EU 5G-DRIVE: 5G harmonised research and trials for service evolution between EU and China

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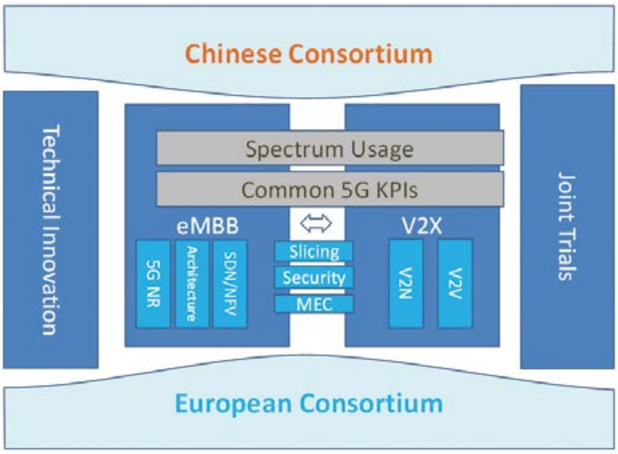
1.1. Objectives

2017 witnessed substantial progress in 5G development. On December 22nd 2017, the 3rd Generation Partnership Project (3GPP) approved the first technical specifications for the 5G New Radio (NR). This significant milestone paved the way for large-scale pre-commercial trials of 5G systems. Consequently, 5G is now on the agenda of global market adoption. Prior to witnessing real-life deployments of the first 5G networks, global technology consensus and spectrum harmonisation still remain the key issues before 5G standardisation is finally ratified. International collaboration and alignment among key regions are essential to facilitate this process. China and Europe are two of the key regions undoubtedly called to play this critical role.

The European Commission has taken the first step to boost 5G global cooperation. Through joint funded projects, global 5G events and several other initiatives, a plethora of collaborations has been established between China, United States, Japan, South Korea and Brazil. These joint technological ventures play a crucial role for an aligned 5G Research and Innovation (R&I) ecosystem across regions. Particularly, joint projects allow the direct collaboration of major stakeholders between the EU and other regions on key R&I challenges, and facilitates early consensus of business cases, technologies and regulations.

Back in early September 2015, the 5G Public Private Partnership (PPP) Infrastructure Association (5G-IA) signed the Memorandum of Understanding (MoU) with the International Mobile Telecommunications 2020 (IMT-2020) Promotion Group of China for jointly promoting 5G development between the two regions. After two years of strategic collaboration, the increasing need for a closer collaboration to synchronize 5G technologies and spectrum issues before the final roll-out of 5G has become a key issue. Consequently, the European Commission and China have agreed to fund a joint project on 5G trials in order to address two most promising 5G deployment scenarios, namely enhanced Mobile Broadband (eMBB) and Vehicle-to-Everything (V2X) communications. This project, established by major 5G players in both regions, takes the ambition to fulfil this goal.

Figure 1-1: EU-China 5G collaboration targets



The main objective of this project 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, 5G-DRIVE will develop 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. The main targets of this collaboration are illustrated in Figure 1-1. More specifically, the 5G-DRIVE project has the following technical, regulatory, and business objectives:

Technical objectives:

- OBJ1: to build pre-commercial end-to-end testbeds in two cities with sufficient coverage to perform extensive eMBB and Internet of Vehicles (IoV) trials. Joint test specifications will be defined through the collaborative agreement with the Chinese project.
- OBJ2: to develop and trial key 5G technologies and services, including (but not limited to) massive multi-input multi-output (MIMO) at 3.5GHz, end-to-end network slicing, mobile edge computing for low latency services and V2X, Software-defined networking (SDN) for transport and core network, and network and terminal security.
- OBJ3: to develop and trial cross-domain network slicing techniques across two regions for new services.
- OBJ4: to demonstrate IoV services using Vehicle-to-Network (V2N) and Vehicle-to-Vehicle (V2V) communications operating at 3.5GHz and 5.9GHz, respectively.
- OBJ5: to analyse potential system interoperability issues identified during the trials in both regions and to provide joint reports, white papers, and recommendations to address them accordingly.
- OBJ6: to submit joint contributions to 3GPP and other 5G standardisation bodies regarding the key 5G technologies developed and evaluated in the project.

Regulatory objectives:

- OBJ7: to evaluate spectrum usage at 3.5GHz for indoor and outdoor environments in selected trial sites and to provide joint evaluation reports and recommendations on 5G key spectrum bands in Europe and China.
- OBJ8: to investigate regulatory issues regarding the deployment of V2X technologies, i.e. coexistence in the 5.9GHz band, and to provide joint reports.

Business objectives:

- OBJ9: to investigate and promote 5G business potential through joint development of 5G use cases and applications.
- OBJ10: to strengthen industrial 5G cooperation between the EU and China.
- OBJ11: to promote early 5G market adoption through joint demonstrations in large showcasing events.

5G-DRIVE will address the above objectives through joint trials with the twinned Chinese project through three trial sites, dedicated research innovation in trial-related key 5G technologies and broad cooperation and well planned joint event with the China side.

1.2. Concept and methodology

1.2.1. Overall Concept

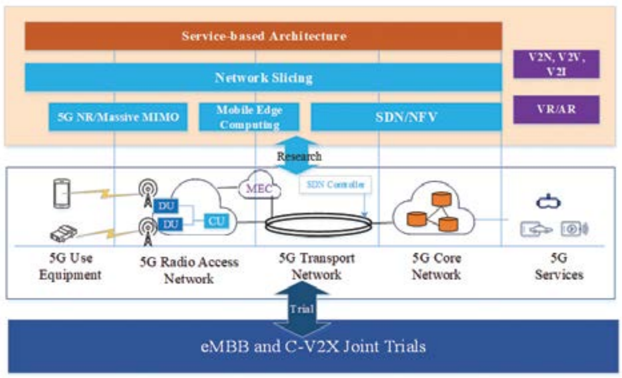
5G-DRIVE addresses the objectives as stated in the ICT-22-2018 EU-China Collaboration for the 5G call. Section 1.2 provides a detailed mapping of how 5G-DRIVE addresses the challenges, as outlined in the H2020 2018/19 work programme. The project's overall concept is illustrated in Figure 1-2; the figure 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 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 this project 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 three research organisations (UoS, VTT and JRC). While all three testbeds are set up with commercial grade equipment, each one has a special focus: the Surrey testbed can support capacity provision in very dense deployments over a 4 km² area; the Espoo testbed 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 5G-DRIVE. In the research stream, the project will investigate network and RAN slicing, Mobile Edge Computing (MEC), massive MIMO 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 of the project will be integrated into the most appropriate testbed. Wherever possible, we 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 form 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.

Figure 1-2: Overall concept of 5G-DRIVE



5G-DRIVE is based on the existing and currently under design 5G standards, namely the 3GPP releases 13-14, and any relevant findings will be fed back into the appropriate standardisation organisation and working group. The project will exploit three already-existing 5G testbeds (Espoo, Surrey, and Ispra - details can be found further down in this section), which have been set up with commercial-grade and experimental equipment and are being used to test new research outcomes and new services. Furthermore, wherever possible, 5G-DRIVE will also collaborate with projects from the ICT-17-2018 call to further enhance the testbed capabilities and availability for the joint EU-China trials that will be implemented in this project.

