5G Trial Cooperation between EU and China

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***Abstract*—The H2020 project 5G-DRIVE (5G HarmoniseD Research and TrIals for serVice Evolution between EU and China) cooperates with the Chinese twin project to trial and validate key functions of 5G networks operating at 3.5 GHz bands for enhanced Mobile Broadband (eMBB) and 3.5 GHz and 5.9 GHz bands for V2X scenarios. 5G-DRIVE will instil significant impact on the validation of standards and trigger the roll-out of real 5G networks and V2X innovative solutions driving new business opportunities and creating thereby new jobs and brand new business models. This paper presents the overall approach of 5G-DRIVE, the advances beyond the current state of the art for key 5G enabling technologies, as well as the considered use cases.**

Keywords—5G, enhanced mobile broadband, vehicle-to-vehicle (V2V), Massive MIMO, Network Function Virtualisation (NFV), Software-Defined Networking (SDN), Mobile Edge Computing (MEC), network slicing, transport network, EU-China collaboration.

I. INTRODUCTION

5G can be seen as a game changer, enabling industrial transformations through wireless broadband services provided at gigabit speeds, as well as to provide support of new types of applications connecting devices and objects. Moreover, 5G intends to boost versatility via software virtualisation allowing innovative business models across multiple sectors (e.g. transport, health, manufacturing, logistics, energy, media and entertainment). While these transformations have already started on the basis of existing networks, they will need 5G to reach their full potential in the coming years.

The European Commission has launched a Public-Private-Partnership (5G-PPP) backed by 700 million euro of public funding with the aim of ensuring that 5G technology is available across Europe by 2020. However, research efforts alone will not be enough to ensure Europe's leadership in 5G. A wider effort is needed to make a reality the 5G and the services that will flow from it, in particular for the emergence of a European "home market" for 5G.

Since major research efforts are underway worldwide, it is essential to avoid incompatible 5G standards emerging in different regions. To help shape a global consensus as regards the choice of technologies, spectrum bands and leading 5G applications effective, EU coordination and planning on a cross-border basis will be needed. The launch of commercial 5G services will also require substantial investments, the availability of a suitable amount of spectrum, and close collaboration between telecom players and key user industries cross regions. Network operators will not invest in new infrastructures if they do not see clear prospects for a solid demand and regulatory conditions that make the investment worthwhile. Equally, industrial sectors interested in 5G for their digitization process may want to wait until the relevant 5G infrastructure is tested and ready. The cooperation between regions will help mitigate fragmentation in terms of spectrum availability, service continuity across borders (e.g. connected vehicles) and implementation of standards.

5G-DRIVE [1] will trial and validate key functions of 5G networks EU and China 5G networks operating at 3.5 GHz bands for enhanced Mobile Broadband (eMBB) and 3.5 GHz and 5.9 GHz bands for Vehicle-to-everything (V2X) scenarios. The key objectives are to boost 5G harmonisation and Research and Innovation cooperation between EU and China through strong connected trials and research activities, with a committed mutual support from the China "*5G Large-scale Trial*" project led by China Mobile.

5G-DRIVE will test and demonstrate the latest 5G key technologies in eMBB and V2X scenarios in pre-commercial 5G networks. It will run extensive trials in three trial sites in Finland, Italy and UK, respectively. The Chinese twin project will run large-scale trials in five cities. These twinned trials aim to evaluate synergies and interoperability issues and provide recommendations for technology and spectrum harmonisation. Additionally, key research innovations in network slicing, network virtualisation, 5G transport network, edge computing and New Radio (NR) features will be considered to fill gaps between standards and real-world deployment.

5G-DRIVE will instil significant impact on the validation of standards and trigger the roll-out of real 5G networks and V2X innovative solutions driving new business opportunities and creating thereby new jobs and brand new business models.

This paper summarizes the main activities in 5G-DRIVE towards its goals. The paper is organized as follows: Section II presents the overall approach of 5G-DRIVE. In Section III, we consider the advances beyond the current state of the art for key 5G enabling technologies. Section IV investigates the main 5G-DRIVE scenarios, while Section V focuses on the trial sites that will be used for testing and validation purposes. Finally, in Section VI, we present the key collaboration research topics between EU and China.

