Testbeds for the Implementation of 5G in the European Union: The Innovative Case of the 5G-DRIVE Project

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Abstract. An essential part of the actual EU policy towards promoting and validating 5G applications and of related solutions is via the establishment of an explicit plan and of a detailed roadmap for trials, tests and experimental activities though dedicated testbeds, in parallel with the current research and development activities coming from the 5G-PPP framework. The present paper discusses the fundamental role of the proposed trials' initiatives within the broader European framework for the establishment and the promotion of 5G and also analyses the corresponding streams as indispensable parts of the 5G-PPP context, aiming to support innovation and growth. In addition, as part of the broader initiative for trial actions we identify the case of the 5G-DRIVE project that aims to realise 5G deployment scenarios (i.e., enhanced Mobile Broadband and Vehicle-to-Everything communications), between the EU and China, by discussing the fundamental features of the respective trials sites.

Keywords: 5G · 5G Action Plan (5GAP) · 5G Public Private Partnership (5G-PPP) · Horizon 2020 · Enhanced Mobile Broadband (eMBB) · Experimental platforms · Mobile edge computing (MEC) · Network slicing · Pilot trials · Testing and validation facilities · Vehicle-to-Everything (V2X)

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1 Introduction

Over the last decade the European Union's (EU) electronic communications policy has been effective in delivering more competition, lower prices and more choices for businesses and consumers [1]. However, the full economic and social benefits of this sort of broader digital transformation will only be achieved if Europe can ensure extensive deployment and reception of very high capacity networks, in rural as well as urban areas and across all of society that will be able to offer innovative facilities and related services in a broad thematic range. One of the central aims of the European Commission's (EC) Digital Single Market Strategy [2] was, *therefore*, to generate the precise environment and conditions for the deployment of advanced digital-very high-capacity-networks.

While "basic broadband" (i.e., of a speed of at least 2 Mbps) is available to every European, mainly enabled by legacy infrastructures, this is no longer good enough for the ongoing digital transformation, strongly promoted by the actual European policies and being aligned to relevant international trends affecting both market and society. Transformative solutions based on Internet connectivity (such as cloud computing, Internet of Things, high performance computing, big data analytics etc.) are expected to modify business processes as well as to influence social interactions. New digital applications *-like virtual and augmented reality (VR/AR), increasingly connected and automated driving, artificial intelligence-* will necessitate the speed, quality and responsiveness that can only be delivered by very high-capacity broadband networks.

Digital technologies support innovation and competitiveness across private and public sectors and enable scientific progress in all disciplines. The proposed Horizon 2020 (H2020) Work Program (WP) 2018–2020 [3] covers a great variety of modern Information and Communication Technologies (ICT) thus aiming to modify multiple domains, with particular emphasis given among others, to the development of the 5th Generation of Mobile Communications (the so called as "5G") ([4, 5]). By properly pursuing the change initiated under the previous EU WPs, it is expected that related research activities will continue to promote more innovation-orientation to ensure that the EU industry remains strong in the core technologies, being at the roots of future value chains.

However, a suitable strategic approach is essential for the EU so as to realise a clear and leading position in the international "arena" and to obtain any relevant (early) advantage of the new market opportunities promoted and enhanced by 5G, via appropriate validation of the related 5G services and facilities, for the benefit of the "whole" economy and society.

2 Actions for Tests-Trials at EU Level Towards the 5G Promotion

The promotion of the digitisation process in some "key" industrial sectors based on 5G connectivity, as well as the dawn of modern business models, clearly implicate for closer partnerships between the concerned sectors and the telecommunication sector.

While a few markets will naturally lead innovation and attract most of the initial investments, a number of sectors recognise the need to "run" pilot trials to increase predictability, reduce investment risks and validate both the technologies and the concerned business models. Experiments are also needed to "provide input" for the standardisation effort towards establishing validated norms and recommendations.

Among the actual priorities of the EC, working interactively with Member States (MSs) and industrial stakeholders/market actors is the voluntary establishment of a common timetable for the launch of early 5G networks (initially scheduled to be operational by the end of 2018) and followed by the launch of fully commercial 5G services in Europe by the end of 2020. According to the 5G Action Plan (5GAP) [6], the relevant EU timetable is actually driven by the following key objectives: (i) Promoting preliminary trials, under the 5G-PPP arrangement [7], to take place from 2017 onwards, and pre-commercial trials with a clear EU cross-border dimension from 2018; (ii) supporting commercial launch of 5G services in at least one major city in all MSs in 2020, *and*; (ii) encouraging MSs to develop national 5G deployment roadmaps as part of the national broadband plans, with uninterrupted coverage in all urban areas and along main transport paths in 2025.