Being a research and innovation project, the expected project outcomes will be of different technology readiness levels - whilst we expect that all technologies investigated will be evaluated through simulations and demonstration (Technology readiness level (TRL) 5), there will be a large part of the work that will reach TRL 7-8 and will be part of the trials planned.

The remainder of this section provides a brief overview and introduction to the three European trial facilities that will be used in 5G-DRIVE. These testbeds are operational and will be extended with research findings. In addition, they will also be adapted to meet the requirements of the various test scenarios foreseen in 5G-DRIVE.

Test facilities

> The Surrey Trial Site

UoS and its 5GIC provide unique state-of-the-art 5G test and demonstration platforms. These include a Cloud-RAN (C-RAN) test platform 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. In addition, the test network provides a unique environment to test operation of heterogeneous access networks in a real life environment on the UoS' main campus.

The testbed is connected to the Vodafone Core Network, Fujitsu Cloud Computing facilities and covers a 4 km² 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 unique end-to-end testbed incorporates a different range of frequency bands 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.

This testbed supports advanced research activities from concept development to proof of concept and field test. To this end, the 5GIC infrastructure includes:

- State-of-the-art and calibrated link and system level simulations for Physical layer and System Level concept evaluation.
- Medium access control (MAC)/baseband (BB)/radio frequency (RF) evaluation platforms based on System on Chip (SoC), Field-programmable gate array (FPGA) and digital signal processing (DSP) technologies. The current facilities include Texas Instrument (TI) multi-core DSP platform, Xilinx Zynq SoC platform, and Altera Arria V FPGA platforms.
- Demonstration network that combines a set of highly promising potential 5G concepts.

A high-level view of the 5GIC test network is illustrated in Figure 1-3. The 5GIC test network will support key technologies such as:

- Dense cluster of small cells controlled and operated as C-RAN architecture;
- Umbrella macro-cell base stations mostly used to support high-mobility users, as well as signalling facility for dense small cell clusters;
- A variety of wireless and fibre backhaul technologies to connect small cell clusters to RAN processors, as well as inter-cluster and base station communications for

Coordinated Joint Processing among clusters and access points.

The initial version of the platform consists of:
- LTE Rel.9 compliant user equipment (UE) (with physical hardware capable of supporting multiple virtual UEs);
- LTE Rel.9 compliant eNodeBs (Baseband units (BBU)) and RRH;
- Support for X2 and common public radio interface (CPRI) interfaces;
- Outdoor WiFi access points (AP) for providing network access to end user devices;
- Ancillary test/measurement equipment.

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 platform is fully reprogrammable (supporting online compile, debug and run cycle), and there are multi-level debug options. The stack design is based on modular Software (SW) approach & commercial off-the-shelf (COTS) based RF and RF interfaces are supported.

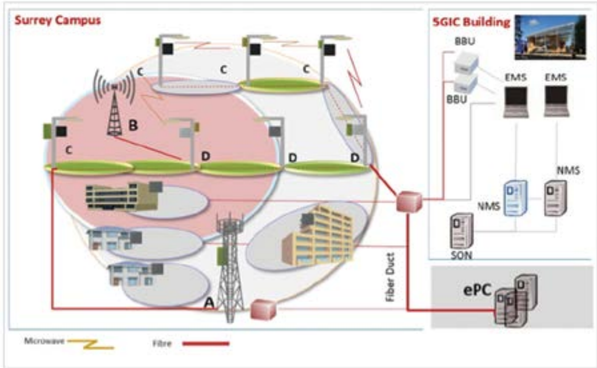
The initial version has been rolled out and first demonstrations were shown during the official opening in September 2015, the equipment is constantly updated to mirror research findings and to trial new approaches.

Figure 1-3 shows a high-level view of the 5GIC test network, incorporating three (3) sites:
- A: Macro Site (BB+3 RRH) + point to multi-point (P2M) Microwave (e.g. 28GHz);
- B: Micro Site (BB+3 RRH) + point to point (P2P) Microwave / millimetre wave;
- C: Small Cell (Omni) + P2P millimetre wave (e.g. 60GHz); D: Small Cell (Omni).

The testbed is defined in three phases: in the first one, a proof of concept and emulation platform is complete and hosted in the current premises. This phase did not include outside cell-coverage and consisted of a comprehensive set-up including both lab equipment (various types of programmable platforms, channel emulators, mobility models, etc.), plus simulators for boundary conditions.

The second phase including the deployment of the core and access servers, as well as of three macro-base stations and underlying small cell area coverage (3 macro and 62 small cells) was installed in summer 2015, prior to its official opening in September 2015.

Figure 1-3: High-level view of the 5GIC test network



Since then, different trials have already taken place and project findings (both on radio level as well as protocol and system level) have been implemented and subsequently trialled. The third phase is currently being implemented, allowing drive tests for eMBB and ultra-reliable low latency communication (URLLC) testing. This phase is expected to be completed in April 2018.

The external (outdoor) testbed is complemented by an experimental setup based on Open Air Interface (OAI) and TI's Universal Software Radio Peripherals (USRP). This setup leverages commercial handsets (4G), as well as a mix of USRP and Lime Radios implementing both UE's and eNodeB's to verify advanced resource sharing scenarios.

> The Espoo Trial Site

The Espoo trial site provides 5G testing facilities built in several national projects under the 5GTNF (5G Test Network of Finland) framework. As shown in Figure 1-4, the Espoo site is in the Otaniemi region in Espoo. In the context of 5G-DRIVE, it will focus on the development and evaluation of both eMBB and IoV scenarios.

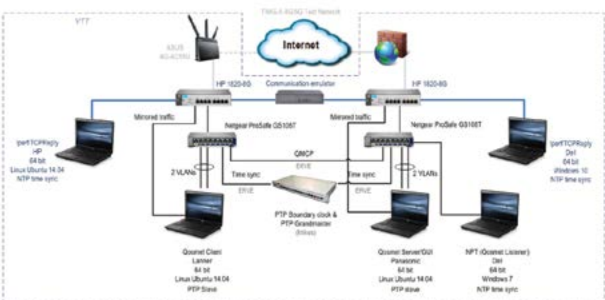
The test network structure of the Espoo site is shown in Figure 1-4. The current network infrastructure is built on top of Nokia's NetLeap LTE test network. It will be gradually upgraded to 5G networks when 5G NR and 5G core network components are available. Currently, core network functionalities are mimicked with 4G/5G emulators. The support for real 5G will be added to the network in the later phase of the project.

The network contains both indoor and outdoor eNodeBs operating at 2.6GHz, lamp post integrated small cell networks operating at 3.5GHz and mm-wave bands at 26GHz, as well as Wi-Fi networks operating at unlicensed 2.4GHz and 5GHz. The eNodeBs are shared between Nokia and VTT. VTT can create its own virtual mobile network with its own evolved packet core (EPC) and can utilize the edge computing platform for developing localized services. 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.

