5-8]. Since mmWave and VLC location measurement from each RRLH is obtained at different times, a location data fusion algorithm combines these measurements using Extended/Unscented Kalman and Particle Filter prediction algorithms to provide location data at a higher frequency and accuracy.

RSS and TDoA data are transmitted to a location database on a VNF in the MEC that is processed into location data by a location server VNF in the MEC, which can be accessed by smart phone applications.

Simulation results have predicted that VLC location accuracy can be obtain between 1 cm and 40 cm with a mean of 18 cm depending on location in room and mmWave location accuracy is highly dependent on the received signal to noise ratio [5-9]. These use cases show that an unprecedented level of indoor localisation accuracy can be obtained using a 5G compatible radio-light system.

This can be used in museum, supermarket and train station use case scenarios, which require a database that holds museum exhibits, food products and maintenance infrastructure media associated with location information, respectively. Also, these use cases offer managers with services like adding, editing and deleting museum exhibits, food products and maintenance infrastructure related media. On the other hand, the museum visitors, shoppers and maintenance engineers have an application that allows them to know where is the exact location of the exhibits, food products and maintenance infrastructure. This can be viewed either from a smart phone, smart tablet or an Augmented Reality (AR) headset.


a) Location based Django backend access to database

b) Android app on User Equipment to database

**Figure 5.3 Backend and UE GUIs Interfaces**

Results are shown in the above figures as the manager is able to view all the exhibits on a user graphical interface (c.f. Figure 5.3a) from location data with a required accuracy of about 10cm. Also, the Android application shows the exhibits fetched from the database (c.f. Figure 5.3b). By using a head mounted AR display virtual data models can be displayed over the real equipment. This improves maintenance times in a train station scenario.

## 5.4 3D Indoor Localisation for Emergency Scenarios

There are many scenarios needing indoor localisation such as building fire, kidnap/terrorism incident, medical emergency, building evacuation in emergencies. Indoor scenarios are not supported by GNSS and also cannot rely on the existing wireless infrastructure (like WiFi nodes, femto cells). These nodes can get damaged in the emergency and can also suffer from power loss. 3D Indoor Localisation for emergency services imposes high reliability and accuracy constraints. Also, there is a need to continually update the user locations (e.g. of emergency crews) with low latencies. Such scenarios are under study in [5-10].

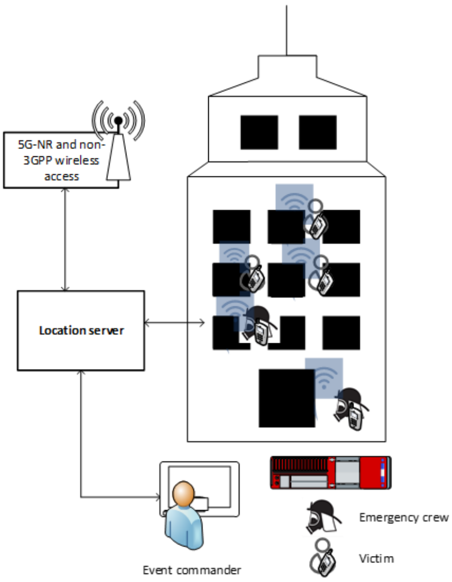


**Figure 5.4 Concept of 3D Indoor Localisation for Emergency Services**

The service provider for this localisation service would enter into an agreement with the emergency services to meet the necessary accuracy, reliability and service availability criteria enabled by 5G. This use case requires that the devices with victims and emergency crew will be 5G-NR compliant, and that the gNBs in the vicinity and any ad-hoc gNBs can be quickly configured to collaborate.

Performance indicator requirements on the 5G networks:

- Localization accuracy: Horizontal ±2m; Vertical ± 1m
- Security and privacy need to be very high
- Maximum update interval = 40 s
- Initial service setup time = 135 s
- Service level reliability 99.9%
- Service level availability 98%

## 5.5 Positioning and Flow Monitoring in Large Venues and Dense Urban Environments

Large venues and shopping areas (airports, train stations, malls, stadiums, etc.) exhibit the gathering of large crowds, with complex mobility behaviour. This calls for efficient flow and resources management, and creates opportunities to maximise QoE (Recommendations, Queues, logistics, staff, security, etc.). A Geolocation Server will use 5G-based signals and/or other measurements to satisfy service requirements and decide on positioning methods to use and/or to fuse [5-10].

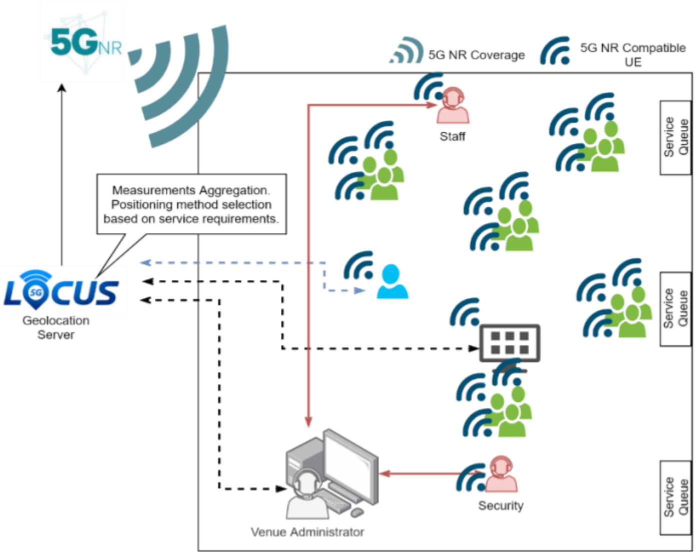


**Figure 5.5 Positioning Architecture**

5G based reference signals will be used to collect measurements and deploy hybrid positioning methods to extract locations and track mobility. This use case's goal is to guide the exploration of positioning methods that, preferably, exploit 5G NR as source of measurements, in order to support defined service requirements and generate positioning information that can be fed into advanced analytics. The use case will also rely on hybrid positioning techniques, fusion of measurement data, and opportunistic positioning based on available measurements, and network-based localization.

Performance indicator requirements on the 5G networks are:

- Reference TR 38.855: Study on NR positioning support
- Localization accuracy: H, V: 3m
- Latency: 1s
- Time to Fix: 10s
- Update rate: 10s
- Service reliability: 80%
- Sevice availability: 80-90%

## 5.6 Localization and Network Management for Education

The challenges of future "smart classes" are twofold. On the one hand, devices have very stringent requirements on the network, which must provide a very high bandwidth with a low latency, as well as high location accuracy also with a low latency. On the other hand, the scenario is in itself a challenge for wireless technologies, since all these requirements must be fulfilled in traffic hotspot and indoors conditions. The network operator will need to have a minimal deployment that suits the requirements of the users. The network capabilities must fulfil the requirements of the contents uploaded by the creators, who must know the limitations in advance [5-10].