II. OVERALL APPROACH

The project's overall concept is illustrated in Figure 1; the figure shows the three core streams and depicts the flow from research, to adaptation into existing testbeds and pre-commercial testbed deployments, to the real-world trials of the 5G radio access network (RAN) and wider 5G network. The

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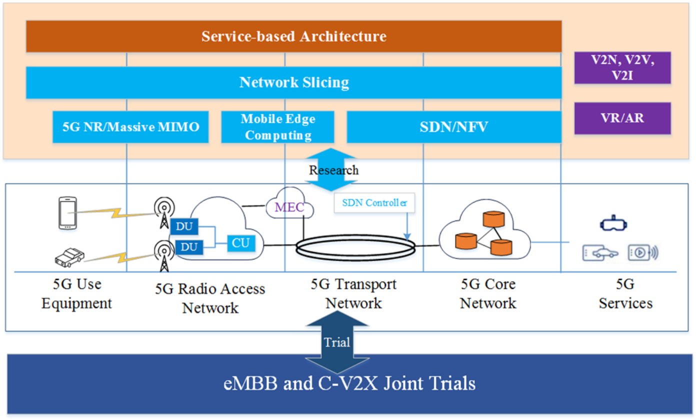
project brings together solid research competence, commercial grade testbeds, and some of the stakeholders who will eventually become major customers of 5G systems.



AR: Augment Reality, CU: Centralized Unit, C-V2X: Cellular-V2X, DU: Distributed Unit, V2N: Vehicle to Network, V2V: Vehicle to Vehicle, V2I: Vehicle to Infrastructure, VR: Virtual Reality

Fig. 1. Overall concept of 5G-DRIVE

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. All testbeds are defined in an evolutionary approach and allow the gradual introduction and testing of new equipment, as well as new features, algorithms and protocols.

In the research stream, the project investigates network and RAN slicing, Mobile Edge Computing (MEC), massive Multiple-input and Multiple-output (MIMO) for the 5G NR, as well as Software-Defined Networking (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, as well as stakeholders from the automotive and intelligent transports markets.

5G-DRIVE is based on the existing and currently under-design 5G standards, namely the 3rd Generation Partnership Project (3GPP) Rel-14 (LTE-V2X), Rel-15 (5G phase I) and Rel-16 (5G phase II). Relevant findings will be fed back into the appropriate international coordinating bodies (e.g. the Conference of European Postal and Telecommunications – CEPT) and standards development organisations (e.g. European Telecommunications Standards Institute – ETSI).

III. 5G Enabling Technologies

5G-DRIVE will investigate eMBB services and new technologies for connected and automated vehicles. In this section, we summarise the advances beyond the state of the art for 5G key technologies relevant to the 5G-DRIVE trials.

A. NFV and SDN

ETSI NFV [2] is at present working on Issue 3 of NFV specialisations, which aims to specify interfaces, address security [3,4], authentication, charging, billing and accounting [5], as well as multi-domain issues. In the context of network slicing [6], NFV is working on slice stitching, orchestration scalability and NFVO [7] multi-tenancy. The integration of the NFV approach with SDN is also a research subject [8]. 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 to allow programmable interactions between the SDN controller and switches via the P4 (Programming Protocol-Independent Packet Processors) [9] language. In the context of NFV, 5G-DRIVE will investigate policy-drive, slicing-capable orchestration; scalable slice management and efficient resource allocation to slices. It will also look into efficient SDN-based transport networks, as well as into exploiting SDN capabilities for network slicing for flexible and efficient data plane operations.

B. Network Slicing

There are still many open issues related to network slicing [10,11]. Some recent 3GPP technical standards, such as TS 28.530 [12], TS 28.531 [13] and TS 28.533 [14], define very high-level network slice management and orchestration issues. The detailed standardisation of these topics is not finalised yet. At the time of writing, 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 infrastructure resource allocation to slices. Additional key challenges are slice security and isolation. The issue of per-tenant slice management has also not been solved yet. 5G-DRIVE will considers mature slicing concepts for its testbeds, but at the same time will focus on unresolved issues like network stitching, NFV orchestrator (NFVO) multi-tenancy, scalable multi-domain orchestration and slice management.

C. MEC

New services for connected vehicles in the 5G era have very stringent performance requirements in terms of communication delay (1 ms is being targeted for traffic safety applications, e.g. collision avoidance of autonomous vehicles), reliability, and scalability. 3GPP identified autonomous vehicles as one of the use cases that should be addressed by 5G with the support of Ultra-Reliable and Low Latency Communications (URLLC) [15]. Recently, the MEC ISG in ETSI has published a study on MEC support for V2X use cases that highlights MEC as an enabler for URLLC within the context of V2X communications [16].

MEC has many applications. For the Internet of Vehicles (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 to enable data and applications to be housed close to the vehicles [17]. This can reduce the round-trip time and enable a layer of abstraction from both the core network and applications provided over the Internet. MEC applications can run on small form-factor servers co-located at the 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 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.

D. *Cellular V2X Communications (C-V2X)*

C-V2X is an umbrella term which encompasses various 3GPP approaches to vehicular communications using cellular technologies, namely LTE-V2X and 5G-V2X.

As a first contribution, 5G-DRIVE will bring together the Chinese and European approaches on the choice of technologies for V2V communications. China is strongly supporting the use of LTE-V2X and its evolution in the 3GPP standards (i.e. 5G-V2X), whereas the EU is still considering a potential co-existence between LTE-V2X and ITS-G5. The project will conduct trials to test the KPIs performance under 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 an Internet of Things (IoT) platform is planned. 5G-DRIVE will 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 for realising higher levels of automation based on short-range communication services. Additionally, the IoV trials in 5G-DRIVE will also address vulnerabilities to cyber-attacks, data protection issues and the potential coexistence of LTE-V2X and ITS-G5 in the 5.9 GHz band.

E. *Transport Network*

5G-DRIVE will consider the design, development and demonstration of the core functionality of a software-defined X-haul transport network that is responsive to load and the requirements of different services. This network is designed such that it can be orchestrated through a common framework/architecture to the whole 5G infrastructure (core and RAN). Thus, specific control plane functions and abstraction for interaction with the orchestrator 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, as well as 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.

IV. Use Cases

A. *Enhanced Mobile Broadband (eMBB) Use Case*

5G is intended to support a wide range of services; however, the first commercial use of the technology is expected to be eMBB and fixed wireless access services. As identified by Next Generation Mobile Networks Initiative (NGMN), there are three large categories of services covered by eMBB [18]. These are high-speed access in dense areas (offices, stadiums, urban centers, etc.), broadband everywhere (suburban, rural and road network) and high-speed mobility (trains, planes, etc.). Each of these scenarios has its own performance expectations [18].

A particular use case for an eMBB scenario is Cloud-based 3D Augmented Reality (AR). Conventional game consoles or personal computers are highly depending on the signal processing capabilities of the GPU. Cloud-based AR enables users to stream video games or virtual contents from cloud servers like any other streaming media. It provides a new opportunity for more varied and interactive contents, and makes user devices lighter and cheaper. While some technologies, such as eye tracking and foveated rendering are essential ingredients for high-resolution head-mounted displays (HMDs), bandwidth and latency requirements have pushed the expectations for 5G networks.

Display resolutions and high immersive content will play a key role to push users to seek out more robust data service and plans. FOV could range from 1080×1200 per eye to retina AR display (6600×600) per sys and require data rates at the low end (30 fps) between 100 Mbps to 9.4 Gbps at the high end (120 fps). 5G network speed is required to reach tens of Gbps to support the speed requirement of AR application, providing a more uniform experience for users of AR given the ultra-high data volume requirements that can be handled more effectively.

The other eMBB use case to be tested in the project is the support of the drone for the remote inspection. The test drone will be equipped with the high-definition (HD) camera used to inspect the solar-panel installed on the roof of an office building. The real-time Full-HD/4K video will be transmitted through the 5G network. Under this use case, several positioning technologies for the drone, including network based positioning using 5G networks, Global Navigation Satellite System (GNSS) based positioning, real-time kinematic (RTK) enhanced positioning, will be tested.

B. *Vehicle-to-Everything (V2X) Use Case*

V2X activities in 5G-DRIVE will be built around the following use cases:

GLOSA (*Green Light Optimised Speed Advisory Systems*) – In this use case, an RSU co-located with a traffic light sends information about the remaining time until the next light status change (green to red, or vice-versa). In turn, neighbouring vehicles will use this information to inform their corresponding drivers about the optimal speed needed to minimise stopping time through the traffic light.

Intelligent Intersection – This use case focuses on arbitrating automated vehicle interactions in a traffic-lightless intersection. CAM messages sent by incoming vehicles will be processed by a local RSU to schedule right-of-way grants in a centralised manner. The RSU is will improve situation awareness of the passenger car.

These use cases have already been implemented and verified for manual-driven and automated-driven scenarios in past projects using ITS G5 devices [19-21]. In the context of 5G-DRIVE, the aim is twofold: to benchmark benefits and drawbacks of LTE-V2X vs. ITS G5; to study the feasibility of LTE-V2X for automated driving requirements.

V. Trial Sites

As shown in Fig. 2, Surrey trial site, in UK, includes 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. In the context of 5G-DRIVE, it will focus on the development and evaluation of the eMBB scenario.

A. Surrey

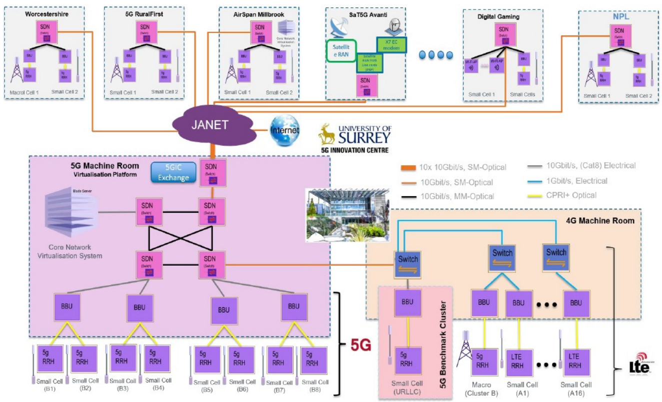


Fig. 2. 5GIC Testbed and Current Connected Sites

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 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.

B. Espoo

The Espoo trial site, in Finland, shown in Fig. 3, 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. 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. 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.

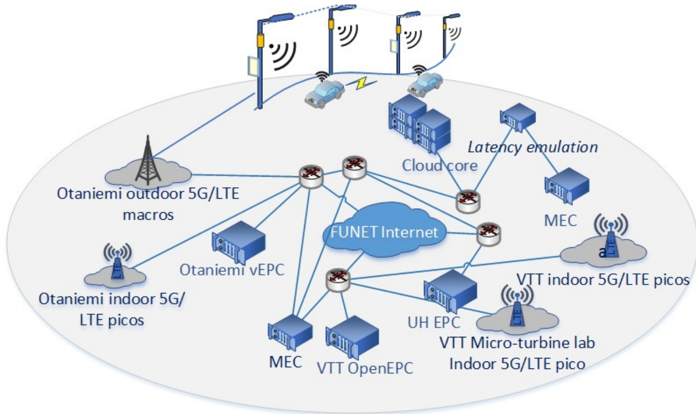


Fig. 3. Espoo, Finland 5G Testbed

C. Ispra

The JRC Ispra site, in Italy, shown in Fig. 4, 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.

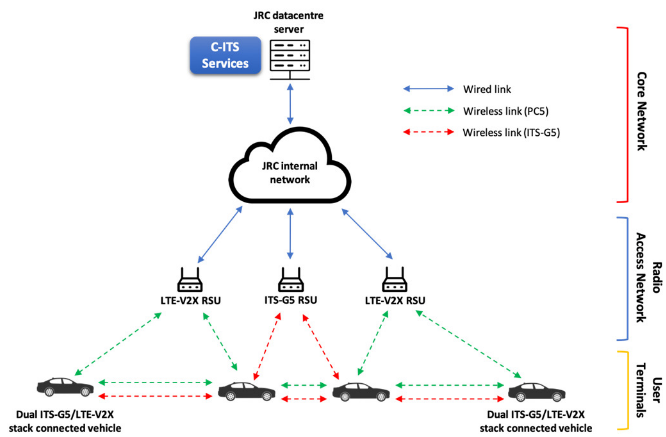


Fig. 4. The ITS-G5/LTE-V2X Testbed at JRC Ispra

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.

D. Collaboration in Trials with the Chinese Twinning Project

The trial work conducted in 5G-DRIVE will address joint experimental activities with the major 5G trial project in China. 5G-DRIVE has signed a Collaboration Agreement with the Chinese "*5G Large-scale Trial*" project coordinated by the China Mobile Research Institute, which lays the foundation and framework for the cooperation towards achieving the joint goals. The Chinese *5G Large-scale Trial* project has eight partners, including vendors and research institutes. Its main goal is to verify the large-scale deployment of 5G networks for eMBB and C-V2X tests in real-life scenarios, covering indoor and outdoor scenarios in complex urban areas. China Mobile plans to conduct the eMBB trials in five cities and the V2X trials in one location, as depicted in Fig. 5.

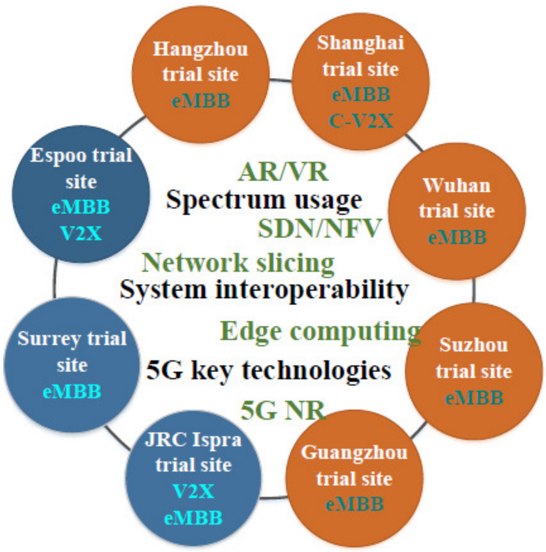


Fig. 5. Trial sites in 5G-DRIVE and the Chinese twin project

In addition to trials, 5G-DRIVE will also focus on research on key 5G topics. There will be several iterations between research and trial activities. Research concepts will be first evaluated in simulations. Later on, selected proposals will be further implemented and verified in the trial sites.

VI. Key Research Pillars

The first 3GPP release of the 5G standards has already been published. However, cellular technology is continuously evolving and future 3GPP releases will be published in the coming years. Moreover, during the testing process of the already standardised features some technical issues might be identified. With contributions to the 5G standard in mind, the project will address the following research topics through the collaboration framework set by the project.

A. Radio Access and Transport Network

This topic considers RAN, distributed massive MIMO and data transport for beyond 5G mobile communications. The spectrum bands include mmWave band and C-band. The planned work includes codebook design and beam allocation of massive MIMO, cooperative transmission of distributed massive MIMO network with non-orthogonal multiple access (NOMA), and joint channel estimation and beamforming techniques of massive MIMO in high-speed vehicular environments. The study focuses on how to compensate for the huge path-loss of mmWave signals, minimize the interference between users, make full use of caching and computing resources to boost transmission performance, and trace the channel fluctuation in high speed mobile scenarios.

Moreover, 5G-DRIVE will study virtual radio resource management under the new architecture to provide network-wide resource coordination. A particular focus is on the fronthaul/Xhaul segments, where there is a need to meet specific latency and latency variation requirements set by service/application and by the individual components of the split-RAN data (for example, distinguishing between timing protocol data, control primitives and user data). As the 5G RAN will utilize the new DU/CU and control plane (CP)/user plane (UP) separated architecture, the new radio resource management solution will take advantage of centralized control at CU and CP/UP separation. Different transport network segments are also investigated with the study encompassing the need for high bit-rate, low latencies combined with SDN control. In particular, novel algorithms are under development for time-sensitive networking and inter-technology convergence (e-Common Public Radio Interface – eCPRI, Ethernet, Passive Optical Network – PON). For that purpose, artificial intelligence (AI) will be used for joint optimisation of distributed caching techniques with SDN controlled heterogeneous data transport.

B. Network Virtualisation and Slicing

The 5G-DRIVE testbeds use network virtualisation technologies like SDN and NFV that will be applied to implement the network slicing approach. The network slicing will be used in order to implement "parallel" networking solutions tailored for specific services (eMBB, IoV). The 5G-DRIVE slices will provide end-to-end services and will be implemented in a multi-domain environment. For the purpose of slice lifecycle management, a NFV Management and Orchestration (MANO) compliant orchestrator (Open Source MANO – OSM, Open Network Automation Platform – ONAP and OpenBaton) with necessary extensions will be used. The slice-oriented operations, orchestration and management will be as much as possible compatible with the 3GPP approach. Unfortunately, the network slicing technology is not mature yet and is still a subject of intensive research and standardisation activities. This research topic focuses on unsolved yet issues of network slicing like multi-tenant orchestration, scalable management of multiple slices, efficient data plane slicing, slice stitching and allocation of resources to slices based on priorities.

C. 5G New Services

5G envisions a programmable network that enables easy deployment of future services. In that context, we will analyse the control plane enablers that will use a lightweight, but programmable control plane enabling easy implementation of advanced services. In the group of advanced services, we will focus on context-aware control plane services and applications. More specifically, we will identify and develop mechanisms to control and manage a set of network functions and services that can be dynamically and flexibly provisioned, replaced, migrated, or failed over, so as to support high device density, tackle cross-interference, enable low-latency control, reduce network load, etc. Autonomic (closed-loop) service assurance for network slices will also be also studied. Particular emphasis will be put in ensuring that the 5G network bandwidth is sufficient for sharing massive amounts of LiDAR data and offer therefore, platform collaborative sensing. The data will be partly processed in MEC server and partly in vehicle side.

D. Security and Privacy for the Internet of Vehicles

Future security challenges in communications channels of IoV within the 5G complex ecosystem are under investigation. Since the openness of SDN-based 5G interfaces will increase the attack surface, novel solutions for SDN scan attacks and lack of strong authentication mechanisms will be tackled. In parallel, 5G-DRIVE will also analyse and identify personal data protection challenges related to vehicular networks. In particular, 5G-DRIVE will research and analyse risks related to environments where the same infrastructure is shared among different actors (also due to the use of network slicing), but also in different countries (where each country set its own level of data privacy).

VII. Discussion

The H2020 project 5G-DRIVE cooperates with the Chinese twin project to trial and validate key functions of 5G networks operating at 3.5 GHz bands for enhanced Mobile Broadband (eMBB) and 3.5 GHz and 5.9 GHz bands for V2X scenarios. This paper summarizes the main activities in 5G-DRIVE towards its goals. We considered the overall approach of 5G-DRIVE, as well as the advances beyond the current state of the art for key 5G enabling technologies. Furthermore, we investigated the main 5G-DRIVE scenarios, and presented the trial sites that will be used for testing and validation purposes. Finally, we presented the key collaboration research topics between EU and China. 5G-DRIVE intends to instil significant impact on the validation of standards and trigger the roll-out of real 5G networks and V2X innovative solutions driving new business opportunities and creating thereby new jobs and brand new business models.

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