Figure 1-4: Espoo trial site at Otaniemi Espoo

eNodeBs are connected to a 10Gbps SDN-enabled backhaul and to an OpenStack cloud environment. The Espoo testbed provides facilities and test environments for SDN/MEC, indoor positioning, latency reduction, reliability and other technology topics targeted by 5G-DRIVE.
One unique feature of the Espoo testbed is the use of timing signal from VTT MIKES Metrology for high-accuracy, one-way latency measurements, time-based positioning and synchronisation of timing dependent devices. The timing signal is generated from atomic clocks and is delivered over fibre network using Precision Time Protocol (PTP)-based synchronisation technology. An example of the latency measurement configuration is shown in Figure 1-5. This setup has been used for evaluating URLCC performance for smart grid communications.

Figure 1-5: The latency measurement setup at VTT.



> The JRC Ispra Trial Site

The JRC Ispra site is a fully-fenced research campus equipped with high-level safety and security features a controlled environment for hands-on experimentation, testing and demonstration purposes. As shown in Figure 1-6 (left), 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, testing and other experimentation activities according to the project needs. Every year, the JRC Ispra site is visited by several European Commissioners, MEPs and other senior EU and Member State representatives. This will give 5G-DRIVE unprecedented and targeted exposure to key decision makers.

The following subsections outline some of the key credentials of the JRC Ispra trial site:

Localisation and Mapping:

The JRC Ispra site has been mapped at very high resolution using drones and LIDAR, with digital maps available. This information can be used for network planning (i.e. predictions of radio propagation and network coverage), as well as vehicle localisation and intelligent routing. The imagery was obtained using light fixed-wing unmanned aerial systems and processed with automatic photogrammetry software (APS) from MENCI. The obtained resolution of the ortho imagery is 6 cm and the area covered in one flight using 2 UAVs working in swarm mode is 2.6 km^2.

Figure 1-6: Left: Aerial view of JRC Ispra campus (2016) Right: VELA 9 experimental facility in JRC Ispra

Connectivity Infrastructure:

The JRC owns various LTE eNodeBs of both commercial and experimental grade (Nokia FlexiZone indoor/outdoor units and USRP-based 4G eNodeBs). In addition, it has deployed a software-defined LTE core network to provide mobility, session management and user authentication services, amongst other. This software-defined EPC is currently running on standalone small-form factor PCs, but it is expected to be refactored as a set of Virtual Machines (VM) running on JRC datacentre servers in the near future. Further enhancements to the communications infrastructure (additional base stations in the 3.5GHz band and V2X equipment) have already been planned.

Mobile Edge Computing:

MEC infrastructure can be connected to the core network using either radio links or low latency fibre once the overall physical layout of the trial site is stable. These systems will take the form of small-form factor PCs featuring roadside sensing and fast computing capabilities. On-board sensing systems will comprise video, LIDAR, radar and Global Navigation Satellite System (GNSS) capabilities, as information such as accurate position, velocity and time will need to be exchanged in V2X messages.

Security, Privacy and Trust Network:
The JRC is equipped with production-level Public Key Infrastructures (PKI), some of which have been already extensively used in the road transportation sector. The JRC is responsible for the European Root Certification Authority (ERCA), which is the PKI used to support the Digital Tachograph application. The ERCA is currently used to generate cryptographic material to be installed and deployed in vehicles.

JRC staff has the expertise needed to build a similar PKI for V2X needs. In fact, the JRC has been directly involved in drafting the Certificate Policy for the European V2X (also referred to as the Cooperative Intelligent Transport Systems (C-ITS) Trust Model). The creation and testing of various attack vectors will also be implemented. In this context, the in-house experience in jamming, denial of service at the physical layer and cybersecurity attacks can also be leveraged.

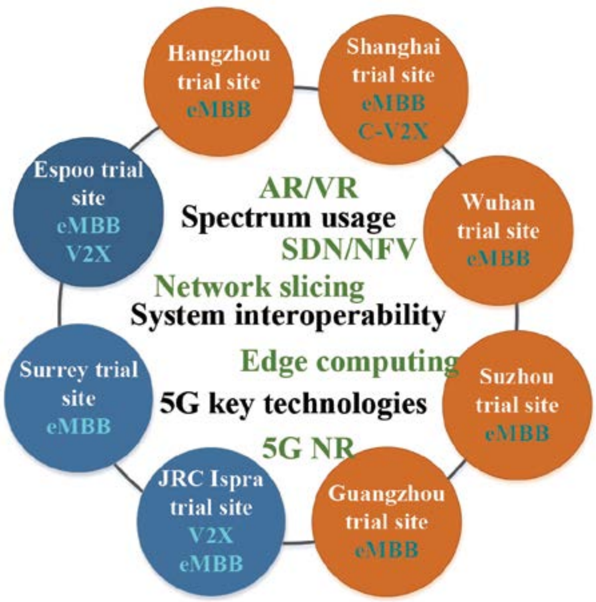
Additional Capabilities:
The JRC Ispra site is equipped with state-of-the-art laboratories for testing vehicles to characterise their emissions, performance and electromagnetic compatibility. In particular, the following facilities are available:
- 4 test-cells to measure emissions, fuel and energy consumption of all types of vehicles (light and heavy duty, internal combustion engines, hybrids and plug-in hybrid vehicles) (VELA 1-8);
- 4 Portable Emission Measurement Systems (PEMs) to measure emissions and fuel consumption from vehicles driven in real-life road conditions;
- 2 test cells to measure the electromagnetic compatibility of vehicles with the fields generated by external sources and by the vehicles themselves (VELA 9 and EMSL).
- In particular, the VELA 9 laboratory shown in Figure 1-6 (right) allows the measurement of electromagnetic fields generated by a vehicle running at a speed of up to 160km/h. This facility will provide significant benefit to the 5G-DRIVE project, as it will allow researchers to check the compatibility of V2X communication technologies with the fields generated by the most powerful commercial electric engines.

1.2.2. Methodology and collaboration with the Chinese Consortium

5G-DRIVE will work in parallel on research and experimental trials. The trial work in the project will focus on joint experimental activities with the major 5G trial project in China. 5G-DRIVE has received a Letter of Twinning Support (see Section 4-5, Appendix 1) from the coordinator of the China project (China Mobile) and with a mutual commitment to establish a solid bilateral cooperation with the Chinese project called: "5G Product R&D Large-scale Trial" coordinated by China Mobile Research Institute. The China Mobile project will start in June 2018 and continue for two years. The project has eight partners, including China Mobile, Huawei, Ericsson China, Datang Mobile, Shanghai International Automobile City, and three research institutes. The main purpose of the project is to verify the large-scale deployment of 5G networks for eMBB and cellular V2X (C-V2X) tests in real environments, covering indoor and outdoor scenarios in complex urban areas. China Mobile plans to conduct the eMBB trials in five cities in China, and the V2X trials in Shanghai. Figure 1-7 shows the trial sites in 5G-DRIVE and China Mobile's project.