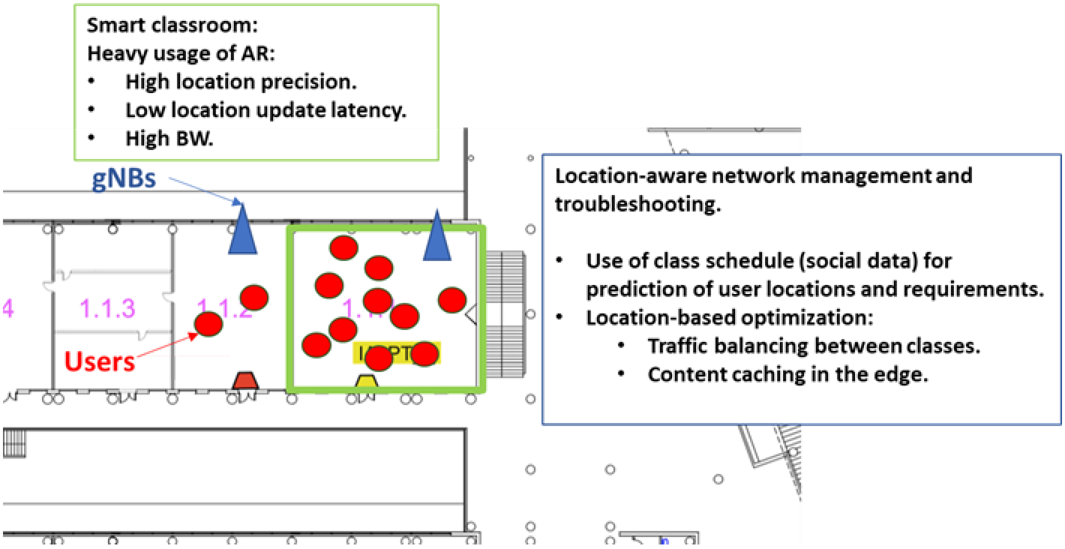


**Figure 5.6 Location aware network management architecture**

5G is needed for communication rate and availability as well as for accurate positioning, which can be obtained by exploiting interoperability with different devices (including non-3GPP sources) and access points. The contents accessed by the users will be designed with a known margin for latency (both for data and location), location accuracy and data bandwidth. In order to obtain a solution able to work with any type of 5G devices, it should be standards compliant.

Performance indicator requirements on the 5G networks are:

Localization accuracy: H, V: 10cm

- Security and privacy very high
- Maximum update interval = 10 ms
- Initial service setup time = 10-20 s
- Service reliability: 99%
- Service availability: 98%

## 5.7 Device-free Localization

There are many scenarios where we need to detect, localize, or extract analytics related to people and things (targets) not equipped with communicating devices such as cars/bikes/pedestrians for road safety, anti-intruder systems, and people flow monitoring. In many of such scenarios there are communication systems emitting signals for other purposes (e.g., 5G base stations for communication, 5G V2X communication). The device-free localization consists in processing such signals 'of-opportunity' after target backscattering at one or multiple nodes to extract information about presence, range, location that may serve as input for analytics extraction [5-10].

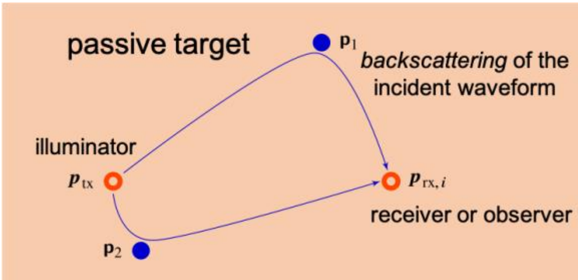


**Figure 5.7 Device-free localization concept**

The signals used for device-free localization will be 5G-NR compliant. The eNBs is in the vicinity of the monitored area and can illuminate the scene. One or multiple UEs can receive the signal, acting as radar-UEs.

The location accuracy can vary depending on the application. As an example, road safety might need very strict accuracy requirements (less than 1 meter) whereas flow monitoring applications can accept larger errors (5m).

Device-free localization introduces privacy by design:

- The update interval can vary depending on the application. For road safety we might need a very short update time (<1s) that can be larger for flow monitoring (40s).
- The setup time is needed to allow clutter mitigation algorithm to collect enough data and learn the environment, it could be in the order of 2min.
- The reliability depends on the application scenario. We expect higher values for safety applications (99%) and lower values for flow monitoring (90%).
- The availability depends on the application scenario. We expect higher values for safety applications (98%) and lower values for flow monitoring (90%).

## 5.8 Positioning and Flow Monitoring for Controlling COVID-19

In addition to the use cases above, a use case for flow monitoring and controlling of Corona Virus Disease (COVID-19) situations is being considered with three purposes (user stories): (1) a person is tested positive to the virus and it is needed to trace back the persons he/she has potentially been in proximity within a certain number (to be set) of previous hours/days; (2) a person is 'at risk' or was tested positive to the virus and it is needed to identify if he/she is moving outside a constrained area (e.g., more than a certain number of meters from home or any other quarantine place); and (3) automatic control of non-allowed grouping person [5-10].

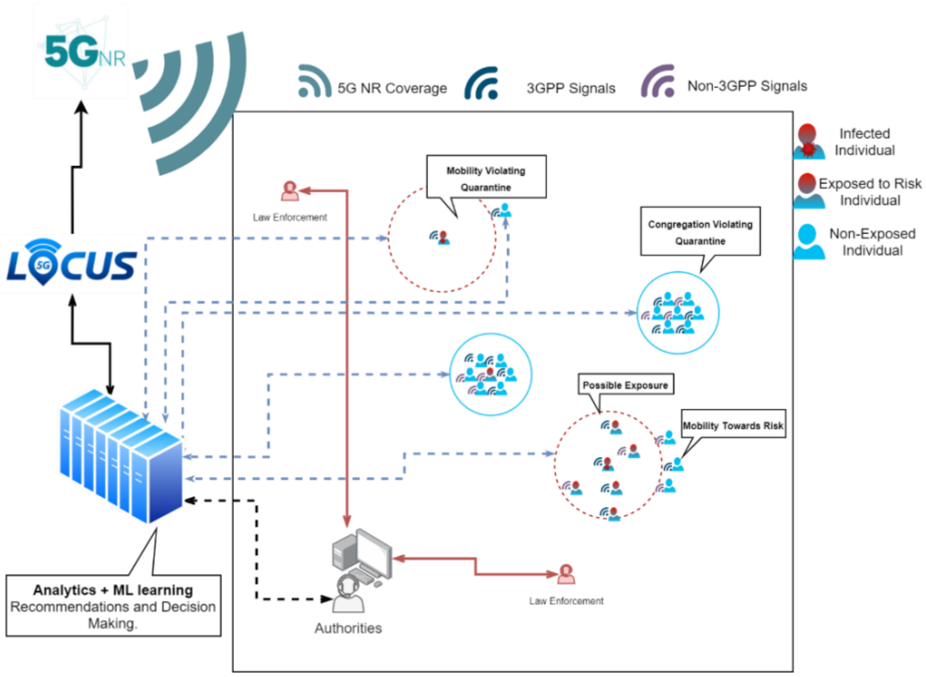


**Figure 5.8 Epidemic proximity and back tracing architecture**

5G (when available) and 3GPP technologies are needed and complement non-3GPP technologies (GNSS, Wi-Fi, Bluetooth) for covering high percentages of population with granularity in the proximity or localization accuracy needed for the various purposes.

The goals are:

- extraction of location-aware analytics for the purposes of user stories 1 and 2;
- provision of real time information on people grouping for the purpose of user story 3;
- advertise people if there is a positive tested person in the same area where they are.

Performance indicator requirements on the 5G networks are:

- Localization accuracy below 3m (H and V) with availability at least 90% for user story 1 and 3.
- Localization accuracy below 30m (H) with availability at least 80% for user story 2.
- A time-to-fix below 10 s and a latency below 1 s is required.

## 5.9 Plug & Play Network Slicing Customization for Verticals

5G envisions empowering vertical-oriented services for diverging businesses with varying customization requirements and allowing verticals to control their own network slices to meet these service customization requirements, at not only service provisioning time (e.g., through the SliceNet One-Stop API) but also service run time. Currently, such runtime control for service customization by verticals is very constrained due to lack of enablers.