Many EU cities are already strongly engaged in 5G development, trials and pilots and first commercial deployment will already start in specific EU cities in 2019. The EC EU 5G Observatory website/online platform [8] has been officially launched on late of September 2018 and provides independent monitoring information concerning the main actual and likely market developments, 5G trials and other actions taken by MSs, as well as industry stakeholders regarding 5G market introduction in EU and in a global context. This allows assessing the progress of the EU 5GAP and to take actions to fully implement it. The Observatory focuses primarily on developments in EU, along with major international developments that could impact the EU market.

Most of the actual roadmap implementation is both driven and supported by the industry sector, on a private basis. In fact, the core part of the 5G trials and pilots is - and will be achieved- through private trials (commercial and pre-commercial) between network operators and manufacturers/vendors and is increasingly involving vertical stakeholders. Through the present 5GAP, the EC supports the creation of suitable requirements for the intended 5G deployment in Europe, particularly the identification of the related harmonised spectrum and of the regulatory conditions, while supplementary support for trials and pilots is made available from the EC H2020 program in support of the 5G-PPP implementation, specific national programs of MSs as well as from specific programs (such as the European Space Agency (ESA) Satellite for 5G Initiative).

The EC strongly supports pilots and experiments in the course of the 5G growth, though the coordination of the 5G-PPP, via selected 5G trials. The EC counts on the trial results to be able to identify and address specific sectorial policy issues and seek the active support of MSs to resolve them whenever they constitute a major obstacle to high value applications relying on 5G. Furthermore, there is requirement need to guarantee that hardware, terminals (here the term implicates not only for smart phones but also a full range of Internet of Things (IoT) and connected devices (cars, drones, urban furniture, etc.)) and devices based on 5G connectivity are available in due time before 2020, to encourage uptake and demand.

Experimental platforms for 4G/5G in Europe are the results of private and public efforts at national and European level. Accelerating trial capabilities and other pilots, the platforms remain subject to continuous efforts targeting the full 5G picture and future evolutions. As such, actual 5G infrastructure deployment roadmap is highly dependent on the capability to deliver relevant and comprehensive set of platforms addressing remaining gaps & challenges. Thus, one should also consider such platforms as valuable and demonstrated set of 5G enablers, beyond the trial objectives. However, complementarity and efficiency of the efforts deserve coordination among the diversity in the documentation of the existing platforms. As a consequence, it is of tremendous importance to describe the matching elements of each platform compared to the complete 5G landscape. For this, a common classification and documentation for 5G platforms addressing different target groups is mandatory. Consistent data structures and unified meta-information like name of the platform, countries where the platform is deployed and additional information on features and capabilities is fundamental. Collections of data provided by platforms have to support answers of diverse stakeholders' research, public sector or industry.

From a high-level perspective, one way to "view" the 5G ecosystem can be in terms of platforms (hardware (HW) and software (SW), services and use cases). For new platforms and services to be created, key decisions need to be taken, both business-wise and technically. Business cases have so to be developed, while tests, trials and evaluations conducted to satisfy the various stakeholders that expected outcomes need to be achieved. Considering vertical sectors, these will make use of such innovations and generate use cases for their particular sector(s). Investment and development will be required (implicating that new processes or ways of doing business may need to be considered), key decisions are to be made, business cases are to be developed and evaluations are to be conducted. Usually, some use cases may be more demanding than others and will "drive" the platform and services design and implementation. Some vertical sectors can be earlier/early adopters for the new technology/services and others will follow and make use of it, once it is proven.

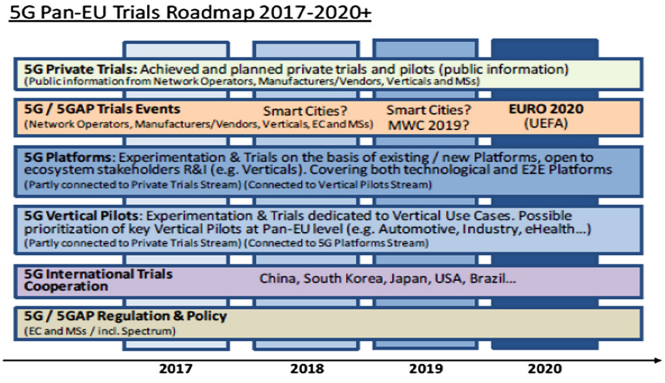

Fig. 1. Pan-European Trials Roadmap 2017–2020 - strategy and streams [9].