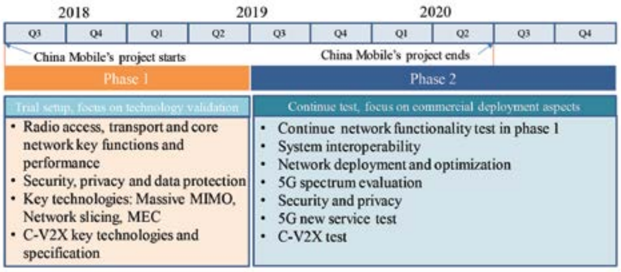
5G-DRIVE will be divided in two phases. The first phase covers June 2018 to May 2019, whilst the second phase spans from June 2019 to December 2020. This time schedule is synchronised with China Mobile's project, as shown in Figure 1-8. The duration of 5G-DRIVE will expand over six months more than that of the Chinese project in order to conduct additional trials, evaluate the results and prepare the final trial reports.

Figure 1-7: Trial sites in 5G-DRIVE and China Mobile's project



In the beginning of the first phase, the two projects will agree on the cooperation methods and data sharing mechanism. The collaboration agreement will be signed by the two projects. Under the agreed collaboration framework, the two projects will work out the joint trial plans for eMBB and V2X. The joint trial specifications will be defined accordingly. These include common test targets, related key performance indicators (KPI) and test procedures for selected topics.

Figure 1-8: Project schedule and focus topics in each phase



In the first phase of the project, the joint tests will focus on the verification of 5G key technologies, including 5G NR, network slicing, MEC, and SDN for transport networks. The joint work on V2X in this phase includes the requirement analysis and technique specification for C-V2X. Depending on the availability of 5G UE (which is expected by the end of 2018) the initial trial will start in 2018. The eMBB trial will be mainly performed in the Surrey trial site, while the availability of the eMBB trial in Espoo and Ispra trial site will depend on the agreement with the ICT-17-2018 project. The Espoo and Ispra trial site will focus more on the V2X trials, based on the ongoing V2X activities in each site.

In the second phase of the project, the joint tests will focus on system interoperability, network coverage and support for 5G services. The joint verification of V2X key technologies will be conducted in this phase. The network performance for V2N, including the network coverage, latency, positioning accuracy and reliability will be tested in this phase. The key trial tropics in different phases are summarized in Figure 1-8. Considering the total budget of 5G-DRIVE, it is a challenge to deploy large-scale trials. However, 5G-DRIVE will consider cooperating with ICT-17-2018 projects to perform additional joint trials on network planning and network deployment optimisation and cooperate with China Mobile's project in these fields.

In addition to trials, the other significant work in the project is research on 5G key topics. Research work will start from the beginning of the project and will focus on the key 5G technologies supporting the trials. Therefore, there will be several iterations between research and trials. Research problems identified in trials will be investigated in research tasks. The research outcome will be verified by experiments in the trial site. A key research topic is the support for network slicing. Interoperability problems, as well as implementation issues in different network layers and network virtualisation technologies in radio access, transport and core networks will be studied. Regarding the end-to-end 5G network for eMBB and V2X services, radio access technologies, transport network, security, privacy, and data protection issues in 5G networks will also be considered. Research concepts will be first evaluated in simulations. Later on, selected proposals will be further implemented and verified in the trial sites.

The trial setting and expected joint outcomes of 5G-DRIVE and China Mobile's project are summarized in Figure 1-9.

Figure 1 9: Trial goals and planned joint outcomes of 5G-DRIVE and China Mobile's project

	Trials	IPR	Specifications	Reports
5G-DRIVE	• 3 trial sites for eMBB • 5+ gNBs • 10+ UEs • Cover dense urban and office building • 2 V2X trial network	• 3+ patents • Cover 5G key technologies , including massive MIMO, network slicing, V2X, MEC, etc.	• Joint test specifications 2+ • Cover field equipment, performance, interoperability, 2X specifications	• Deliverables 10+ • Joint test report 4+ • Cover key technology evaluation report, system interoperability, service platform
China Mobile's Project	• 5 large scale trial networks • 50+ gNBs • 100+ UEs • Cover dense urban and office building • 1 C-V2X trial network • >20km² • 5+ intersections • 15+ intersection units	• 10+ patents • Cover 5G key technologies , including massive MIMO, network slicing, V2X, network planning, etc.	• Test specifications 10+ • Cover field equipment, terminal functions, performance, interoperability, C-V2X specifications	• Research report 10+ • Test report 15+ • Cover key technology evaluation report, network planning methods, system interoperability, terminal functionality test, IoT, vendor equipment interoperability

1.3. Ambition

5G-DRIVE will conduct joint trials for eMBB and LTE-V2X scenarios with the major 5G projects in China. These joint trials will be based on common test end-to-end-architectures, use case applications, test procedure and KPIs. Furthermore, 5G-DRIVE will investigate the application of new technologies and services such as network slicing, MEC, and privacy-friendly communications for connected and automated vehicles. The overarching ambition of 5G-DRIVE is to contribute to a common understanding and harmonisation of technical conditions between the EU and China, i.e. standards, interoperability requirements, coexistence conditions, and resilience.

1.3.1. State of the art

5G-DRIVE has ambitions to investigate 5G eMBB services and new technologies for connected and automated vehicles. In the following, the state of the art of 5G key technologies relevant to trials, as well as how 5G-DRIVE will make advance on these topics, are described. 5G-DRIVE will mainly cover the following 5G key technologies: 5G NR, network slicing, NFV, SDN, MEC, C-V2X, and transport network.

• 5G NR/Massive MIMO

The mobile access technology goes through a revolutionary change every ten years, which is in response to the capacity demands resulting from the massive data growth over the last ten years. Capacity for wireless communication is related to spectral efficiency and bandwidth. Presently, almost all wireless communications use spectrum in 300 MHz to 3GHz bands. Recent research indicates that massive MIMO significantly improves the sum spectral efficiency (SE) of cellular networks by spatial multiplexing of a large number of UEs per cell [MA10]. The main difference between massive MIMO and classical multi-user MIMO is the large number of antennas, at each base station whose signals are processed by individual radio-frequency chains. By exploiting channel estimates for coherent receive combining, the desired signal power is reinforced, while the power of the noise and independent interference does not increase. Therefore, the massive MIMO technology has been proposed as a key NR technology for the next generation of cellular networks [LA14].

Despite the theoretical potentials for extremely high data rate provision by massive MIMO, there are several key technical challenges for applying mmWave for mobile networks [BJ16], including severe path-loss, high power consumption in RF power amplifiers and data converters, narrow beamwidth and side-lobes leading to higher sensitivity to misalignment between the transmitter and the receiver. To address these challenges, the extensive research and deployment for the future mobile networks has already been carried out around the world. Samsung first achieved 1 GB/s data transmission at 28GHz in May 2013. Google also put substantial research efforts into mmWave communications. Verizon has submitted applications to the Federal Communications Commission (FCC) to obtain special temporary authorisation (STA) to test mmWave communications technology at 28GHz. T-Mobile is also expected to obtain STA at 28GHz and 39GHz. Nokia in collaboration with National Instruments achieved a peak rate of 15 Gbps using their proof-of-concept system at 73GHz band in April 2015. Recently, the EU has also launched "Beyond 5G" research within the H2020 framework (ICT 2017-09 Call).