The Plug & Play (P&P) control framework enables flexible and powerful control capabilities for verticals regarding their own services over the commissioned network slices. Firstly, the P&P framework defines the different levels of capability exposure from the network slice service provider to vertical users. The network slice control capabilities are expressed in different functionality in terms of Monitoring Only, Monitoring, and Control and Management etc.

regarding the involved components, VNFs, topology and so on in a concerned network slice. Various levels of monitoring, control and management are defined and can be specified by a vertical, subject to the SLA between the vertical and the network slice service provider. Secondly, the P&P framework realizes such fine-grained and technology-agnostic capability exposure and control by utilizing micro-services. A P&P network slice instance comprises a group of self-contained micro-services following a micro-service topology graph and each of the micro-services can be activated or updated on demand at runtime individually without disrupting the rest of the existing P&P instances, and thus the P&P framework is able to implement the customizable control logic in relation to the concerned network slice for the vertical in a P&P manner. The containerization and orchestration of the micro-services can employ Docker and Kubernetes respectively, among other technologies [5-11].

This P&P framework was used to support the service customization of three typical use cases in eHealth, smart grid and smart city lighting. For instance, in the eHealth use case, the P&P framework allows the eHealth vertical to control and customize their network slice-based eHealth service instance by deploying a specialized VNF (TeleStroke) to be deployed on demand to the MEC platform at the edges of a 5G network. This way, the TeleStroke VNF is plugged to the existing network slice service instance, activated and then started to function for the vertical, i.e., it intercepts imagery from an ambulance's onboard video streaming to detect and diagnose stroke of the patient in the ambulance, which is a time-critical mission. In terms of monitoring, the P&P framework empowers and employs the One-Stop API's graphical user interface (GUI) to show the agreed topology view and components information of this network slice service instance to the vertical, e.g., all the end-to-end network segments such as RAN, MEC and Core network and their locations. Moreover, the P&P framework allows verticals to plug in machine learning pipelines to a use case so that the use case can benefit from the added artificial intelligence to improve the performance of the network slice-based service.

## 5.10 Automatic vertical service building and ordering and its mapping to network slices

Nowadays, in practice most of operators' networks provide almost none or very limited support for the verticals to allow them to easily and automatically define and create their services over the operator's networks via open APIs. To this aim, many 5G research projects start working on different network slicing solutions based on SDN/NFV, however they are mainly focused on the level of network services and infrastructures from operator point of view, but not providing means for the verticals to directly build their services at their side, who typically have no knowledge about network technology as well as they have no insight of the operators' networks and their infrastructure. On the other end, a few 5G PPP projects, such as [5-12] and [5-13], provided methods to allow verticals to define complex vertical services using software development kits (SDK). The SDKs are used to define and combine services complemented by tools for validation and verification of the services before they are actually on-boarded and instantiated in the system. It is still considered to be complex for the verticals to create services easily and directly.

In order to lower the entry barrier for the verticals in terms of complexity as well as the time required for defining and building the service, a catalogue of service descriptors has been proposed, called **Vertical Service Blueprints**, defining mainly business and performance requirements of the vertical services, which can be completed with actual values regarding dimensioning and SLA requirements during the service on-boarding phase. We expect that most vertical services can be predefined in such a catalogue and offered to the verticals. This service catalogue is offered to the verticals via a **vertical-facing API** that enables the verticals to define and order vertical services in an automated manner. This vertical oriented API is exposed on the

North Bound Interface (NBI) of the service management platform, namely on top of the **Vertical Slicer**, which is the common entry point for all verticals into the 5G system. The Vertical Slicer includes a set of mapping functions to translate vertical related business requirements to network slice requirements and to map them to new or reusing existing network slices.

The **5G Vertical Slicer** (5G-VS) [5-14] allows defining vertical services from a set of offered Vertical Service Blueprints (VSB), which, along with instantiation parameters, will result in Vertical Service Descriptors (VSD). The VSBs/VSDs are used for the verticals to describe their vertical services including their SLA requirements. The SLA requirements can be of different kinds presenting specific business and service requirements, for example: (i) end-to-end latency and bandwidth requirements, necessary for the service to function correctly, (ii) number of supported users, coverage area, etc., related to the dimensioning of the service, (iii) availability and reliability, (iv) deployment time, energy efficiency, i.e., optimization targets for the deployment of the service.

Then, the 5G-VS maps the vertical service descriptions and requirements defined in the VSD onto a network slice, which is described with extended ETSI NFV Network Service Descriptors (NSD). More specifically, the VSDs including such SLA requirements will be translated to an NSD with appropriate selection of deployment flavours and instantiation level. To that end, the NSD is determined from the VSD. Using a rule-based approach, specific values of the SLA requirements are then translated into the selection of deployment flavour and instantiation level. Some of the SLA requirements can be encoded in the NSD itself. For example, bandwidth requirements can be expressed in the NSD as bandwidth requirements on virtual links, the number of supported users can be mapped to a corresponding instantiation level with sufficient VNF instances handling the expected number of user and reliability could be mapped to a deployment flavour with or without redundant components.

In addition, the 5G-VS provides arbitration among several vertical service instances in case of a vertical or other customer may request instantiation of several services and they may have agreed on an overall resource budget regarding compute, storage, transport, and radio capacity, as defined in the SLAs between the verticals and the service provider. The arbitration function in the 5G-VS maps priorities of vertical services and SLA requirements to ranges of cardinalities of resources. These cardinalities are used while deploying the NFV-NS and, in case of actual resource shortage, to assign resources to the most important vertical service instances.

Another main role of the arbitration function is to map the vertical services to network slices, while allowing multiple vertical services to share one or more network slices or network slice subnets. Following the network slice model defined by 3GPP, a network slice can include multiple slice subnets, where each slice subnet can be shared among multiple end-to-end network slices, thus improving the infrastructure utilization efficiency. A typical example could be the sharing of the same vEPC among different vertical service instances with similar requirements in terms of mobile access, or the sharing of a service component for the collection of vehicle messages among multiple automotive services that make use of the same messages. The logic behind network slice sharing is service- and customer-driven. In other terms, any decision about re-using a slice subnet instance should comply with the requirements of the services using it, for what concerns the isolation among services. Essentially, for a new vertical service request, the arbitration function will decide if a new network slice needs to be instantiated and any existing slice subnet that can be re-used to build the new slice; and for each slice subnet to be re-used, if and how it needs to be scaled to meet the requirements of the additional vertical service.

In summary, this automatic process of building and ordering vertical service and mapping them to network slices significantly reduces the time needed for current manual translation and configuration of the network slices.

A set of VSBs and VSDs has been created for the demonstration of different vertical use cases including automotive, entertainment and eHealth, and smart factory verticals in the project. They are provided to the service platform through the vertical-oriented API to define and customize individual vertical services, and with the developed translation and arbitration functions provided by the 5G-VS, the vertical services are automatically mapped to network slices including their SLA requirements. The benefit has been shown in all vertical PoCs [5-15] for instance entertainment and eHealth use cases, demonstrating that the service provisioning time, enabled by the proposed solution, has been reduced from hours to a few minutes, meeting the 5G requirements for vertical service provisioning.

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# 6 Satellites in support of verticals

The roll-out of terrestrial 5G has started at high-density population and traffic areas, such as large cities, campuses, highways, high-speed rail networks, utilising the existing backbone infrastructure in these areas. However, users expect services to be available anytime, anywhere, specifically including rural and remote areas. Through its global coverage and availability today, satellite communications (SatCom) can support in a cost-effective way the deployment of selected 5G services to underserved rural and remote areas as well as mobile maritime and airborne platforms (ships, planes).

Satellite solutions allow telecom operators, service providers and vertical sectors to accelerate 5G deployment everywhere creating new and growing market opportunities for all stakeholders in the 5G ecosystem. Many vertical industry segments such as transport and logistics are relying on mobility solutions with ubiquitous coverage of their area of business activity, which can be achieved via satellite.