Within the 5G-PPP context, the Trials Working Group (WG) is elaborating a solid and comprehensive strategy to develop the Pan-EU coordinated trials [9] as well as international trials with the participation of non-EU countries. The 5G Pan-EU Trials Roadmap is addressing several of the 5G Action Plan (5GAP) key elements and targets to develop the necessary synergies between these elements. The main objectives of the Roadmap are to: (i) Affirm global European leadership on 5G technology, 5G networks deployment and profitable 5G business models; (ii) demonstrate benefits of 5G to vertical sectors, public sector, businesses and consumers; (iii) show a clear path to successful and timely 5G deployment; (iv) provide robust response to the EC 5GAP, *and*; (v) complement commercial trials and demonstrations as well as national initiatives [10].

This roadmap includes several inter-related streams, as depicted in detail in Fig. 1, and these comprise of: (i) Private experimentation and trials; (ii) large-scale 5G events and showcases, including national and pan-EU events; (iii) development and use of Research & Innovation (R&I) platforms for 5G experimentation and trials; (iv) R&I experimentation and trials in the context of vertical applications and use cases; (v) 5G international trials cooperation, *and*; (vi) 5G and 5GAP Regulation and Policy ensuring acceleration of 5G adoption and deployment (including spectrum, network neutrality, EU de-fragmentation, etc.).

In a "similar" -*or somehow "equivalent"*- approach, the EC in cooperation with the 5G Infrastructure Association (5G IA) has also identified [9] the following distinct steps (covering the broader period 2014–2024) as depicted in Fig. 2, below. This figure also incorporates relevance of intended trials to major events, so that to support 5G innovation for the benefit of the involved end-users. In addition, Fig. 2 summarises the overall 5G Pan-EU Trials Roadmap time plan and relevant standardisation, regulatory and ecosystems time plan(s).

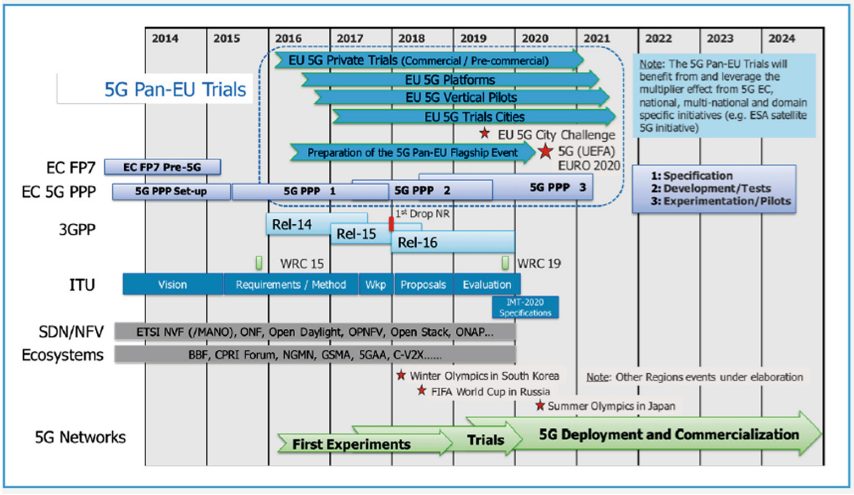

Fig. 2. Overall 5G Pan-European Trials Roadmap 2014–2024 [9].

Before 2018 (i.e., before the first 5G standard release by the 3rd Generation Partnership Project (3GPP) in Release 15, Stage 3) [11] it has been envisaged to have technical trials run by independent trial consortia in various countries, independent of the status of standardisation, to demonstrate and validate the new 5G capabilities as well as foster an ecosystem around the new 5G capabilities. Vertical industries have been involved in this trials' phase, while these trials have demonstrated several key 5G functionalities and technical/technological enablers. During and after 2018 European stakeholders moved to agree on trial specifications (e.g., use-cases, scenarios, interfaces, agreement to transfer use-cases across trial networks) valid for Pan-European trials, based as much as possible on standard-compliant systems. These trials, as performed in a more "extended" framework, aim to demonstrate wider interoperability and support for vertical use-cases in order to claim global public attention. In the following subsections we briefly discuss the various conceptual streams, as appearing in Fig. 1.

5G Private Trials Stream: This has been the case of the early stages when trials have been realised by specific initiatives promoted by some market actors for their own needs and priorities or, *exceptionally*, within the "limited" framework of some collaborative actions or projects.

5G/5GAP Trials Events Stream: There are and will be an increasing number of 5G private experimentations and trials done on bilateral (Network Operator (NO) and Manufacturer/Vendor), trilateral (NO, Manufacturer/Vendor and Vertical stakeholder) and multilateral (NO, Manufacturer/Vendor and different stakeholders) basis. Such experimentations and trials shall be considered upon private basis, while information will be either available *a posteriori* (achieved) or *a priori (*pre-announcement). The 5G-PPP Trials WG is responsible to collect the major public information related to announced and pre-announced experimentation and trials. Specific added value analysis will be achieved through different perspectives, such as: (i) Industrial stakeholders; (ii) countries, (iii) 5G pillars (eMBB, URLLC (Ultra-Reliable and Low-Latency Communication) and mMTC (massive Machine Type Communication)) and KPIs (e.g., data rate, mobility, latency, density, reliability, positioning accuracy, coverage, etc.); (iv) timing (2018, 2019, 2020 and onwards) *and*; (v) standardisation phases and releases (e.g.: 3GPP Release15 [11], Release16 [12] and onwards).

5G Platforms Stream: 5G Platforms are a useful tool to support the 5G European trials. These platforms can support the execution of 5G services and use cases, including for mass market and vertical sectors. Due to the high diversity of platforms, use cases, trials and maturity stages of technology, the 5G Platforms can be classified in three different levels, that is: (i) Research; (ii) End-to-End (E2E) Trials, *and*; (iii) pre-Commercial. A number of platforms have been designed in Europe (e.g. from EU-funded research projects) that can serve as a "basis" for 5G trials [13]. However, because the standardisation of 5G is an ongoing activity, 5G Platforms will have to evolve from existing and new platforms, requiring further investments. In such scenario, cooperation between platforms is a way to rapidly adapt to changes/improvements to standards, to reduce costs, permit large trials, and even to interconnect with sites in other regions. The 5G-PPP Trials WG is assessing the interest, feasibility conditions and possible solutions to create and maintain a pan-European platform, or a network of federated platforms, to be used for 5G pan-European trials.

5G Vertical Pilots Stream: 5G experimentation and trials will evidently address vertical applications and use cases. The vertical trials may be partly connected to the private trials and directly connected to the 5G available platforms (pre-Commercial and R&I). The selection of vertical pilots should take into account the sectors already mentioned in the 5GAP, including but not limited to, the media and entertainment, public safety, eHealth, automotive, transport and logistic sectors. It will also incorporate the progress already achieved by the 5G Infrastructure PPP on the 5G use by vertical sectors. The 5G-PPP Trials WG's aim is to support the selection of vertical and use cases for trials for a better understanding of the technical and technology requirements. In any case, the pre-definition of the vertical trials will address: (i) Description of vertical sectors; (ii) use cases addressed; (iii) technical requirements, *and*; (iv) technologies required for the provision of requirements. This step can enable a gap analysis to focus further R&I to overcome any remaining technology gaps.

5G International Trials Cooperation Stream: Multiple European 5G network trials and most of the 5G technologies under trials will be available for commercial deployment by 2020. In any case and beyond the 5G EU-focused developments, the 5G Pan-EU trials are implemented within a global context where several trials, pre-commercial and even commercial deployment initiatives are already taking place in other countries and regions outside the EU. Since 5G will be deployed worldwide, it is required to work not only towards accelerating global 5G standards, but also on trialing and interoperability with other main regions. EU-"X" joint trials, where "X" includes international counterpart countries like China, Japan, Korea, Brazil and US, are "key" to ensure a common understanding of 5G as well as global interoperability. On the private side, the 5G IA has already signed bilateral Memorandums of Understanding (MoUs) with the leading 5G visionary organisations in China (IMT-2020 5G promotion group), Korea (5G Forum), Japan (5G Mobile Communications Promotion Forum) and 5G Americas (North and South America). Specific joint experimentations and trials will be developed in the context of these MoUs.

5G/5GAP Regulation and Policy Stream: As the validation of 5G services and facilities is to take place via trials and experimentation, it is expected that this will also affect EU policies and relevant regulation. For certain domains like access to and use of selected frequency bands of spectrum, results are to be immediate, while for other cases results may affect further development of technical solutions as well as corresponding market policies.

The ongoing twenty-one (-21-) 5G-PPP *Phase 2* projects [7] (2017–2019) contribute to the prototyping, experimentation and trialing of 5G technologies and components for specific use-cases including vertical use-cases developed with vertical stakeholders. This infrastructure offers the suitable level of openness to allow vertical industries to test their innovative 5G business cases by using *ad-hoc* network resource control in an E2E interoperability framework. With the application-specific requirements and usage scenarios for 5G already identified, the experiments are investigating 5G functionalities spanning eMBB, uRLLC and mMTC. These requirements stem from an analysis of business aspects and applications driven by the verticals. In the automotive sector, *in particular*, industry stakeholders within the 5G-PPP are embracing connected and autonomous cars, vehicle-to-infrastructure, entertainment and corresponding media services. The anticipated impact is huge and extensive, as this

promotes new ecosystems of commercial and public-sector product and service providers.

In the same scope, the 5G-PPP *Phase 3* of pan-EU 5G E2E facilities/platforms (ICT-17) projects [7] started in July 2018 and cover 20 platforms/nodes in EU (each one in a European city). Simultaneously, the three *Phase 3* corridors (under ICT-18) projects started in November 2018, address multiple EU "test corridors" [14]. The so called as the 5G corridors make Europe the biggest experiment area rolling out the 5G technology. This confirms Europe's leadership in large-scale testing and early deployment of 5G infrastructure also enabling connected and automated driving, *among others*. As of October 2018, 10 digital cross-border corridors have been identified for Connected and Automated Mobility (CAM).

As of October 2018, more than 140 trials and pilots have been reported as "being active" within the EU. In June 2019, 6–7 PPP *Phase 3* Vertical Pilots (ICT-19) projects will "target" large scale trials and pilots, including complete E2E 5G systems and leveraging the existing platforms projects. It is expected that additional 5G test corridors projects will be launched in the context of the PPP *Phase 3*. In addition to the 5G private trials and pilots reported in the EC EU 5G Observatory, the 5G Infrastructure PPP Verticals Cartography, launched in September 2018, tracks city-based 5G trials and pilots from 5G Infrastructure PPP *Phase 2* projects across eight vertical clusters: Automotive, Energy, Health, Industry, Media and Entertainment, Public Safety, Smart Cities, Transport and Logistics planned in 2018–2020 [15].

3 The Context of the 5G-DRIVE Project

The 5G-DRIVE project [16] aims to perform a "close" collaboration between EU and China to synchronise 5G technologies and spectrum issues before the final roll-out of 5G in order to "address" two most promising 5G deployment scenarios, namely enhanced Mobile Broadband (eMBB) and Vehicle-to-Everything (V2X) communications. The eMBB is one of three primary 5G New Radio (NR) use cases defined by the 3GPP [17] as part of its SMARTER (Study on New Services and Markets Technology Enablers) project [18]. This "addresses" the human-centric use cases for access to multi-media content, services and data. Actual technology trends purely "demonstrate" that the demand for mobile broadband will continue to increase, thus leading to eMBB. The related usage scenario covers a range of cases, including wide-area coverage and hotspot, which have different requirements. On the other hand, V2X communication is the transfer of information from a vehicle to any "entity" that may affect the vehicle, and *vice versa*. It is a vehicular communication system that integrates other more specific types of communication as V2I (Vehicle-to-Infrastructure), V2N (Vehicle-to-Network), V2V (Vehicle-to-Vehicle), V2P (Vehicle-to-Pedestrian), V2D (vehicle-to-Device) and V2G (Vehicle-to-Grid).

The 5G-DRIVE project falls within the context of the ICT-22-2018 Call ("EU China 5G Collaboration") [3]. The main scope is to conduct 5G trials addressing two specific scenarios: (i) Scenario no 1 - eMBB on the 3.5 GHz band, which is a priority band in the two regions for early introduction of very high rate services; and; (ii) Scenario no 2 - Internet of Vehicles (IoV) based on LTE-V2X using the 5.9 GHz

band for V2V and the 3.5 GHz band for V2N. The overall goal is to evaluate in real setup innovative end-to-end 5G systems built on the outcomes of the previous phases of the 5G R&I. More specifically, the optimisation of the band usage in multiple scenarios with different coverage is a key target, so as the validation of the geographic interoperability of the 3.5 and 5.9 GHz bands for these use cases. Both scenarios shall be implemented in both regions (EU and China) through testbeds with interoperability forming the core of the R&I work.

The underlying trials' testing facilities shall implement the latest mature and broadly commonly agreed 5G systems, network architectures and technologies spanning from the core/transport networks, the radio access, up to the service, orchestration, management and security components. The trial facility shall not be restricted to innovative 5G radio access technology, but should include and enable the evolution of 5G networks innovations in network slicing, virtualisation, cross-domain orchestration, in view of supporting resource control from multiple tenants. In EU, trials are preferably implemented over the 5G end-to-end platforms developed under ICT-17-2018 [3]. The 5G trials' infrastructures shall facilitate the testing and validation of innovative applications for each of the defined scenarios, including efficiency solutions in the areas of spectrum usage, energy consumption and costs.

The main objective of the 5G-DRIVE context is to "bridge" current 5G developments in Europe and China through joint trials and research activities in order to facilitate technology convergence, spectrum harmonisation and business innovation before large scale commercial deployments of 5G networks take place. In order to achieve this goal, the 5G-DRIVE develops "key" 5G technologies and pre-commercial testbeds for eMBB and V2X services in collaboration with the "twinned" Chinese project led by *China Mobile*. Trials for testing and validating key 5G functionalities, services and network planning will be conducted in eight cities across the EU and China.

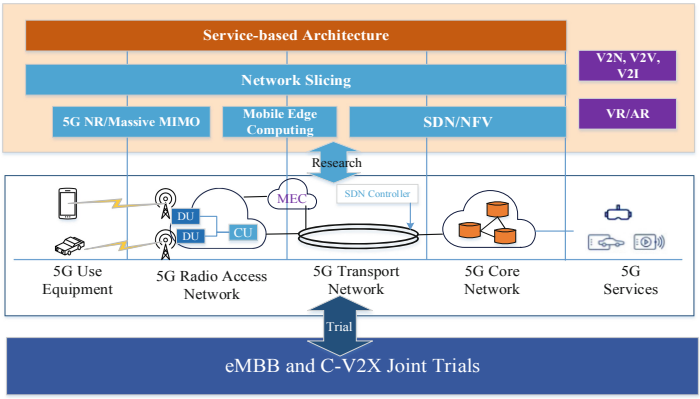

Fig. 3. Overall concept of the 5G-DRIVE project's approach.

5G-DRIVE's overall concept is illustrated in Fig. 3, which shows the three "core" streams and depicts the flow from research, to adaptation into existing testbeds and commercial testbed deployments, to the real-world trials of the 5G radio access network (RAN) and the wider 5G network. The project "brings together" solid research competence, commercial grade testbeds, and some of the stakeholders who will eventually become major customers of 5G systems.

In the 5G-DRIVE context there are partners with rather extensive 5G testbed installations - these are three facilities that have been defined, specified and deployed to "meet" the individual requirements of the involved three research organisations (UoS, VTT and JRC, as discussed in detail in the following sub-sections). In fact, three testbed sites have already been set up with commercial and experimental-grade equipment, supporting capacity provision in very dense deployments, network slicing and V2X, as well as testing of new technologies in any part of the network in a fully-controlled environment. While all three testbeds are set up with commercial grade equipment, each one has a special focus: the University of Surrey (UoS) testbed can support capacity provision in very dense deployments over a 4 km^2 area; the Espoo testbed (VTT) demonstrates the use of slicing and V2X; the JRC facility allows the testing of new technologies in any part of the network in a fully-controlled environment. All testbeds are defined in an evolutionary approach and allow the gradual introduction and testing of new equipment, as well as new mechanisms, algorithms and protocols.

These characteristics will be exploited in the entire 5G-DRIVE's context. In the research stream, the project will investigate network and RAN slicing, mobile edge computing (MEC), massive MIMO (Multiple Inputs, Multiple Outputs) for the 5G NR, as well as SDN and network function virtualisation (NFV) techniques applied to different traffic and load scenarios. Techniques and mechanisms in the research stream will be integrated into the most appropriate testbed. Wherever possible, 5G-DRIVE will endeavour to deploy such new mechanisms into all three testbeds.

The core objective of the project is to extensively trial eMBB and V2X service delivery under real world conditions. The stringent requirements for the delivery of such services will be defined jointly with the mobile operators in the consortium (Orange, OTE), as well as stakeholders from the automotive and intelligent transports markets (BMW, Vedia, Dynniq, ERT). These partners will be involved in the use case and trial requirements definition, as well as in its subsequent implementation and analysis. The inclusion of these stakeholders is imperative to ensure that the trials and solutions "do meet" the requirements from the vertical domains.

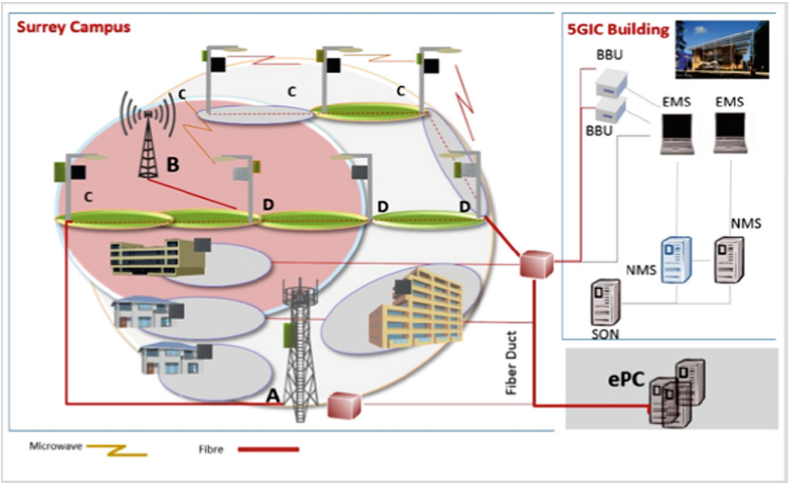

Fig. 4. High-level view of the University of Surrey's test network in the UK.