Advances beyond the state of the art

Cloud-like computing and storage is being pushed to the network edge to bring the data content much closer to the mobile users to reduce transmission latency. 5G-DRIVE will aim to improve mmWave massive communications in mobile networks significantly by flexibly exploiting distributed caching and edge computing. Meanwhile, how to apply mmWave massive MIMO in high mobility environments for V2X use case, expand transmission distance, and achieve high energy-efficiency are very important challenges to tackle. From a broader perspective, the RF implementation of mmWave technology is crucial and a long-term goal is to obtain a cost-efficient full digital implementation for massive MIMO technologies.

- **Network slicing**

5G delivers an infrastructure that can natively accommodate various services and applications with unprecedented flexibility. Industry 4.0, automotive and transportation, health, power grid, broadband TV, augmented and virtual reality are some of the sectors and applications that will be supported by an intelligent sharing of resources termed network slicing. The network slicing concept enables creation of many virtual networks over a common infrastructure. In opposite to Virtual Private Network (VPN) concept, in which isolated IP network partitions can be created, the network slicing enables creation of fully-fledged networks that can be combined with applications while maintaining the isolation and privacy. The concept is linked with ETSI NFV technology [ET14]. It is worth mentioning that the ETSI NFV framework has no inherent support for network slicing, however it is possible to provide logical isolation of virtual networks, i.e. grouped and interconnected virtual network functions (VNF). In [SL17] it has been proposed to introduce a slice specific entity, i.e. Slice Controller as a part of the operations support system (OSS)/business support system (BSS) domain, which communicates with NFV management and orchestration (MANO), beyond which everything relies on standard NFV concepts and procedures. There are three main benefits of network slicing: dynamic deployment of networking solutions with short time to market and low capital expenditure (CAPEX); ability to create the networks that are tightly coupled with their service(s); delegation of almost complete network slice management to a slice tenant (a vertical).

Many network slicing approaches, including the 3GPP one, are in fact based on the next generation mobile networks (NGMN) concept [NG15]. According to NGMN, a slice instance is built over physical or logical resources (computation, storage and transport) that are fully or partly isolated from other resources. It is built using Network Functions that are processing functions of the Network Slice Instance (NSI). The NSI is defined by the Network Slice Blueprint (NSB) and is a complete, instantiated logical network that meets certain characteristics as required by a Service Instance(s). The network slice defined by International Telecommunication Union (ITU) Telecommunication Standardisation Sector (ITU-T) IMT-2020 Focus Group is programmable, managed group of infrastructure resources, network functions and services, having the ability to expose its capabilities. IMT-2020 introduces two types of network slicing extensions: vertical and horizontal. Network slicing is a subject of intensive research of 5G PPP research projects like 5G NORMA [NO16] that proposes a mobile network architecture for the multi-tenant environment or the 5GEx project [EX16] that is focused on transport networks multi-domain slicing.

There are also 3GPP slicing-like related concepts applicable to 4G core network, called DÉCOR [DE14] and enhanced DECOR (eDECOR) [ED16]. DECOR allows for the deployment of several dedicated EPCs as ipso facto core network slices which share the same RAN. Recent 3GPP works led to the introduction of the Next Generation System (NextGen), which introduces the network slicing to the mobile core architecture, with a split of planes (user/control) and dividing of control plane network functions into common and slice-specific ones (TR23.799). The control plane functions common to all slices include slice selection, authentication and mobility management. One of the benefits of the common functions is the ability of the terminal to the simultaneous attach to several slices. The 5G system incorporates also a NR definition which enables RAN slicing (TS38.300). Therefore, the 3GPP network slice may be composed of integrated RAN and Core Network slices. Recently, the 3GPP has published several documents related to miscellaneous aspects of network slicing, as network slices management (TS 28.530), provisioning (TS 28.531), selection (TS 29.531) and security (TR 33.811).

Advances beyond the state of the art
There are still many open issues related to network slicing. Some recent 3GPP technical reports, like TR 28.801, TR 28.800 and TR 28.802 describe a work in progress that is related to generic and network slice specific management and orchestration. The standardisation of these topics is not finalized yet. The most important open issues are related to multi-domain slicing (slice stitching) in the context of orchestration and operations, performance of the sliced data plane, slice exposure, description and matching, RAN slicing as well as efficient allocation of infrastructure resources to slices. Other key challenges consist of slice security and isolation. The issue of slice management by a tenant is also not solved yet. The 5G-DRIVE project will use the mature slicing concepts for its testbeds but at the same time will work on unresolved issues like network stitching, NFV orchestrator (NFVO) multi-tenancy, scalable multi-domain orchestration and management of slices.

• NFV/SDN
NFV is one of the main building blocks of network softwarisation. Its goal is to facilitate the way that software-based networks are built, deployed and managed. NFV introduces resource virtualisation layer and decouples software from a (generalized) hardware. The softwarised assets become the innovation and differentiating value, while hardware becomes a commodity. COTS hardware for software networks will be generic by design and agile in operation, replacing what is currently a proprietary landscape with strict dependencies between physical network functions (PNF) and legacy telecommunication hardware. Virtual network functions (VNF) on top of virtualized infrastructure and generic hardware have a significant impact on network operations, their cost to maintain (operational expenditure (OPEX)) and upgrade, and business agility for operators to mix and match from a variety of vendors and VNF developers. An important part of the NFV is MANO (Management and Orchestration) that provides agnostic deployments and lifecycle management of VNFs based networks [ET14]. There are already several open source MANO compliant platforms like open network automation platform (ONAP), open source MANO (OSM) and OpenBaton that can be used by 5G-DRIVE for orchestration of VNFs based networks. In February 2017 ETSI NFV industry specification group (ISG) published a white paper on 'Network Operator Perspectives on NFV for 5G' [NF17]. This paper treats NFV-based network slicing as one of the key features of 5G networks.

SDN is another key technology of software-based networks. It enables a new network control paradigm, and is often combined with NFV to realize large-scale complex networks. The OpenFlow based SDN separates centralized control plane (based on a single logical entity called SDN controller) from the distributed data plane based on flow switches [ON15]. SDN allows for simple manipulations of data flows by the control plane or applications. SDN can be combined with NFV [NF15N] for the needs of mobile networks providing required flexibility, helping in mobility management and optimisation of the transport traffic. On the market, there are already several open sources platforms out which the most popular ones are OpenDaylight, Ryu and Open Network Operating System (ONOS) that can be used in the 5G-DRIVE project.

Advances beyond the state of the art
ETSI NFV is at present working on Issue 3 of NFV specialisations trying to specify interfaces, address security, authentication, charging, billing and accounting as well as multi-domain issues. In the context of network slicing NFV is working on slice stitching, orchestration scalability and NFVO multi-tenancy. The integration of the NFV approach with SDN is also a research subject. The SDN technology is mature, however it still raises many issues in terms of scalability and efficiency of operations. One of the recent directions is to add more protocols between the controller and switches in order to improve the control plane scalability (for example by the publish-subscribe mechanism) and allows for programmable interactions between the SDN controller and switches by the use of the P4 (Programming Protocol-Independent Packet Processors) language. In the context of NFV, the 5G-DRIVE project will investigate slicing capable orchestration that is policy driven, scalable management of slices, and into efficient allocation of resources to slices. We will also look into efficient transport networks that are based on SDN, and we will exploit the SDN capabilities for network slicing looking for flexible and efficient data plane operations. In that context, the P4 language will be investigated.