As seen during the COVID-19 crisis, unprecedented traffic volume growth may add important strain on terrestrial mobile networks, resulting in potential QoE degradation for the user, even in urban areas where proper terrestrial telecommunication infrastructure exists. Satellite connectivity can complement terrestrial networks by offering additional bandwidth to ease bottlenecks and carry the extra traffic. For example, its multicast and broadcast capabilities to deliver very high-quality content at speeds up to 1Gbps, constitute a cost-effective way to transmit linear low latency content to users thereby easing the strain on terrestrial networks.

Satellite infrastructures are far less exposed to earth surface-bound incidents like natural disasters or man-made conflicts and terrorist attacks, thereby offering high levels of reliability and security. These are fundamental properties for emergency services and as a backup for terrestrial infrastructure in cases of disruption.

The satellite sector identified the following top vertical markets for SatCom services:

- Transport and logistics
- Maritime and airborne communications
- Disaster relief and emergency response
- Broadband services for media and entertainment
- Network offloading and increased network resilience
- Multicast video and MEC content distribution
- Capacity and coverage for multiple verticals
- Interconnection of non-public networks (NPNs)
- Trunking and Backhaul
- Massive Internet of Things and Machine Type Communications (mIoT/mMTC)

**SatCom achievements in 5G PPP**

5G PPP projects developed and demonstrated cost effective, standards-based, “plug and play” SatCom solutions enabling the acceleration of 5G deployment worldwide with a primary focus on backhauling for vertical sectors [6-1] and on enabling E2E experimentation [6-2] towards accelerating the uptake of 5G in Europe.

Concerning backhauling the following eMBB use cases have been demonstrated:

- **Edge delivery & offload for multimedia content and MEC VNF software:** Providing efficient multicast/broadcast delivery to network edges for content such as live broadcasts, ad-hoc broadcast/multicast streams, group communications, MEC VNF update distribution;

- **5G Fixed backhaul:** Broadband connectivity where it is difficult or not possible to deploy terrestrial networks such as maritime services, coverage on lakes, islands, mountains and rural areas across a wide geographic region;
- **5G to premises:** Connectivity complementing terrestrial networks, such as broadband connectivity to home/office small cell in underserved areas in combination with terrestrial wireless or wireline;
- **5G Moving platform backhaul:** Broadband connectivity to platforms on the move, such as airplanes and vessels

Over the air live demonstrations were successfully performed at:

- EuCNC 2018 conference in Ljubljana, Slovenia – provisioning of E2E managed connectivity between a remote node and the core network via the geostationary ASTRA 2F satellite and the SES teleport premises in Betzdorf, Luxemburg. The demonstration showcases satellite backhauling features and efficient edge delivery of multimedia content as a proof-of-concept for their integration into the 5G network. The demonstration utilised a prototype satellite hub and a terminal towards 5G capabilities which incorporate SDN, NFV and MEC technologies provided by VT iDirect.
- EuCNC 2019 conference in Valencia, Spain – several demonstrations such as (i) over the air MEC based layered video streaming over a 5G multilink satellite and terrestrial network, (ii) over the air multicast over satellite video for caching and live content delivery, (iii) video of delivery of 5G connectivity services to airline passengers, and (iv) demonstration of hybrid 5G backhauling to extend services for rural markets and large gathering events [6-3].

Concerning enablement of E2E experimentation the following capabilities, providing satellite backhauling, have been deployed as part of the 5G PPP facilities to support verticals (c.f. section 4.2):

- Main platform site in Norway served by Telenor's satellite fleet;
- Moving experimentation facility site served by SES' satellite fleet interconnecting the Luxembourg and Berlin facility sites.

The moving experimentation facility site is building upon synergies with the European Space Agency's (ESA) Advanced Research in Telecommunications Systems (ARTES) funded project SATis5 [6-4]. It provides satellite backhaul capabilities to fixed and nomadic edge nodes, exhibiting the following characteristics [6-5]:

- Satellite backhauling
- 3GPP 5G Core Network (Open5GCore) seamless integrated with satellite hub platform
- Edge-Central 5G Core Network functionality split
- Fixed 5G Edge Node
- Nomadic 5G Edge Nodes
    - On-board satellite connected Rapid Response Vehicle (RRV)
    - Small form-factor lightweight transportable terminal
- NFVI (OpenStack), MANO (Open Source MANO – OSM, Open Baton)
- Network Slicing (eMBB, mMTC, URLCC use cases)
- Interconnection with other EU testbed sites and remote nodes (e.g., Berlin, Killarney)

- RAN (AMARI Callbox Classic 5G Standalone/Non-Standalone – SA/NSA eMBB, 4G/LTE NB-IoT, 60 GHz Point-to-point/Point-to-Multipoint eMBB, LoRa LoRaWAN IoT)

**Complementary activities by ESA**

ESA provides support for 5G SatCom essential technology developments, infrastructure design and implementation, validation trials and vertical pilots through its *Space for 5G* strategic programme line [6-6].

Several ESA ARTES projects support the development and design of advanced technology building blocks of 5G SatCom, standardisation and regulatory aspects, therefore constituting the foundation of future converged terrestrial and satellite 5G networks [6-7]. The main ESA projects are:

- The **SATis5** testbed [6-8] provides a full E2E technology integration of the 5G communications environment including satellite and terrestrial links as well as demonstrating ([6-9] and [6-10]) efficient edge-core network functionality split and management for on-site deployments.
- **OSMOSIS** [6-11] developed a reference E2E hybrid satellite/terrestrial network to support prototyping of products in the areas of multimedia broadcast, adaptive bitrate streaming, content distribution networks and E2E QoS management.
- **EdgeSAT** [6-12] works on the alignment of edge network computing capabilities for satellite remote terminals in a global 5G uniform network. The ambition is to enable SatCom to reap the benefits of edge network computing concepts and capabilities.
- **ViBES** [6-13] redesigns performance enhancement proxies as a set of NFVs for 5G SatCom use cases such as evolutions of multipath TCP, caching, pre-fetching, Quick UDP Internet Connection – QUIC, MPEG-DASH and WebRTC.

As a key concluding remark, the results from the projects supported by 5G PPP and ESA demonstrate that the operational integration of satellite into 5G leveraging enablers such as SDN, NFV, MEC and network slicing under common network management and orchestration is feasible in the short term and timely to fully support the 5G roll-out.

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# 7 Standardization activities related to verticals

5G standardisation for verticals is a multi-stakeholder effort across different standardisation organisations. Moreover, verticals' industry associations have set up specific working groups to collect and define requirements for verticals. Many of these associations are market representation partners in 3GPP, (e.g., GSMA, Next Generation Mobile Networks – NGMN – Alliance and Global Suppliers Association – GSA) on the telecommunications and the industry vertical sides (e.g., 5GAA, 5G Alliance for Connected Industry and Automation – 5G-ACIA [7-1], EMEA Satellite Operators Association – ESOA, Public Safety Communication Europe – PSCE, The Critical Communications Association – TCCA). Other associations also supporting standardisation include the European Broadcasting Union – EBU, the 5G Media Action Group – 5G MAG, the European Utilities Telecom Council – EUTC, the International Association of Lighthouse Authorities – IALA and the International Union of Railways – UIC.

3GPP is the main global standards organisation for mobile communications, focusing on the design of the 5G system and supporting a variety of industry verticals. Note that 50% of the work carried out focuses on 5G functionalities applicable across diverse verticals. The 3GPP work programme covers a multitude of enablers as part of a toolbox of functionalities that verticals can use to create their own services [7-2].

Other relevant standards organisations working on 5G standardisation include ETSI, (e.g. on MEC, Experiential Networked Intelligence – ENI, NFV, Open Source MANO, Zero Touch Network and Service Management – ZSM, the Internet Engineering Task Force – IETF, the Internet Research Task Force – IRTF, the Institute of Electrical and Electronics Engineers – IEEE, and last but not least ITU.

The 5G PPP is working on several fronts to support the 5G standardisation process whereas the 5G IA's pre-standardization Working Group (WG) supports projects in defining and driving their inputs in relation to standardization activities. The WG reports on impact on standardization across the various phases of the 5G PPP Initiative [7-3]. In [7-4], detailed information is captured from phase 2 projects on 5G architectures, with a total of 219 inputs analysed and grouped as follows:

- **Overall architecture**: 50 inputs from six projects to 3GPP SA2, SA4, SA5 and SA6; IETF, ETSI TC-SES SCN, DVB TM-IPI, including the implementation of 5G-V2X systems, multimedia broadcast and satellite access.
- **Radio and edge architecture**: 41 inputs from six projects to 3GPP RAN1, RAN2, RAN3; ETSI MEC and DVB TM-WIB, including inputs on 5G NR enhancements for V2X and multimedia broadcast.
- **Core and transport architecture**: 58 inputs from four projects to 3GPP CT1, CT4, 3GPP SA2; ITU-T SG15; ETSI ISG NFV, ETSI ZSM and IETF; with most of them related to terminals.
- **Management and orchestration architecture**: 50 inputs from twelve phase 2 projects and one phase 3 project to ETSI OSM; ETSI ENI, ETSI ZSM, ETSI SES-SCN; IETF, IRTF; Metro Ethernet Forum (MEF); NGMN MANO requirements for 5G; Linux Foundation.

These inputs are among the over 700 inputs tracked to date across the three phases of 5G PPP, where 3GPP is the most targeted organisation for technical specifications, followed by ETSI. These cover most of the 5G features reported in Table 2 on page 17 and used by different verticals.

The 5G IA works closely with a sub-set of other 3GPP Market Representation Partners (MRPs) to help capture needs from verticals and find a way to integrate them in 3GPP. This work is coordinated by a small task force led by 5G IA, 5GAA, 5G-ACIA and PSCE, flanked by high-level 3GPP Technical Specification Group Chairs and ETSI leadership.

The online Standards Tracker developed within 5G PPP serves as a collaboration tool between standards specialists in the telecommunications industry and sector specialists across industry verticals [7-5]. The tracker is the direct outcome of two 5G Vertical User Workshops that took place in February 2019 [7-7] and July 2019 [7-8], which explored delegate journeys and reviewed 3GPP processes with verticals firmly in mind. Impacts from the workshops include dedicated 3GPP support services, such as a practical guide for verticals, newcomer sessions at plenaries, a mentoring process between well-established and new delegates who can learn from each other, liaisons for participation in vertical forums and MRPs to help create a stronger bond. The abovementioned tool captures these common requirements with a view to setting the right mind-set for verticals venturing into the 5G space, helping them find peers with similar functional requirements, harmonising them, attending 3GPP meetings and amplifying each other as a key step towards achieving scales of economies [7-6].

In the context of the 5G PPP Initiative, the workshops are now being replaced by webinars. The first such webinar took place in May 2020 and attracted 308 participants from 27 countries (13 European, 11 in Asia, the South Pacific and North America). It explained how sector specialists can contribute to upcoming technical specification work in Release 18 by showing the enablers and functionalities already available in Releases 16 (June 2020) and 17 (December 2021). These two releases bring the cornerstones for 5G standards with a set of technologies that will be re-usable across verticals to enable them run new services. Work spans new functionalities, features and enhancements for industry sectors, such as eMBB, mMTC, URLLC, including satellite integration, 5G proximity services (side-link in the RAN area), a light version of multicast solution for verticals like public safety, as well as enhancements for IIoT in the manufacturing sector, etc.

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# 8 SMEs and Verticals

SMEs employ 93 million people in Europe, account for 67% of the total employment in the EU-28 non-financial business sector, and generate 57% of value added, again in the EU-28 non-financial business sector. In the European Union's manufacturing sector, in which large enterprises are generally dominant, SMEs account for 58% of total employment and 42% of total value added. In the business services sector, where most of the ICT work is performed nowadays, SMEs account for 82% of total employment and 76% of value added [8-1].

The progressive arrival of 5G shall bring disruption in business models for incumbent operators and verticals alike. While opportunities will surely arise for large, well-positioned market participants, there should also be opportunities for agile and flexible SMEs who have mastered the key technologies and services that enable the new business models emerging from the deployment of 5G not only in the telecommunications ecosystem but also in the 5G-enabled vertical sectors. This was anticipated by the EU 5G PPP, that has since its inception implemented a strategic plan to involve gradually vertical stakeholders in the projects, along with players from the telecommunications and ICT ecosystem. In parallel, the involvement of SMEs in the 5G PPP has been progressing along the Phases, almost reaching 20% in budget.

There are many SMEs present in vertical markets such as media, transportation, energy, smart cities, and public safety. The "Find your SME" web page [8-2] and the SME brochure [8-3], both dedicated to promoting expertise and skills of SMEs, focuses both on technological expertise as well as knowledge and involvement in vertical sectors.

With the advent of Phase 3 of the 5G PPP, five years after the first set of projects were launched, results are starting to show up and SME success stories are appearing. Most success stories focus on technology advancements, as was staged in the first two phases of the 5G PPP. Achievements in vertical solutions are expected to mostly show up in a 2-5-year time frame, especially once the projects focusing on "5G innovations for verticals with third party services" [8-5] will have been completed.

Still, some achievements in vertical sectors are starting to appear for some SMEs, where their technological achievements make a difference. Ubiwhere, an SME from Aveiro, Portugal, benefited from their participation in the 5G PPP to eventually deploy 5G-enabled solutions related to energy and automotive, e.g. for electric vehicle charging stations and CCAM (Cooperative and Connected Automated Mobility) services and applications. The German SME InnoRoute from Munich benefited from its participation in the 5G PPP to enter the Industry 4.0 business, with customers in the automotive and industrial markets. Thanks to the 5G PPP, IS-Wireless from Poland strengthened its knowledge of the public safety domain and connected with stakeholders from that area, while Nextworks from Italy did the same in the broadcasting and media sector. Nemergent from Spain increased its involvement in mission-critical services, and Visiona could make the drone industry benefit from their expertise.

This shows that the 5G PPP has the capability to demonstrate the feasibility for SMEs to develop and deploy 5G innovative solutions in vertical markets. This will hopefully allow more SMEs to follow a similar path, eventually increasing the European market share on a global scale. This will strengthen the chances for European SMEs to achieve sustainable growth and become key players in the new business environment created by the 5G paradigm, considering that "the rising demand from various (vertical) applications has been recognized as the major drivers for the 5G infrastructure market growth" [8-4].

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# 9 Spectrum for the vertical industries

In 2016, an action plan [9-1] was launched by the European Commission to boost EU efforts for the deployment of 5G infrastructures and services and meet the challenge of making 5G a reality for all citizens and businesses by the end of 2020. A roadmap was set out for public and private investment on 5G infrastructure across Europe for the coordinated commercial launch of 5G, including measures to make spectrum bands early available for 5G. Three “pioneer” frequency bands, each characterised by varying properties, suitable for the introduction of 5G-based services in Europe were identified, namely the 700 MHz band, the 3.4-3.8 GHz band, and the 26 GHz band (24.25-27.5 GHz) whose combined use will help unleash the full potential of 5G.

At the same time, CEPT started a comprehensive list of actions regarding 5G named “CEPT roadmap for 5G” [9-2]. Relevant actions were taken regarding both the harmonization within Europe for mobile/fixed communications networks (MFCN) of the 3.4-3.8 GHz and 26 GHz frequency bands to make them suitable for 5G and the revision of existing harmonized spectrum for MFCN (i.e., the 700 MHz, 800 MHz, 1.5 GHz, 2.1 GHz, 2.6 GHz, 1800 MHz, and 900 MHz frequency bands) to ensure its suitability for 5G.

In many European countries, 5G spectrum has been already awarded in the three pioneer bands or is in the process to be awarded and MNOs are deploying or preparing to deploy their networks to fulfil 5G technical requirements and market needs, including those put forward by verticals.

According to the 5G Observatory Quarterly Report 7 [9-3], up to March 2020, at EU level on the whole, 13 countries have already assigned spectrum for 5G in one or two bands as at end December 2019 and many commercial 5G networks have emerged. The 700 MHz band has been assigned in seven European countries: Denmark, Finland, France, Germany, Hungary, Italy, and Sweden. Spectrum in the 3.4-3.8 GHz band has been assigned for 5G in 12 countries: Austria, Czech Republic, Finland, Germany, Hungary, Ireland, Italy, Latvia, Romania, Slovakia, Spain, and United Kingdom. Spectrum at 26 GHz has been assigned in Italy. Finally, at least one 5G spectrum auction is scheduled for 2020 in 26 European countries.

Pre-commercial trials to validate 5G’s capabilities have increasingly moved their focus on trialling 5G across vertical industries [9-3], with media and entertainment (36 trials), transport (31 trials), and automotive (22 trials) resulting in the most trialled verticals.

Since the 5G commercial launches in late 2018, commercial 5G services have been deployed in ten European countries as of the end of March 2020 [9-3], with the common global footprint of the IMT technologies specified in harmonised standards and deployed in substantially nationwide licensed IMT frequency bands.

It is widely recognised that the main technological step change of 5G networks is their capability to serve the very different needs of end users, including verticals in multiple scenarios, by leveraging a wide set of connectivity options including, but not limited to, network slicing, small cells as well as wide geographical coverage and using the very diverse 5G spectrum assets.

Multiple models could be designed on how connectivity for vertical industries can be implemented, e.g. through cooperation models between MNOs and vertical industries in order to harvest the benefits of optimization of use of network infrastructure and spectrum, preserving the availability of sufficiently large contiguous blocks of spectrum required to deliver most 5G services and the global IMT footprint, as discussed further below.

Different spectrum regulation options exist to support cooperation between MNOs and vertical industries. Cooperative models could be implemented e.g., by means of voluntary commercial negotiations where on the one side the vertical industry actor engages itself in defining its needs and requirements and on the other side the MNO actor engages itself in providing the required services including possible specific dedicated SLAs including spectrum leasing. Cooperation between MNOs and vertical industries in fact relies on the recognised 5G capability to provide new levels of performance which opens the way for innovative uses in a number of vertical industries which expect customised networks and products that meet their specific needs. Furthermore, cooperative commercial negotiations would provide the suitable flexibility to adapt to the dynamics of the business models of vertical sectors largely still in development.

Possibly, commercial negotiations could be supported by light-touch regulatory provisions, e.g. mechanisms to have operators granting reasonable requests from vertical industries by providing them with customised solutions in terms of coverage and performance. Also, MNOs' wholesale reference offers could be a suitable mechanism for cooperation, although not as flexible to fulfil diverse vertical industries' scenarios as a purely commercial negotiation.

Where vertical industries may have specific technical needs and require access to spectrum, an effective option consists in implementing spectrum leasing agreements between MNOs as primary spectrum licensee, holding the spectrum usage rights, and the vertical industries.

Examples of voluntary commercial based agreements have been already implemented, where nation-wide MNOs lease part of their frequency holdings to "micro-network" operators to build private networks for industrial customers [9-4]. There could also be cases where national spectrum regulation requires MNOs to allow spectrum access to implement local networks.

For example, in Italy [9-5] the MNO licensees in the 26 GHz frequency band are required to allow access to third parties, who are not operators of public telecommunications services, in the form of wholesale supply of capacity, according to agreed technical modalities depending on the characteristics of the networks (e.g., in slicing mode), and which may also include the use of frequencies by the accessing party. The applicant needs to be previously authorized for the management of the network and the use of frequencies and cannot resell pure electronic communications services to the public. In Italy the 26 GHz band was licensed for 5G use in 2019 however no access request has been addressed to MNOs so far.

In the UK, the regulator has recently made spectrum available for coordinated localised access on a shared basis [9-6] by means of two new licence products: the Local Access licence (launched at the end of July 2019) and the Shared Access licence (launched in December 2019). In particular, the Local Access licence provides a way for other users to access spectrum in the frequency bands that are already licensed to mobile operators, but which is not being used or planned for use in a particular area within the next three years, in locations where this would not adversely impact the incumbent licensee's planned use of the spectrum, in terms of both interferences and operation constraints. Licences are for a defined period (the default licence period is three years), with no guarantee of access after the licence period has ended. The Shared Access licence gives access to spectrum bands which support mobile technology and is currently available in four different bands (2 x 3.3 MHz shared spectrum at 1800 MHz; 10 MHz shared spectrum at 2300 MHz; 390 MHz at 3.8-4.2 GHz; and 2.25 GHz in the lower 26 GHz band) with two kinds of licence: low power and medium power, limited to indoor low power licences in some cases (e.g., the lower 26 GHz band and the 2300 MHz shared spectrum at least initially). Licences are for an indefinite period but can be revoked including for non-use or for spectrum management reasons. As of the end of February 2020, there has been one Local Access licence granted for a broadband wireless service at a rural location (out of nine applications, of which four unsuccessful and four still under consideration) and nine Shared Access new licences [9-7].

Other regulation arrangements could provide mechanisms to require operators leasing agreements between operator to access spectrum to implement local networks. This is for example the mechanism applied in Finland to the 3.5 GHz band, where licence conditions require "the licensee to lease on reasonable and non-discriminatory terms the right to use the frequency to another operator to provide a network service in a geographical area for which the licensee does not offer a tailored network service despite a request to do so. This will allow sufficient spectrum availability for the construction of national commercial networks, but at the same time promote the implementation of tailored and local solutions" [9-7].

In Italy, operators with 80 MHz assignments in the 3600-3800 MHz band are required by regulation to provide lease on reasonable and non-discriminatory terms an access service to any operator for the development of 5G services in a specified area, up to the minimum of the area covered by a single plant [9-5].

The cooperation models mentioned above are based on the common approach that spectrum usage rights are fully awarded to mobile network operators, who maintain the spectrum usage rights also in case of leasing agreements and no spectrum is reserved to vertical industries.

An alternative approach could be implemented where, in addition to substantial nationwide spectrum usage rights awarded to MNOs, dedicated spectrum could be made available to verticals to e.g., take account of the request by the vertical sectors that some specific services require frequencies for their own telecommunications networks. When considering how to define and achieve the best means to ensure availability of advanced services for local or industrial users, the issue of possibly reserving spectrum to vertical industries has been lengthily debated, following the vertical industries' requests to be assigned dedicated spectrum. An example of this model has been implemented in Germany, where local licenses for 5G are released in the 3700-3800 MHz frequency range. Frequencies are allocated according to demand, with preference given to Industry 4.0 or agricultural and forestry applications for an initial period of ten years [9-9]. Services are limited to company internal communications in e.g., company premises, industrial parks, exhibitions, any sort of telecommunication services for the public is not allowed; furthermore, in order to ensure efficient and interference-free use of spectrum, collaboration with MNOs and possible operators of geographically adjacent radio networks is required [9-10]. Similarly, 80 MHz is to be assigned for local licences in Sweden in the 3720-3800 MHz band, while 320 MHz (3400-3720 MHz) will be for national licenses [9-11], [9-12]. Also concerning the 26 GHz band, there are examples of spectrum reserved for local licences. For example, in Finland 850 MHz (24.25–25.1 GHz) in the lower part of the band will be excluded from the auction for national use and reserved for the construction of local networks e.g., in ports and industrial facilities, while three 800 MHz frequency blocks (25.1–27.5 GHz ) will be auctioned for national use [9-13].

However, spectrum set-asides do not prevent MNOs from making agreements to manage private networks for enterprises either in their nationwide spectrum assignments or in privately-owned spectrum, which is not licensed directly by the operator itself. An example is Deutsche Telekom in Germany which is reported to expect to manage most private 5G networks at 3.7-3.8 GHz [9-14].

In general, deploying a large number of small specialized verticals-oriented networks can prove to be less efficient than providing different services by a smaller number of large networks, leveraging on 5G flexibility and slicing features. In particular, possible drawbacks of the spectrum set-aside approach are:

- the development of possible "non-standard" solutions for niche markets, which could not interoperate with the 5G environment and could become outdated in very short time,
- the risk of spectrum rights fragmentation, which could seriously undermine the possibility to assign the sufficiently large contiguous blocks, especially in the low and mid frequency bands, required to deliver most 5G services,
- supplemental coexistence issues between networks,

- the risk of spectrum waste as spectral resources assigned outside a conventional market-based national award procedure and dedicated to restricted use cases could remain underused.

In general, the deployment of options and business models should ensure that 5G flexible solutions assist in the full digitization of verticals following standardized solutions and avoiding potential issues e.g., spectrum fragmentation to the detriment of sufficiently large contiguous blocks availability especially in the low and mid frequency bands, increased coexistence issues between networks and the risk of underusing spectrum. Finally, competition issues should be carefully addressed and solved in a fair way if spectral resources are assigned outside the mainstream of conventional market-based national award procedures.

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# 10 Design the beyond 5G system

The current 5G PPP Programme has provided significant achievements [10-1] such as:

- **Measurable Programme Key Performance Indicators** (e.g., contributions by the private side and a leverage of 10 times the EC investment for large industry and SMEs, a significant participation of SMEs (~20% of beneficiaries), an increase of new jobs/skills for all participating entities, a significant impact in the yearly turnover (10.1%) and yearly revenues (11.9%) for the participating SMEs, addressing all technical KPIs etc.).
- **Large number of technical achievements** (i.e., 15 key technical achievements of Phase 1 projects [10-2] and 60 highlighted technological results for Phase II projects [10-3].
- **Multiple technical contributions to standardization bodies** (i.e., 611 contributions until September 2019).
- **Widespread dissemination and promotion of European achievements** (e.g., organization of / participation in many global events and over 800 publications in journals and conferences (September 2019) and 24 cross 5G PPP white papers [10-4])
- **Provision of key roadmaps** (e.g., Trials Roadmap Version 4.0 [10-5]). The 5G PPP has created 5G technology leadership for the European industry through the hard work of 5G PPP projects, Working Groups, and Task Forces.
- **Preparing Europe for deployment:** moving from initial research activities to large scale trials and testbeds while getting closer to market applications. This has also created **wide awareness of 5G across EU Member States** in view of preparing for their spectrum licensing policies.
- **Involvement in multiple vertical industries** from concepts to large scale trials [10-6], [10-7] as captured in the verticals cartography [10-8].
- **The overall mobilization of the scientific community** (universities and research centres) in Europe as well as the business sector (large industries and SMEs) contributed to a great deal of European know-how that secured **a major share of 5G contracts worldwide** [10-1].

This 5G PPP Programme has been instrumental to support 5G development and deployments across Europe, to build EU industrial capabilities and to promote pan-European synergies and engagement of several SMEs.

Although several achievements have been accomplished, many challenges remain. The **Smart Networks and Services (SNS) Programme** proposal [10-9] aims to organise the European research and innovation activities for the evolution of communication networks in the timeframe until 2028.

Figure 10.1 presents the targeted impact areas of the SNS Partnership where the first impact target is the full industrial digitization and support of vertical industries, which is expected to bring significant financial benefits and ensure the competitive edge of EU industry.


**Figure 10.1 Targeting areas for the SNS Partnership proposal**

This target is not yet fully achieved even with the current releases of 5G networks. A close collaboration among all actors including communications operators and the vertical/IoT-industries is required to integrate business and technological enablers and support vertical domain applications. At the same time, independently of the addressed vertical sectors, the digital transformation is needed to open new business opportunities related to the provision of end-to-end cybersecurity and privacy services.

Thus, in the next decade it will be decisive for Europe to develop lead markets to ensure its competitiveness at a global scale and keep the technology leadership.

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# Abbreviations and acronyms

| | |
|---|---|
| **3GPP** | 3rd Generation Partnership Project |
| **5G IA** | 5G Infrastructure Association |
| **5G PPP** | 5G Public Private Partnership |
| **5GAA** | 5G Automotive Association |
| **5G-ACIA** | 5G Alliance for Connected Industries and Automation |
| **5G-MAG** | 5G Media Action Group |
| **AE** | Acoustic Emission |
| **AGV** | Automated Guided Vehicle |
| **AI** | Artificial Intelligence |
| **APA** | Access Point Assignment |
| **API** | Applications Programming Interface |
| **AR** | Augmented Reality |
| **ARTES** | Advanced Research in Telecommunications Systems (ESA) |
| **CAM** | Cooperative Awareness Message |
| **CAM** | Connected Automated Mobility |
| **CAN** | Controller Area Network |
| **CAPEX** | Capital Expenditure |
| **CCAM** | Cooperative, Connected and Automated Mobility |
| **CDN** | Content Delivery Network |
| **CEPT** | Conférence Européenne des administrations des Postes et des Télécommunications (European Conference of Postal and Telecommunications Administrations) |
| **CISPE** | Cloud Infrastructure Services Providers in Europe |
| **CMM** | Coordinate Measuring Machine |
| **COVID-19** | Corona Virus Disease (emerged in 2019) |
| **CTTC** | Centre Tecnològic Telecomunicacions Catalunya |
| **CU** | Central-Unit (related to functional split) |
| **C-V2X** | Cellular V2X |
| **DENM** | Distributed Environment Notification Message |
| **DG** | Directorate-General (EC) |
| **DHCP** | Dynamic Host Configuration Protocol |
| **DL** | Down-Link |
| **DOI** | Digital Object Identifier |
| **DoS** | Denial-of-Service |

| | |
|---|---|
| **DU** | Distributed Unit (related to functional split) |
| **DVB** | Digital Video Broadcast |
| **E2E** | End-to-End |
| **EB** | Exabyte |
| **EBU** | European Broadcasting Union |
| **EC** | European Commission |
| **ECC** | Electronic Communications Committee |
| **ECSEL** | Electronic Components and Systems for European Leadership |
| **ECSO** | European Cyber Security Organisation |
| **eMBB** | enhanced Mobile Broadband |
| **EMEA** | Europe, the Middle East and Africa |
| **EN** | European Standard (ETSI) |
| **ENI** | Experiential Networked Intelligence (ETSI) |
| **ERTICO** | European Road Transport Telematics Implementation Co-ordination Organisation |
| **ESA** | European Space Agency |
| **ESOA** | EMEA Satellite Operator's Association |
| **ETP** | European Technology Platform |
| **ETSI** | European Telecommunications Standards Institute |
| **EU** | European Union |
| **EUCNC** | European Conference on Networks and Communications |
| **EUTC** | Europe Utility Technology Council |
| **E-UTRAN** | Evolved Universal Terrestrial Radio Access Network |
| **EVS** | Extended Virtual Sensing |
| **FMA** | Follow Me Application |
| **FMS** | Follow Me Service |
| **GB** | Gigabyte |
| **GE** | Gigabit Ethernet |
| **GLOMO** | Global Mobility (GSMA award) |
| **GNSS** | Global Navigation Satellite System |
| **GPS** | Global Positioning System |
| **GSA** | Global Suppliers Association |
| **GSM** | Global System for Mobile communications |
| **GSMA** | GSM Association |

| | |
|---|---|
| **HAP** | High-Altitude Platform |
| **HD** | High Definition |
| **HDR** | High Dynamic Range |
| **HEVC** | High Efficiency Video Coding |
| **HTTP** | Hypertext Transfer Protocol |
| **HTTPS** | Hypertext Transfer Protocol Secure |
| **IALA** | International Association of Lighthouse Authorities |
| **ICC** | International Conference on Communications (IEEE) |
| **ICT** | Information and Communication Technologies |
| **IEEE** | Institute of Electrical and Electronics Engineers |
| **IEG** | Independent Evaluation Group |
| **IETF** | Internet Engineering Task Force |
| **IIoT** | Industrial Internet of Things |
| **IMT** | International Mobile Telecommunications |
| **IoT** | Internet of Things |
| **IP** | Internet Protocol |
| **IPT** | Institute for Production Technology (Fraunhofer) |
| **IRTF** | Internet Research Task Force |
| **ISO** | International Standards Organisation |
| **ISSN** | International Standard Serial Number |
| **IT** | Information Technology |
| **ITS** | Intelligent Transportation Systems |
| **ITU-R** | International Telecommunication Union-Radiocommunication |
| **ITU-T** | International Telecommunication Union-Telecommunication |
| **KDT** | Key Digital Technologies |
| **KPI** | Key Performance Indicator |
| **LAN** | Local Area Network |
| **LB** | Load Balancer |
| **LIDAR** | Light Detection and Ranging |
| **LTE** | Long Term Evolution |
| **LX** | Level Crossing |
| **MANO** | Management and Orchestration |
| **MB** | Megabyte |
| **MEC** | Multi-access Edge Computing |

| | |
|---|---|
| **MEF** | Metro Ethernet Forum |
| **MFCN** | Mobile/Fixed Communications Networks |
| **MIMO** | Multiple-Input and Multiple-Output (related to antenna) |
| **mIoT** | Massive Internet of Things |
| **ML** | Machine Learning |
| **mMTC** | massive Machine Type Communications |
| **MNO** | Mobile Network Operator |
| **MPEG-DASH** | Dynamic Adaptive Streaming over HTTP |
| **MR** | Mixed reality |
| **MRP** | Market Representation Partner (3GPP) |
| **MSS** | Maximum Segment Size |
| **NB** | Narrow-band |
| **NEM** | Networked Electronic Media |
| **NESSI** | Networked European Software and Services Initiative |
| **NFV** | Network Function Virtualisation |
| **NFVI** | NFV Infrastructure |
| **NGMN** | Next Generation Mobile Networks |
| **NPN** | Non Public Network |
| **NR** | New Radio |
| **NS** | Network Service |
| **NSA** | Non-Stand Alone |
| **NSD** | Network Service Descriptor |
| **OEM** | Original Equipment Manufacturer |
| **ONAP** | Open Network Automation Platform |
| **OPEX** | Operational Expenditure |
| **OSM** | Open Source MANO |
| **OVS** | Open Virtual Switch |
| **P&P** | Plug and Play |
| **PAS** | Publicly Available Specification |
| **PCP** | Pre-Commercial Procurement |
| **PGW** | Packet Data Network Gateway |
| **PMR** | Private Mobile Radio |
| **PN** | Pseudorandom Noise |

| | |
|---|---|
| **PoC** | Proof-of-Concept |
| **PoP** | Point of Presence |
| **PPDR** | Public Protection and Disaster Relief |
| **PSCE** | Public Safety Communication Europe |
| **QoE** | Quality of Experience |
| **QoS** | Quality of Service |
| **QUIC** | Quick UDP Internet Connection |
| **RAN** | Radio Access Network |
| **RAT** | Radio Access Technology |
| **RRLH** | Remote Radio Light Head |
| **RSS** | Received Signal Strength |
| **RRV** | Rapid Response Vehicle |
| **RSU** | Roadside Unit |
| **RTT** | Round Trip Time |
| **SA** | Stand Alone |
| **SA** | Service and System Aspects (ETSI) |
| **SAE** | Society of Automotive Engineers |
| **SatCom** | Satellite Communications |
| **SBA** | Service Based Architecture |
| **SCADA** | Supervisory Control And Data Acquisition |
| **SDA** | Strategic Deployment Agenda |
| **SDK** | Software Development Kit |
| **SDN** | Software Defined Networks |
| **SDO** | Standards Developing Organisation |
| **SGW** | Signalling Gateway |
| **SLA** | Service Level Agreement |
| **SME** | Small and Medium-sized Enterprises |
| **SNS** | Smart Networks and Services |
| **SWD** | Staff Working Document (EC) |
| **TB** | Transport Block |
| **TBD** | To Be Defined |
| **TC** | Technical Committee (ETSI) |
| **TCP** | Transport Control Protocol |
| **TDoA** | Time Difference of Arrival |

| | |
|---|---|
| **TR** | Technical Report (ETSI) |
| **TS** | Technical Specification (ETSI) |
| **TSN** | Time Sensitive Networking |
| **TV** | Television |
| **UCC** | Use Case Class |
| **UDP** | User Datagram Protocol |
| **UE** | User Equipment |
| **UHD** | Ultra-High Definition |
| **UIC** | Union Internationale des Chemins de Fer (International Union of Railways) |
| **UL** | Up-Link |
| **URL** | Uniform Resource Locator |
| **URLLC** | Ultra-Reliable Low Latency Communications |
| **USB** | Universal Serial Bus |
| **Uu** | Interface between the mobile and the radio access network |
| **V2I** | Vehicle to Infrastructure |
| **V2V** | Vehicle-to-Vehicle |
| **V2X** | Vehicle-to-Everything |
| **vEPC** | Virtual Evolved Packet Core |
| **VLC** | Visible Light Communications |
| **VNF** | Virtual Network Function |
| **VR** | Virtual Reality |
| **VS** | Vertical slicer |
| **VSB** | Vertical Service Blueprint |
| **VSD** | Vertical Service Descriptor |
| **VTF** | Verticals Task Force |
| **WDM** | Wavelength Division Multiplexing |
| **WebRTC** | Real Time Communication over the Web |
| **WG** | Work Group |
| **WLAN** | Wireless LAN |
| **XR** | Extended Reality |
| **ZSM** | Zero-touch network and Service Management (ETSI) |

# Contributing 5G PPP Projects

| | | |
|---|---|---|
| 5G CAR | 5GCity | 5G MEDIA |
| 5G-MONARCH | 5G-PICTURE | 5G TRANSFORMER |
| IoRL Internet of Radio Light | ONE5G | SLICENET |

**Phase 2 Projects**

| | | |
|---|---|---|
| 5G EVE | 5G-VINNI | 5Genesis |

**Phase 3, Part 1: Infrastructure projects**

| | | |
|---|---|---|
| 5GCroCo | 5G CARMEN | 5GMOBIX |

**Phase 3, Part 2: Automotive projects**

**Phase 3, Part 3: Advanced 5G Validation trials across multiple vertical industries**

**Phase 3, Part 4: 5G Long Term Evolution**

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