As shown in Fig. 4, the UoS trial site and the 5G Innovation Centre [19] includes a Cloud-RAN (C-RAN) test platform [20] which supports clusters of remote radio heads (RRH), supported by high performance core processing facilities for experimental research on advanced techniques such as joint transmission coordinated multi-point transmission and reception (CoMP) schemes [21]. In addition, the test network provides a unique environment to test operation of heterogeneous access networks in a real life environment. In the context of 5G-DRIVE, it will focus on the development and evaluation of the eMBB scenario. The testbed is connected to the Vodafone Core Network, Fujitsu Cloud Computing facilities and covers a 4 km^2 area for the testing of 5G technologies. The coverage area encompasses a stretch of motorway, rural, urban and dense urban radio environments. The outdoor deployment consists of 44 sites and 65 cells (of which 3 are macro cells, the remainder are small and ultra-dense cells). This end-to-end testbed incorporates a different range of frequency bands (3.5 GHz, 28 GHz and 60 GHz) and allows the testing and trialling of new air-interface solutions. Supported by a mix of wireless and fibre optic backhaul connectivity, trials can be matched to meet industry requirements. Finally, the platform can support interfacing to other testbeds, servers and databases for integration of different components provided by other consortium members and external experiments.

The Espoo trial site (see Fig. 5) provides 5G testing facilities built in several national projects under the 5GTNF (5G Test Network of Finland) framework. In the context of 5G-DRIVE, it will focus on the development and evaluation of both eMBB and V2X scenarios. The current network infrastructure is built on top of Nokia's NetLeap LTE test network [22]. It will be gradually upgraded to 5G networks when 5G NR and 5G core network components are available. The network contains both indoor

and outdoor eNodeBs operating at 2.6 GHz, lamppost integrated small cell networks operating at 3.5 GHz and mm-wave bands at 26 GHz, as well as Wi-Fi networks operating at unlicensed 2.4 GHz and 5 GHz. This site enables creating a virtual mobile network with its own evolved packet core (EPC) and can utilize the edge computing platform for developing localized services.

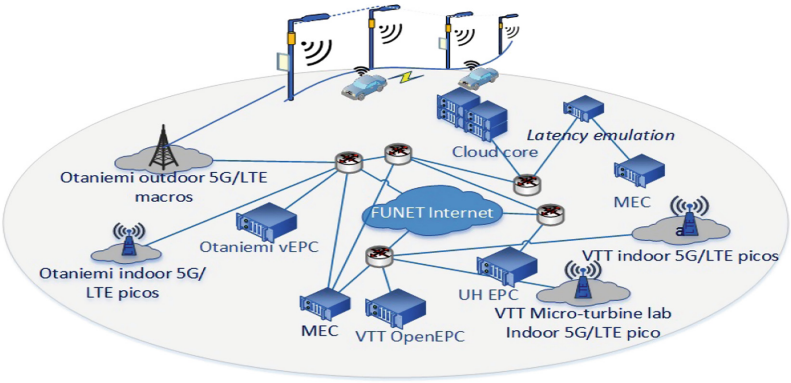

Fig. 5. Espoo trial site at Otaniemi Espoo in Finland.

The design of the test network is such that it is open for experimental EPCs. This enables multi-operator scenarios and testing of network slicing in the project. MEC platforms are currently being installed at the Otaniemi site. With the aid of an artificial delay element (network emulator), the performance of MEC for URLLC use cases can be tested in different latency scenarios. eNodeBs are connected to a 10 Gbps SDN-enabled backhaul and to an OpenStack cloud environment. The testbed in Espoo provides facilities and test environments for SDN/MEC, indoor positioning, latency reduction, reliability and other technology topics targeted by 5G-DRIVE.

The JRC Ispra site is a fully fenced research campus equipped with high-level safety and security features – a 167-hectare controlled environment for hands-on experimentation, testing and demonstration purposes. It features 36 km of roads under real-life driving conditions, as well as 9 Vehicle Emissions Laboratories (VELA 1–9) that can be used for calibration, electromagnetic compatibility/interference testing and other experimental activities. In the context of 5G-DRIVE, the JRC Ispra site will focus on the development and evaluation of V2X scenarios, with a particular focus on laboratory and field ITS-G5/LTE-V2X coexistence testing (see Fig. 6).

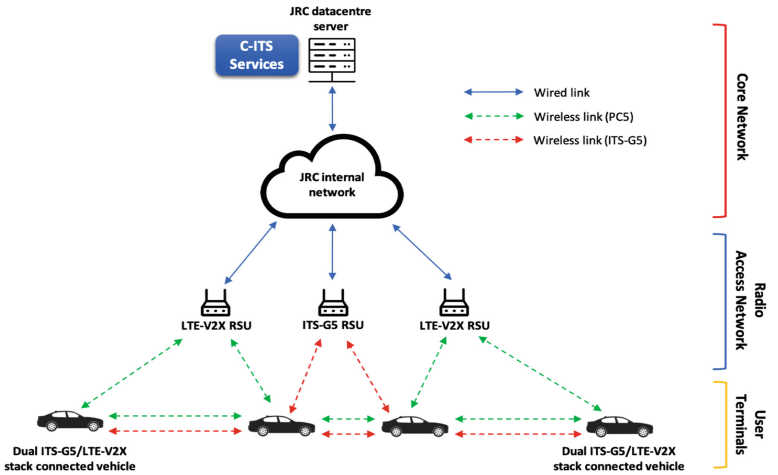

Fig. 6. The ITS-G5/LTE-V2X Testbed at JPC Ispra, in Italy.

The JRC Ispra campus has been mapped at very high resolution using drones and Laser Imaging Detection and Ranging (LiDAR), with digital maps available in various formats. This information will be used for network planning (i.e. predictions of radio propagation and network coverage), as well as vehicle localisation and intelligent routing. As far as network infrastructure is concerned, the JRC owns various LTE eNodeBs of both commercial and experimental grade, as well as a software-defined LTE core network to provide mobility, session management and user authentication services to internal test users. MEC infrastructure can be connected to the core network using either radio links or low latency fibre. These systems will take the form of small-form factor PCs featuring roadside sensing and fast computing capabilities. Finally, the JRC is also equipped with a production-level Public Key Infrastructure (PKI) which has already been used as the European Root Certification Authority for the EU Digital Tachograph project [23]. The JRC has been directly involved in drafting the Certificate Policy for the European V2X (referred to as the Cooperative Intelligent Transport Systems (C-ITS) Trust Model) [25].

4 Conclusion

The present paper has discussed the important role of trials and of dedicated platforms at the European level as fundamental “enablers” for the 5G deployment and validation within the EU. The work identified the important role that 5G is expected to perform, as essential part of the EU policy for evolution and growth, offering benefits to the European market and citizens. More specifically, within the context of the actual 5G-PPP initiative, we have assessed the specific measures proposed and the roadmap already applied -or scheduled- towards establishing the necessary framework for the realisation of pilot actions and/or related trials, to serve the expected transition to the 5G. The European Commission, in particular, emphasizes on the establishment of an

adequate and well-defined framework, able to support 5G growth via suitable experimental efforts. The proper development of the 5G ecosystem in Europe is strongly dependent on a dedicated roadmap that is harmonised to the present EU research effort, being able to promote and enlarge all potential technological and business benefits. To this aim, we have discussed the distinct and separate streams affecting these actions, in parallel to corresponding standardisation efforts, promotion of research programs and events of global character.

The actual 5G pan-European trials roadmap [24] is covering a broader scope than the 5GAP and the 5G Infrastructure PPP *Phase 3* (2018–20+). Most of the roadmap implementation is -and will be- covered by the industry on private basis, with part of this implementation supported by EC through the 5GAP, EC 5G Infrastructure PPP *Phase 3*, EC 5G Investment Fund and by MSs through specific national programs. More specifically, the 5G Infrastructure PPP *Phase 3* platforms projects (2018–2021) provide a pan-European large-scale E2E 5G validation network infrastructure, covering about 20 European sites and nodes on a pan-European basis. This infrastructure will provide the adequate level of openness to make it possible for vertical industries to test their innovative 5G business cases using *ad-hoc* network resource control in an E2E interoperability framework. The future roadmap of actual 5G infrastructure deployment is highly dependent on the capability to up-date existing or deliver a new relevant and comprehensive set of platforms addressing the remaining gaps and challenges as well as to promote new architectures [26].

Part of the above PPP *Phase 3* context is also the case of the 5G-DRIVE project which intends to realise a collaborative framework between EU and China so that to achieve mutual synchronisation of 5G technologies and spectrum issues before the final roll-out of 5G, around two essential 5G deployment scenarios (namely enhanced Mobile Broadband (eMBB) and Vehicle-to-Everything (V2X) communications). In this scope, we have presented, in detail, the related 5G-DRIVE trial sites that have been proposed by this project, as a characteristic example of the actual EU initiatives for trials and as an indispensable part of the European strategic framework for the 5G validation in certain domains that can be of significant benefit for the European economy and society.

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