• MEC
MEC enables innovative service scenarios that can ensure enhanced personal experience and optimized network operation, as well as opening up new business opportunities. Introduced and specified by ETSI ISG MEC (MEC 001-005), MEC has been seen as a remedy to provide time-critical operations at the network edge. Furthermore, providing services near to end users easily offloads the core nodes in order to have full utilisation of the network. ETSI specifies a rich set of functionalities to ensure that MEC concept can be a solution to the problems coming out with the demands of future mobile networks and open for vendor implementation approaches. With the release of ETSI MEC specifications, massive research has been conducted [ET14, MB14] and since the noticeable success made by SDN, several MEC use cases have been proven to benefit from the integration of SDN. With the separation of control and data plane, the data plane is programmable, and control entities (e.g., MME, S-GW-C, P-GW-C) as well as

the MEC applications can be virtualized [SA16]. Accordingly, the MEC applications that can be categorized into common, support, platform. MEC services [CH16] are emerging and MEC becomes the enabler to allow traffic steering control for the vertical service provider. Monitoring applications, as a basic example, can combine the information from RAN and core network to optimize the performance of mobile network. Further statistics with better granularity, e.g., KPI evaluation and traffic profiling, can be provided based on raw information extracted by monitoring applications. At last, the aforementioned knowledge is exploited to program the data path and redirect the traffic to the corresponding service provider in order to achieve lower latency and better user experience [JW15].

Advances beyond the state of the art
MEC has many applications. For the IoV part of the 5G-DRIVE project, it can be used to extend the connected car cloud into the highly distributed mobile base station environment and enable data and applications to be housed close to the vehicles. This can reduce the round-trip time of data and enable a layer of abstraction from both the core network and applications provided over the internet. MEC applications can run on MEC servers that are deployed at the LTE base station site to provide the roadside functionality.

5G-DRIVE will demonstrate that the MEC applications can receive local messages directly from the applications in the vehicles and the roadside sensors, analyse them and then propagate (with extremely low latency) hazard warnings and other latency-sensitive messages to other cars in the area. This enables a nearby car to receive data in a matter of milliseconds, allowing the driver to react immediately.

Moreover, 5G-DRIVE will test how the roadside MEC application is able to inform adjacent MEC servers about the event(s) and in so doing, enable these servers to propagate hazard warnings to cars that are close to the affected area across multiple operators.

Finally, 5G-DRIVE will demonstrate how the MEC can send local information to the applications at the connected car cloud for further centralized processing and reporting while preserving the data privacy of individual drivers.

• C-V2X
V2X communication is essential to redefining transportation by providing real-time, highly reliable, and actionable information flows to enable safety, mobility and environmental applications. Often referred to as C-ITS, or in the United States as Connected Vehicles, V2X figures prominently in a future with safe, efficient and environmentally-conscious transportation and paves the way to connected and automated driving.

C-V2X as initially defined as LTE-V2X in 3GPP Release 14 is designed to operate in several modes: D2D (to link vehicles, roadside and pedestrian to each other), Device to cell tower (mainly to share resources with a MEC), and device to network (mainly to link to the cloud via an IoT platform). C-V2X chipsets will be announced for Q2 2018.

Ad-hoc communications are based on 3GPP D2D communications defined as part of proximity services in Release 12 and Release 13 of the specification. A new D2D interface was introduced as PC5 (name of interface), also known as side link at the physical layer. It has been enhanced for vehicular use cases, specifically addressing high speed (up to 250Kph) and high density (thousands of nodes).

The PC5 allows for two configurations: in "Mode 4" allows V2V ad-hoc networking without any network connectivity. The scheduling and interference management of V2V traffic is supported based on distributed algorithms implemented between the vehicles; in "Mode 3" scheduling and interference management of V2V traffic is assisted by eNodeBs (e.g Base Stations) via control signalling over the UE interface. The eNodeB will assign the resources being used for V2V signalling in a dynamic manner. In both cases GNSS is used for time synchronisation. Note that Mode 3 is not yet fully standardised.

Advances beyond the state of the art
As a first advance, the project will bring together the Chinese and European approaches on the choice of technologies for D2D communication. China is strongly supporting the use of PC5 and its integration with 3GPP standards whereas the EU is still considering a co-existence with 802.11p. Working together will strengthen our understanding of the technology trade-offs and benchmark each other’s solutions.

The project will plan trials to produce evidence that 5G V2N and V2I solutions can answer the KPIs for different IoV scenarios. Especially interesting are the KPIs related to latency as well as discovery and access to relevant data from roadside and cloud. For this, a combined solution between MEC and IoT platform is planned.

From a standard point of view, the project aims to bring new solutions to share vehicle sensing data between each other as well as to cooperatively share manoeuvring intention to predict vehicle trajectory. These next steps are essential if we want higher levels of automation to rely on short-range communication. Additionally, the IoV trials address vulnerabilities to cyber-attacks and data protection.

• Transport network
The traditional transport network has consisted of a backhaul between the base station and the evolved Packet Core functions (Mobility Management Entity (MME), serving gateway (S-GW), packet data network gateway (P-GW) etc., in a 4G network) and a fronthaul, in some deployments, which allowed the separation of centralized base station baseband functions and remote radio functions. In small cell deployments, a "midhaul" segment was defined for the connection of micro-base stations to a controlling macro-base station. For 5G, it is recognized that the transport network will need to evolve radically. There are several significant factors that have led to this

requirement. The first factor is the huge increases in data rates and numbers of users, and the densification of access networks; these will place significant technological demands for bandwidth provision and aggregation (in all transport network segments). Then, there has been the recognition that the sampled waveform transport used in fronthaul up to now, cannot be used for 5G [NG15]. This has led to the definitions of different functional splits in the RAN between centralized and remote functions (to avoid the need to transport sampled radio waveforms) [DO13] [3G17], proposals for new intermediate, aggregation nodes within this new fronthaul [CM15], and proposals for the use of common access network technologies, such as Ethernet [GO15] and Passive Optical Networks (PON) [CH17], to reduce CAPEX and OPEX. Definitions for new transport network interfaces and operations have been evident in Institute of Electrical and Electronics Engineers (IEEE) standards groups (P1914 Next Generation Fronthaul Interface [IENG], 802.1CM Time-Sensitive Networking for Fronthaul) [IECM] and in the CPRI corporation (eCPRI specification [CP17]). Further, it has led to proposals for "X-haul" transport networks, where the distinction between fronthaul, midhaul and backhaul is more nuanced [TZ18]; in fact, a common transport infrastructure may simultaneously carry traffic from different RAN functional splits, as well as traditional midhaul and backhaul, together with fixed access network traffic, enabling fixed-mobile convergence. The final important factor that is affecting change in the transport network arises from the increased softwarisation of network functions - NFV and SDN, as discussed before. This requires the transport network to be similarly softwarized and software-defined, such that it can be orchestrated and centrally managed [TZ18]. The orchestration of the mobile RAN and core networks will, in 5G, require orchestration of transport network functions to provide the required service for given, transported streams [GO18]. To return to the importance of network slicing, as discussed in 1.4.1.1, network slices for different over-the-top (OTT) provision will need to be setup through the core and RAN of mobile networks, and therefore, through the transport network (backhaul, fronthaul, X-haul), too [GO18].

Advances beyond the state of the art

5G-DRIVE will design, develop and demonstrate the core functionality for a software-defined X-haul transport network which is responsive to load and the requirements of different services. This network will be designed such that it can be orchestrated through a framework/architecture that is common with the whole 5G infrastructure (core and RAN). Thus, specific control plane functions and abstraction for interaction with the orchestrator will need to be designed and developed. In terms of the data plane operation, the X-haul will use new, time-sensitive networking algorithms to minimise latency and latency variation for services and individual packet streams. The delay requirements will be verified through testing with new products and applications, and with different RAN functional splits, and the delay and delay variations will be measured under different load and use conditions in laboratory and field testbeds.

1.3.2. Innovation potential

The following objectives represent major innovation potential activities within the 5G-DRIVE project:

- Develop a comprehensive architecture supporting eMBB and IoV scenarios and different use case applications
- Conduct and evaluate real trial tests for radio access technologies and spectrum for eMBB scenario-based on predefined KPIs
- Conduct and evaluate real trials for V2N, V2V communications as well as security vulnerabilities in the IoV scenario
- Carry out innovative research in terms of radio access, transport network, virtualisation network slicing and security for future 5G vehicular networks.

Industrial and Consumer demand satisfied by 5G-DRIVE innovation potential:

The innovation potential of 5G-DRIVE is driven by the need for accurate assessment of eMBB and IoV scenarios in 5G ecosystems and the innovation in the LTE-V2X technology. Car manufacturers, mobile operators and consulting firms are calling for a complete assessment of the two selected scenarios.

While the requirements for 5G capabilities are still being finalized both in the ITU and 3GPP, there is a consensus about the main use cases the technology must support: eMBB, URLLC and massive machine type communications (mMTC). eMBB refers to the extended support of conventional mobile broadband through improved peak/average/cell-edge data rates, capacity and coverage. URLLC is a requirement for emerging critical applications such as industrial internet and specifically IoV. To this end, 3GPP has developed recently the LTE-V2X in Rel-14 addressing the connection between vehicles, V2N, V2I, and vehicle-to-pedestrian (V2P).

It is foreseen also that the improvements planned in Rel-15 will not only ensure that LTE will provide better support for IoV use, but will enable to address new use cases. Therefore, 5G-DRIVE is targeting the investigation of new use cases and services in future 5G vehicular networks.

Key Areas of Innovation

Vehicles are expected to be highly connected and automated in the future with less error than humans. This connectivity not only improves the overall traffic safety by increasing driver awareness, but it also improves the overall traffic efficiency. In the 5G ecosystem, the hyper-connectivity is mainly on a constellation of technologies. Technologies exist or are under-developed but will require further testing and recurring innovation. Nonetheless, the key areas of innovation where 5G-DRIVE is expected to contribute are:

- eMBB scenario and use case applications trial assessment;

- IoV (V2V, 2VN, V2I, V2P) trial assessment and security vulnerabilities testing
- Innovation in radio access, transport networks, slicing, security and privacy-friendly communications for future 5G vehicular networks, built on Car Connectivity;

The most important contribution of 5G-DRIVE will be the demonstration of capabilities of current 5G technologies for two main scenarios: eMBB and IoV. The role of these two scenarios in automotive innovation is increasingly more prominent. Traditionally, research is focused on IEEE 802.11p the de-facto standard for V2X communication and other co-existing technologies. As the determinants of market differentiation shift toward hyper-connectivity, low latency and higher throughput, eMBB and LTE-V2X are gaining momentum. Operators and automotive industry will increasingly rely on those technologies to build a long-term advantage. Vehicle manufacturers will face a growing number of decisions over whether to push the development of certain technologies alone or with a partner. Hence, the interoperability trial assessment that will be carried out by 5G-DRIVE will become increasingly necessary. Therefore, 5G-DRIVE will drive the implementation and deployment of a real-life heterogeneous eMBB/LTE-V2X communications network (with extended capabilities through the realisation of edge services) at the project test sites.

Another significant area of innovation in 5G-DRIVE is the research study that will be carried out. The aim of this network is threefold: on the one hand, it will investigate the radio access and transport protocols. On the other hand, it will study the innovation in virtualisation and networks slicing. Finally, 5G-DRIVE will address meticulously a greater concern for connected vehicles in 5G future vehicular networks: secure and privacy-friendly communications. To secure a vehicle adequately, the security must be considered from the design and at levels and especially at the networking and the MEC level. Hence, 5G-DRIVE is committed to study security and privacy technologies for the new transportation ecosystem.

2. Impact

2.1. Expected impacts

5G-DRIVE will have a significant impact on the uptake of international standards for 5G, as it demonstrates the practical successful deployment of eMBB in the 3.5GHz band and V2X technologies in the 3.5GHz and 5.9GHz bands. By putting advanced communication and computational technologies at the service of innovation and competitiveness across private and public sectors, 5G-DRIVE will ensure a leading position for European industry in a global perspective. This is crucial for effective digitisation of the society and the durable impact of open innovation efforts, which are at the centre of the objectives of the 5G-DRIVE project. The following paragraphs illustrate the impact that is expected, what level of impact we expect to achieve and how we will monitor and verify the achievement of these expected impacts.

2.1.1. Expected impacts set by work programme

1. Holistic 5G networks implementations based on the latest 5G innovations and evaluated in the two prominent usage scenarios.

The trial sites in the project are based on the previous and current national or EU 5G testbed projects. The major vendors are involved in the testbed development and provide the key 5G equipment, including 5G NR base station at 3.5GHz, edge cloud devices, and 5G Core Network to testbed. During the project, the 5G equipment in the trial sites will be upgraded to add new Rel-16 5G features agreed in 3GPP. The University of Surrey's 5G testbed will have 8x 5G base stations and 65x 4G+ base stations to cover 4 km2 area for testing of 5G technologies. A fully-featured virtualised EPC will be tested in the project. The Espoo trial site will be equipped with pre-5G base stations, edge computing server and 5G core networks to cover the total area of 2 km2. Real-time kinematic (RTK) base stations and roadside unit used for V2X trial will be installed in the Espoo trial site. Therefore, it allows the full evaluation of eMBB and V2X services at 3.5GHz and 5.9GHz. The project will have holistic 5G network implementation in different eMBB trial sites based on different vendors' equipment. 5G-DRIVE will also seek the cooperation with ICT-17-2018 projects to utilize their large-scale trial facilities for more extensive evaluations.

2. 5G RAN for the specified bands validated in real world environments.

The studies and trial based evaluation in 5G-DRIVE will help verifying the features and capabilities of the 5G RAN. The trial scenarios and analysis of the trial observations will facilitate identifying any potential shortcomings or limitations of the 5G RAN when used in real world deployments. The testbed equipment, both installed infrastructure as well as user devices, will be used to test 5G RAN operation and performance in the frequency ranges around 3.5 and 5.9GHz. WP3 and WP4 will develop detailed test plans that allow the validation of the 5G RAN in both eMBB as well as V2X services. The outcomes will be of great value to the wider industry as well as the research domain.

3. Global interoperability demonstrations for 5G networks.

Global interoperability is essential for the success of 5G systems. 5G-DRIVE has three trial sites for eMBB services and two trial sites for V2X services. These trial sites will deploy pre-commercial 5G base stations and other 5G equipment provided by major vendors. The operator OTE will directly be involved in the trials, where the system interoperability problem is one of focuses in their trial activities. In China Mobile's project, Huawei, Ericsson and Datang will provide the 5G equipment and the system interoperability is one key test item on their trial agenda. 5G-DRIVE will work with the Chinese consortium in the early phase to define the joint test specification. Interoperability tests from spectrum to key network and terminal functions will be clearly defined in the joint test plan. The project will discuss the feasible plan to bring the trial terminals, including car terminals, or chipset platforms from both sides for system interoperability test. In addition, between selected trial sites, it is feasible to carry out the interoperability demonstration for selected 5G services cross the EU and China. The joint trial tasks defined in WP3 and WP4 for eMBB and V2X respectively will take the efforts to realize interoperability demonstrations between the EU and China.

4. Joint contributions to global 5G standards specifications in relevant organisations (e.g.3GPP, ITU-R), especially in view of 5G phase 2 standardisation (beyond eMBB), and to harmonized spectrum bands.

The 5G-DRIVE consortium has strong standardisation partners. UL is board member of 3GPP project coordination group (PCG) since 1999. It will publish the project results to the board and to the 3 main 3GPP Working Groups (Core, Services and systems aspects (SA) and RAN) as a 5G validation concept with large scale trials. UL leads the ETSI IPv6 ISG defining the impact of IPv6 on 5G as well as on vehicular networking. It is a member of the ETSI ITS and member of the Internet engineering task force (IETF) IPwave which has started to standardise vehicular networking. MI is an ITU-T sector member and serves as Rapporteur on emerging technologies for the IoT at SG20. MI is also main editors of several draft Recommendations and is currently working with UL in defining a reference model of IPv6 addressing plan for IoT networks. The same task will be done to the Chinese IMT2020 responsible for 5G, although they are members of 3GPP PCG. This will harmonise and align China with Europe in view of a worldwide 5G interoperability as well as vehicular networking. MI will coordinate the standardisation towards the ITU and support the task activities, while UL will coordinate the 3GPP contributions. The task will identify relevant technologies to be standardized and will coordinate the effort of the relevant partners from both regions in order to adopt and promote joint contributions that are expected to have higher impact on the process. BMW will publish the results to the 5G Automotive Association (5G-AA) and relevant car-2-car consortia and industry Car standardisation bodies

5. Successful showcasing events with, ideally, joint demonstration across regions.

5G-DRIVE will organise and implement events to showcase the project's results related to the two explored scenarios: eMBB developments and V2X developments. These will provide the opportunity to demonstrate the practical applications of the technologies being addressed in the project. A total of up to five events will be organised in the project. At specific stages of the EU and China projects, China representatives will be invited to also showcase their results. This will be an opportunity to increase the visibility of the projects and results across all relevant stakeholders. Furthermore, one event in China will be organised yearly to further complement the showcasing of results. To maximise impact and participation, these events will be organised back-to-back with other relevant events at the EU level.

6. New or reinforced cooperation between 5G R&I stakeholders from EU and China, with a focus on private companies (industry, telecom operators, SMEs).

5G-DRIVE is intimately associated to two of the strongest and most exciting markets in the world today: mobile communications and the automotive industry.

- Although the number of new smartphones sold per year (ca. 1.5 billion in 2016) is predicted to be reaching a plateau, the mobile communications market is hungry for new services that require increased bandwidth and broader geographical coverage, whilst also being affordable.
- The automotive industry is one of the most innovative sectors of the global economy. It is also a high-value market, with almost 18 million new vehicles sold per year, globally. Sales are largely driven by new features that improve safety, comfort and provide a better driving experience.

The innovations that are being experienced in both of these markets are being achieved as a direct result of cooperation between industry, telecom operators and SMEs (with initial ideas coming also from universities and research institutes).

The large industries are dependent on agile SMEs to develop products that can be delivered quickly to telecom operators to provide new services to their customers. This chain will be clearly visible throughout 5G-DRIVE and will specifically lead to new opportunities for reinforcing cooperation between 5G R&I stakeholders from the EU and China.

2.1.2. Other substantial impacts

• Impacts on the 5G PPP KPIs

5G-DRIVE contributes additionally to the following overall KPIs for the 5G PPP Programme:

- ***Leverage effect of EU research and innovation funding in terms of private investment in R&D for 5G systems in the order of 5 to 10 times.***
  The direct and indirect participation of key industrial companies in the project demonstrates their interest in the topic and willingness to cooperate with Chinese organisation in the field. It is clear that their investment in this area vastly outweighs the relatively small EU research and innovation funding they receive through 5G-DRIVE.
- ***Target SME participation with an allocation of 20% of the total public funding.***
  5G-DRIVE comprises 5 SMEs, which is 29.4% of the partners, and more than 20% of project public funding is allocated to them.
- ***Reach a global market share for 5G equipment & services delivered by European head-quartered ICT***

companies above the level of 43 % global market share in communication infrastructure.
One reason for the information and communications technology (ICT) departments of European head-quartered companies to be participating in 5G-DRIVE is the opportunity to twin with the (much larger) Chinese counterpart project, funded by MIIT. It is anticipated that the collaboration can lead to increased market-share for the companies, across a broad range of 5G areas in both horizontal (infrastructure) and vertical (automotive) sectors.

- ***To demonstrate the use of eMBB to achieve a peak data rate of 20Gbps (DL) and 10 Gbps (UL).***
  These are targets set by the 5G PPP KPIs. 5G-DRIVE will meet these requirements, using specifically the 3.5GHz band (and achieving the corresponding spectral efficiency).

- **Environmental and societal impacts**

5G-DRIVE will demonstrate how 5G technology provides environmental and societal benefits in alignment with defined key performance indicators and strategic objectives in the following areas:

- **Energy efficiency:** Through network slicing, the use of the same RAN to serve multiple services and multi-tenancy.
- **Security:** This is an important aspect, particularly for the vehicle industry. 5G-DRIVE contains partners (UL and MI) having specific competencies in this area.
- **New cost-effective services:** The wealth of new services enabled by 5G is the driving force for its development and deployment. 5G-DRIVE is a key player in showing the feasibility to support these new services in the fields of eMBB and V2X, using already-standardised spectrum bands. Aspects of the project focus on doing this in a cost-effective manner.
- **Demonstrating European competence:** 5G is a global technology for both human and machine communications. For European organisations (from research to industry) to benefit from the worldwide potential, it is necessary to demonstrate European competence in the field. 5G-DRIVE is one way in which, through trials between the EU and China, this competence can be made visible to the rest of the world.
- **Knowledge sharing:** The trial sites are not closed environments only for use by 5G-DRIVE; they are available for use by other researchers, industries and end-users, thereby multiplying the effect of the EU funding by avoiding the need to reproduce the same facilities. The knowledge gained from the project will also be used by the academic partners in their curricula.

The EU 5G-DRIVE Project Team and The China Twinning Team together in November 2018 joint kick-off in Beijing: