5G Promotive Actions based upon enhanced Mobile Broadband (EMBB) Communication Trials between the EU and China

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***Abstract*—The enhanced Mobile BroadBand (eMBB) service type is expected to be the main target for the first 5G deployments internationally. The first 5G standards release has also focused on the system and technology requirements and specifications for the eMBB type of service, which is to support a great variety of modern market-related applications. In the detailed scope of the 5G-DRIVE research project promoting cooperation between the EU and China, the eMBB trials are one of the two general sets of trials to be undertaken towards promoting 5G growth. In this paper, we first identify a variety of challenges rising from the 5G evolution and then we describe the specific innovative framework of the 5G-DRIVE research, together with a detailed context for establishing appropriate KPIs, for the assessment of trials. Then we discuss the two selected use cases dealing with cloud-assisted augmented reality and indoor positioning. For each use case we provide a detailed descriptive framework accompanied by the specific KPIs that are also further extended so that to cover a broader potential scope for reliable market adaptability. We summarize our approach by discussing the performed progress together with widely defined KPIs for the joint assessment of trials in Europe and China.**

Keywords—5G; 5G New Radio (NR), cloud-assisted Augmented Reality (AR), enhanced Mobile Broadband (eMBB), Indoor Positioning Services (IPS), International Mobile Telecommunications (IMT), latency, mobility.

I. INTRODUCTION

Mobile communications have become closely integrated in the daily life of our modern society and economy, "as a whole" [1], and it is expected that they will be involved in a great variety of forthcoming modern services and/or applications and related facilities [2]. In the same scope, mobile devices also play various and continuously evolving roles in our everyday life. Future IMT (International Mobile Telecommunications) systems should support emerging new use cases, including applications that require very high data rate communications, a large number of connected devices, and ultra-low latency and high reliability applications. User devices will get enhanced media consumption capabilities, such as Ultra-High Definition (UHD) display, multi-view High Definition (HD) display, mobile 3D projections, immersive video conferencing, and Augmented Reality (AR) and mixed reality display and interface. This will all lead to a demand for significantly higher data rates. Media delivery will be both to individuals and to groups of users. Today, Internet and communication networks are "critical" tools for most areas and sectors of our modern societies and economies as they are transforming our world; actually, these networks constitute fundamental "pillars" for any evolutionary process supporting effort for growth and development. According to recent market trends as well as to actual European policy measures and/or related initiatives, it is assessed that the communication networks and the wider modern services/facilities environment of the year 2020 and beyond will be *"enormously richer and much more complex than that of today"*.

Within the forthcoming years it is also expected that the underlying (usually heterogeneous) network infrastructure will be able of "*connecting everything*" according to an extended multiplicity of application-*specific* requirements (thus including users, things, goods, computing centres, content, knowledge, information and processes), in a purely flexible, mobile, and quite powerful way [3]. Living within a fully converged environment, the number of smart terminals, machines, "things" (also including sensors and actuators) attached to current networks is growing exponentially and soon it will be possible to connect and operate an immense diversity of new forms of equipment (e.g. smart home gadgets, vehicles, drones and even robots) as well; this extends our ICT-*based* abilities and concepts far beyond our current experience of tablet and smartphone connectivity. In order to "face" these major challenges, such innovative aspects not only necessitate but also imply for the proper establishment and the effective operation of a relevant novel kind of infrastructure [4], able to provide network features and

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performance characteristics to assure progress and growth in all corresponding domains (i.e. technical, business, financial, regulatory, social, etc.). In this scope, the simultaneous (occasionally appearing as "gradual") "inclusion" of modern features (such as of virtualisation and of software-*based* network functionalities) in communications infrastructures is expected to support the corresponding transitional process via further strengthening network flexibility and reactivity [5]. Market actors intend to be strongly involved in such processes, whilst creating new opportunities for novelty and investments. These chances are so expected to take place within the forthcoming "fifth generation" *-or 5G-* of telecoms systems, that will be the most critical building block of our "digital society" in the next decade; 5G will not only be an evolution of mobile broadband networks but will bring new unique network and service capabilities, creating a sustainable and scalable technology but also a proper ecosystem for technical and business innovation [6]. 5G has the potential to deliver substantial performance and capacity improvements for personal, public and enterprise communications. It has the potential to provide a suitable communication solution basis for many vertical applications, as well as to offer new architectural concepts and value chains to efficiently support innovation and future needs [7-8]. 5G is about the seamless interworking of different network technologies, mobile, fixed as well as satellite, and their co-existence within a common infrastructure of standardised and customer specific networks or IT functionalities, designed to fit vertical industries as well as consumers to broaden digital inclusiveness. It is expected that the development of 5G systems will be based on an ecosystem of a close cooperation between industry, SMEs (small- and medium-sized enterprises) and the research community to develop innovative solutions and to ensure the acceptance and exploitation of these solutions in global standards and markets. Fig.1, as below, provides a depiction of the expected 5G evolution towards 2020 and beyond, according to the 5G-PPP roadmap [9].

Fig. 1. 5G evolution towards 2020 and beyond

5G preserves the economy of scale benefits of a common network infrastructure, avoiding technology fragmentation, preventing energy and spectrum wastage and facilitating cross-sector innovation, thus improving the competitiveness of the economy. Thus, 5G can therefore facilitate connectivity, network access and service security of different vertical sectors and be instrumental to the management and automation of business assets and processes.

Actual market growth via the development and exploitation of corresponding 5G networks and of related infrastructures "delineates" a purely innovative framework that drastically affect modern economies and societies. In this scope, new 5G definition(s) and use cases have been developed by the industry. The ITU Recommendation ITU-R M.2083-0 [10], defines the overall objectives of the future development of IMT for 2020 and beyond. It calls for 5G system improvements that cover three generic classes of services, based on anticipated market developments. These are outlined in the broadly known as the "ITU triangle", as illustrated in Fig.2, and imply for: (i) *Enhanced Mobile Broadband (eMBB)*: Mobile Broadband (MBB) addresses the human-centric use cases for access to multi-media content, services and data. The demand for mobile broadband will continue to increase, leading to enhanced Mobile Broadband. The enhanced Mobile Broadband usage scenario will come with new application areas and requirements in addition to existing Mobile Broadband applications for improved performance and an increasingly seamless user experience. This usage scenario covers a range of cases, including wide-area coverage and hotspot, which have different requirements; (ii) *Ultra-reliable and low latency communications (URLLC):* This use case has stringent requirements for capabilities such as throughput, latency and availability. Some examples include wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid, transportation safety, etc.; (iii) *Massive machine-type communications (mMTC):* This use case is characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. Devices are required to be low cost, and have a very long battery life.

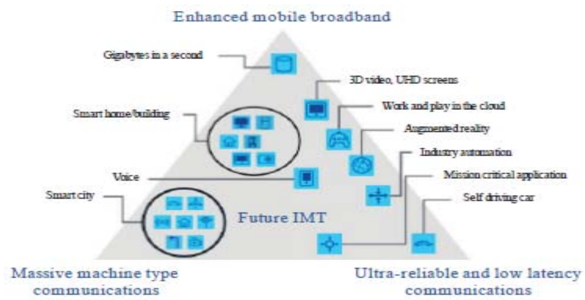

Fig. 2. Future deployment of IMT for 2020 and beyond [10]

Additional use cases are expected to emerge, which are currently not foreseen. For future IMT systems, flexibility will be necessary to adapt to new use cases that come with a wide range of requirements. Such systems will encompass a large number of different features and, depending on the circumstances and the different needs in different countries, they should be designed in a highly modular manner so that not all features have to be implemented in all networks.

Following to the innovative impact rising from the rapid 5G market growth that has been discussed above, Section II presents the detailed scope of the ongoing 5G-DRIVE project that aims to establish a collaborative framework for trials the EU and China so that to promote 5G penetration based on two fundamental scenarios, one of which is about enhanced mobile broadband communications (eMBB). In particular, we discuss the essential aims of the project together with the definition of suitable KPIs (key performance Indicators) for the assessment of the related trials. Section III comes a step forward by identifying the eMBB as a real "5G enabler" and by analysing the selected use cases in the 5G-DRIVE framework; these are cloud-assisted augmented reality and indoor positioning services, both examined and evaluated as of their intended market applicability and of their technical options. Section IV proposes a wider set of KPIs, suitable for the joint assessment of trials in the two regions. Section V summarizes our work, by including a brief synopsis of the progress that has taken place.

II. The Scope of the 5G-DRIVE Project

A. Context and Aims

Following to the previously described challenges towards a fast and reliable 5G evolution, the 5G-DRIVE project [11] is part of the H2020 ICT-22-2018 Call ("EU China 5G Collaboration"), aiming at performing a close collaboration between the EU and China to synchronise 5G technologies and spectrum issues before the final roll-out of 5G. The project's overall concept is illustrated below, (as in Fig.3), which shows the three "core" streams and also depicts the flow from research, to adaptation into existing test-beds and commercial test-bed deployments, to the real-world trials of the 5G radio access network (RAN) and of the wider 5G network. The 5G-DRIVE project "brings together" solid research competence, commercial grade test-beds, and some of the stakeholders who will eventually become major customers of 5G systems

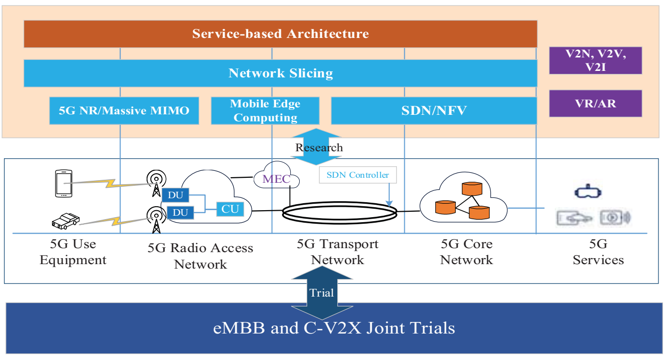

Fig. 3. Overall concept of the 5G-DRIVE project

In 5G-DRIVE there are partners with rather extensive 5G test-bed installations – these are three facilities that have been defined, specified and deployed to "meet" the individual requirements of the three research organisations (i.e.: The University of Surrey (UoS), the VTT Technical Research Centre of Finland (VTT) and the Joint Research Centre of the European Commission (JRC)) [12-13]. While all three test-beds are set up with commercial grade equipment, each one has a special focus: the Surrey test-bed can support capacity provision in very dense deployments over a 4 km² area; the Espoo test-bed in Finland demonstrates the use of slicing and V2X (Vehicle-to-Everything); the JRC facility allows the testing of new technologies in any part of the network in a fully-controlled environment. All test-beds 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 are exploited in the entire 5G-DRIVE's context. In the research stream, the project investigates network and RAN slicing, mobile edge computing (MEC), massive multiple-input multiple output (MIMO) for the 5G NR (New Radio) [14], as well as SDN (software-defined network) & network function virtualisation (NFV) techniques applied to different traffic and load scenarios. Techniques and mechanisms in the research stream of the project are under development into the most appropriate test-bed. Wherever possible, the project will endeavour to deploy such new mechanisms into all three test-beds.

The proposed experimental test-beds/facilities for 5G are able to fulfill a number of requirements [15], so these are: (i) Flexible enough in order to accommodate many different options in terms of technologies (including separate physical layers, frequency bands, etc.) at the different layers and components of the network; (ii) easily reconfigurable so that experimenters can shape it for the sake of testing their own solutions; (iii) based on open source solutions, to magnify its potential exploiting the competences of the largest possible scientific community; (iv) able to provide reproducible results, in order to guarantee fair and scientific testing and comparison of separate technologies; (v) complete, to allow the inclusion of all components of the 5G ecosystem, from the MNO (mobile network operator) to the virtual operator, from the end-user to the M2M (machine-to-machine) application field and the IoT (Internet of Things), etc.; (vi) heterogeneous in terms of radio and optical interfaces tested, as well as of contexts, including body centric communications, vehicular networks, advanced robotics, etc.; (vii) site-agnostic, as far as this is possible, in order to test technologies and solutions in different contexts; (viii) topology-agnostic, in order to cover all wireless solutions (including cellular and satellite technologies) and topologies (from small cells to macro-cells).

The core objective of the 5G-DRIVE project is to extensively trial eMBB and V2X service delivery under real-world conditions. Both scenarios (i.e.: eMBB and V2X) are being implemented in both regions (EU and China) through test-beds forming the core of the R&I work. The core objective of the project framework is to build engagement between current 5G developments in the European Union and China through joint trials and research activities so that to ease technology convergence, spectrum harmonisation and business innovation in advance of potential large-scale market 5G deployment. The stringent requirements for the delivery of such services will be defined jointly with the mobile operators in the consortium as well as stakeholders form the automotive and intelligent transports markets. These are involved in the use case and trial requirements definition, as well as in the subsequent implementation/analysis. The inclusion of these stakeholders is imperative to ensure that the trials and solutions "do meet" the requirements from the vertical domains.

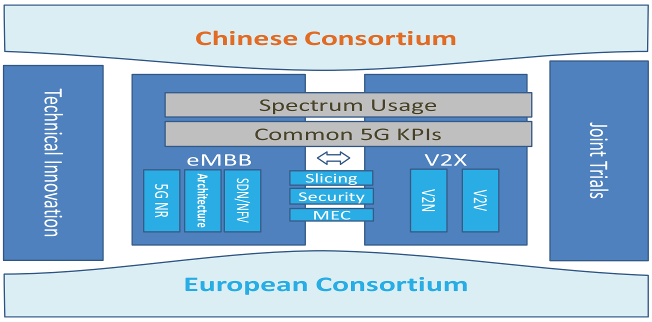

Fig. 4. EU-China 5G-DRIVE collaboration aspects

The 5G-DRIVE effort is based upon 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 test-beds which have been set up with commercial-grade and experimental equipment and are used to test new research outcomes and new services. To achieve this goal, 5G-DRIVE develops "key" 5G technologies and pre-commercial test-beds 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 are actually taking place in eight cities across the EU and China. The main targets of this collaboration are depicted in Fig. 4.

B. *KPIs for Progress Assessment*

The involvement of vertical customers in the current deployment of 5G networks increases the need for realising tests and measurements, taking into account the strict requirements of the vertical applications and the appearance of new business models. The exploitation of network and computing resource virtualisation and sharing, such as NFV and SDN and the diverse technology sectors involved in the infrastructure substrate (i.e. radio, cloud, transport) implicate that the 5G network becomes somehow increasingly complex to manage, monitor and test. When a vertical customer identifies a breach of a certain Service Level Agreement (SLA), the corresponding actions of troubleshooting and conflict resolution may implicate for cross-layer coordination of testing and monitoring. Due to the latter, a more generalised conceptual view is proposed to deal with such instances, that particularly incorporates: (i) Roles and expectation of the vertical customers; (ii) definition of testing and monitoring approaches and testing levels (from access network to service); (iii) the need for, and role of Test as-a-Service (TaaS) to the extent possible; (iv) the need of clearly defined Key Performance Indicators (KPIs) to support the validation of the corresponding 5G technology; (v) the need of a clearly defined KPI testing and validation methodology, including KPI monitoring, analysis, verification & performance diagnosis, and; (vii) the need for a common formalization process for standardizing tests representing different levels of the 5G network. The envisaged landscape of pervasive 5G services calls for solid and extensive trials, validation tests and measurements that innovating vertical firms strongly need to carry out for extracting reliable conclusions related to 5G performance. The trial environments should "mirror" the conditions and configuration that the vertical applications will "face" on their launch in production networks, to verify whether the vertical application can be considered as "5G-ready". And, *even more importantly*, by early testing their innovative use cases over a standards-based full-chain 5G facility, and following a systematic approach, a wide range of vertical industries may timely make well-informed business decisions on launching their services with guaranteed performance levels and, consequently, with higher chances of business success. To support such an effort, the 5G ecosystem needs to accommodate for frameworks that easily test, measure and demonstrate – *for the wide range of new use cases and foreseeable conditions of deployments and scenarios* – suitable KPIs of the related 5G network environments. New approaches and types of testing shall allow the fastest upgrade and deployment steps. Test and Measurements (T&M) procedures, tools, and methodologies (i.e. testing, monitoring, analytics, and diagnostics) need to be agreed upon, to ensure a proper functioning of the deployed networks. The goal is to provide a commonly agreed framework for T&M across the 5G PPP ecosystem that will allow both vertical customers and operators to verify and validate SLA for the different 5G Services.

As a consequence, a set of standard and well-defined 5G KPIs has to be considered for carefully assessing, prior to any development and testing activities, the potential feasibility of every distinct use case over a standard 5G network. More than often, in 5G literature listed 5G KPIs are associated to their values for maximum theoretically achievable and viable performance. A very detailed and reliable approach has been already been proposed by 3GPP in [16], where a great variety of E2E KPIs have been discussed. This Technical Specification has also examined several use cases of practical interest. The following KPI categories have been discussed: (i) ccessibility; (ii) integrity; (iii) utilization; (iv) retainability; (v) mobility, and; (vi) energy efficiency. The variety of standard 5G service slice types (eMBB, URLLC, mMTC), architectural options and alternative configurations have to be taken into account too, since they condition the actual feasibility for a standard 5G environment to support the specific set of 5G KPIs demanded by the application. The key success factor is the collaboration in the actual testing activities with a decisive focus on KPI monitoring & assessment, considering a variety of application scenarios and a selection of 5G network configurations. Following that approach, the involved market actors/verticals not only can benefit from assessing – and hopefully proving – the technical viability (performance-wise) of the related service, but also deriving a model for predicting its service performance in operations for a wide range of foreseeable conditions. That will provide a solid basis for making a well-informed business decision on whether, when, and how they may attempt successfully launching new services.

III. Scope for Enhance Mobile Broadband Communication

A. *General Framework*

Enhanced Mobile Broadband (eMBB) is one of three primary 5G New Radio use cases defined by the 3GPP as part of its SMARTER (Study on New Services and Markets Technology Enablers) project [17]. The objective behind SMARTER has been to develop high level use cases and identify what features and functionality 5G would need to deliver to enable them. It began in 2015 and resulted in over 70 use cases, initially grouped into five essential categories which have, since, been trimmed to three. They are characterized by the performance attributes the particular use cases will require, although there is some overlap. The three fundamental sets of use cases are as discussed in Fig. 2.

We can expect that eMBB will primarily be an extension to existing 4G/LTE services and will be amongst the first 5G services which could commercially be offered. In fact, based on recent estimations set by Ericsson [18] it is expected that there will be one billion 5G subscriptions for eMBB globally by 2023, with Asia and North America likely to be the first adopters. To allow the early deployment of eMBB services, in March 2017 the 3GPP's RAN Group committed to finalise the Non-Standalone (NSA) 5G NR variant by March 2018. In fact, the standard was approved in December 2017 [19]. The NSA mode uses the existing 4G network, supplemented by 5G NR carriers to boost data rates and reduce latency. The non-standalone (NSA) mode of 5G NR refers to an option of 5G NR deployment that depends on the control plane of an existing LTE network for control functions, while 5G NR is exclusively focused on the user plane. This is reported to speed-up 5G adoption, however some operators and vendors have criticized prioritizing the introduction of 5G NR NSA on the grounds that it could hinder the implementation of the standalone mode of the network [20]. The Standalone (SA) variant has been estimated to be completed by September 2018 for the new 3GPP 5G core network architecture. The SA mode of 5G NR refers to using 5G cells for both signalling and information transfer. It includes the new 5G Packet Core architecture instead of relying on the 4G Evolved Packet Core, to allow the deployment of 5G without the LTE network [21]. It is expected to have lower cost, better efficiency, and to assist development of new use cases. Thus, eMBB can be seen as the first phase of 5G, which will be incorporated in the 3GPP Release 15 standards [22]. Most trials, internationally, have focused on eMBB services, as indeed have the technical specifications of the 3GPP Release 15. In this scope, the EU 5G Observatory website (https://5gobservatory.eu/), launched on 27.09.2018, has started to capture information on international trials, although with a principal focus on EU trials, and developments that impact on the EU market. Most of the EU trials have focused on the 3.5 GHz band, which is the commonly used/expected band for initial deployments. In terms of verticals and use cases, there have been more trials in the areas of media and entertainment, and virtual reality (VR), than in the areas of Industry 4.0/Automation, Smart Cities and Agriculture.

5G Phase 2 will go beyond eMBB services to more transformational URLLC and mMTC applications and will be included in Release 16. Taking connected cars as an example, the first phase of eMBB services will involve enhanced in-vehicle infotainment, like real-time traffic alerts, high-speed internet access, streaming real-time video or playing games involving 3D 4K video. The second phase would be autonomous vehicles on a mass scale able to connect to and interact with other vehicles and the surrounding road infrastructure. The eMBB can so be assessed as a sort of natural evolution to existing 4G networks that will offer faster data rates and, consequently, a more enhanced and improved user experience than existing mobile broadband services. Nevertheless, it will provide the opportunity to realise significantly faster downloads so that to contribute towards an increasingly seamless user experience that will improve the status of the quality of service we are actually experiencing from existing broadband technologies. Moreover, it is expected that eMBB will support the provision of 360º video streaming, the provision of Virtual Reality (VR) and AR applications and much more. Within the context of eMBB and for the proper offering of the related use cases in the market sector, there are three distinct attributes/features that 5G has to assure, listed as follows:

- *Higher capacity:* this implicates that the intended broadband access has to be adequately available in densely populated areas, both indoors and outdoors (such as the cases of city centres, office buildings or public venues like stadiums or conference centres). This has also relevance to the necessary deployment of the underlying network infrastructures in order to support the expected coverage.
- *Enhanced connectivity:* this implicates that broadband access has to be offered "everywhere", on order to deliver a reliable user experience.
- *Higher user mobility*: this implicates that it will also predict to enable mobile broadband services in moving vehicles (including cars, buses, trains and/or planes).

B. Selected Use Cases

As of the proposed eMBB use cases, the following two are under deployment and assessment [23]: (i) Cloud-assisted AR, and; (ii) indoor positioning. The eMBB trials have focused on the two trial sites of Espoo/VTT and 5GIC/University of Surrey (UoS).

Augmented Reality (AR) has been studied for several decades and can be combined with human abilities as an efficient and complementary tool to enhance the quality of engineering analysis [24-25]. An AR system can overlay computer-generated contents on views of the physical scene, augmenting a user's perception and cognition of the world. AR allows the users to continue interacting with both the virtual and real objects around them. A near real-time interaction with these virtual and real objects enables a user to judge multiple parameters simultaneously and analyze the problem efficiently. Moreover, AR technology can be utilized to visualize data from hundreds of sensors concurrently, overlaying related and actionable information over your environment via a headset. With much more data flow, 5G helps AR technology to be much faster. Featured with easier and more reachable use, it is more likely to be widely applied in various different functions (including video gaming). 5G would allow for higher flexibility in a great variety of relevant use cases. AR is commonly used on smartphones or tablets in museums to present additional content for exhibits, or for interior design, allowing shoppers to virtually place furniture in a room to see how it matches. Thus, AR serves distinct business cases while VR serves both consumer and business applications. There are certain areas where both AR and VR overlap [26-27]. With 5G, the ability to use AR in live, outdoor environments away from reliable Wi-Fi signals can influence the types of interactions and integrations that developers can build. In conclusion, AR is a combination of the real scene viewed by a user and a virtual scene generated by a computer that augments the scene with additional information. The virtual content can be interacted with in real time, while virtual objects appear fixed in space. The AR improves our perception of the real world as well as our performance in it. Cloud AR/VR brings together significant advances in cloud computing and interactive quality networking to provide high-quality experiences to those who were previously priced out of immersive technologies. The "Cloud" is a computing architecture whereby resources can be called upon an as-needed basis. Those resources include general and specific computing functions as well as persistent storage but may also include software functions. The key advantage of a cloud computing architecture is that it can accommodate any compute and storage requests made by an application.

Cloud-assisted 3D AR is a 5G-DRIVE use case in the eMBB scenario. As opposed to conventional gaming consoles or personal computers (which are highly dependent on the signal processing capabilities of the GPU (graphics processing unit)), cloud-assisted AR enables users to stream video games or virtual contents from cloud servers like other streaming media. This new type of services offers an opportunity for more varied and interactive contents and makes user devices lighter and cheaper. While some new 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. As it is known, display resolutions and high immersive content 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). For the eMBB it 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.

Fig. 5. Screen-shot of the real-time 3D video as shown at the VTT site transmitted from Surrey

The joint AR demo has been tested several times between Surrey trial site and China Mobile trial site in November 2019 (also see Fig.5). However, due to the network firewall security issues, the network performance (i.e., data rate and E2E latency) cannot meet the requirement as expected for this type of services. The average frame rate is below 20 Mbps at 20 FPS. To maintain the QoE levels required in real-time, cloud-assisted 3D AR, the following KPIs have been measured: peak data-rate and FPS (frames-per-second).

Indoor Positioning System (IPS) is a system used to locate objects or people inside a building using lights, radio waves, magnetic fields, acoustic signal, or other sensory information [28]. By the complex nature of indoor environments, the development of an indoor localization technique is always associated with a set of challenges like smaller dimensions, high non line-of-sight (NLoS), influence of obstacles like walls, equipment, movement of human beings, doors, and other factors [29]. Multipath effect signals are reflected and attenuated by walls and furniture and noise interference. These challenges result mainly from the influence of obstacles on the propagation of electromagnetic waves. For instance, the mobility of people incurs changes in physical conditions of the environment, which might significantly affect the behavior of wireless radio propagation. Although these negative effects cannot be eliminated completely, in recent years researches are constantly going on to improve the performance of indoor (human/object) tracking. For getting good and accurate results, a positioning system must be able to handle these problems. Beside this, higher accuracy is also required indoors to locate a user at least in the right room. One of the important aspects indoors is indoor signal property characteristics implicating for:

- *Accuracy* (or location error) of a system is the important user requirement of positioning systems. It can be reported as an error distance between the estimated location and the actual mobile location. Sometimes, accuracy is also called the area of uncertainty; that is, the higher the accuracy is, the better the system is.
- *Responsiveness*, which determines how quickly the location estimate of a moving target is updated.
- *Coverage*: The problem of determining the network coverage for a designated area is important when evaluating the effectiveness of a positioning system. Coverage is closely related to accuracy and can be categorized as local coverage, scalable coverage and global coverage.
- *Adaptiveness*: Environmental influence changes may affect the localization system performance. The ability of the localization system to cope with these changes is called as system's adaptiveness.
- *Scalability:* This is a desirable property in almost any system that suggests how well the system performs when it operates with a larger number of location requests and a larger coverage. Poor scalability can result in poor system performance, necessitating the reengineering or duplication of systems. A scalable

positioning system should be able to handle large numbers of tags, without unnecessary strain.

- *Cost and Complexity:* The cost gained from a positioning system can arise from the cost of extra infrastructure, additional bandwidth, money, lifetime, weight, energy, and nature of the deployed technology. The cost may include installation and survey time during the deployment period. If a positioning system can reuse an existing communication infrastructure, some part of infrastructure, equipment, and bandwidth can be saved. The complexity of the signal processing and algorithms used to estimate the location is another issue, that needs to be balanced with the performance of positioning systems. Tradeoffs between system complexity and accuracy affect the overall cost.

Indoor position information supports navigating within building premises. However, this location information is also a valuable asset for providing and maintaining high quality eMBB services to end-user devices. Positioning offers means to utilize location information to improve network communication reliability, to reduce latency, and to balance data loads [30]. Since most of the network control components are fixed at specific locations, eMBB services to mobile end-user devices require also support for mobility. First the mobile terminal receives the eMBB service signal from one base station and then gradually moves to the coverage area of another base station, so a handover in the indoor network is executed. Mobility comes at a cost in terms of extra signalling messages, processing resources and delay in set-up and data message transactions. Due to the nature of network control and monitoring, additional signalling overhead gets created from sending infrequently small packets. From the mobile network side, this requires re-allocation and scheduling of radio resources with increased latency. Location information can be used by the network and devices to optimise communication and to save energy by reducing signalling. Combining location information with other forthcoming functionalities, it may be possible to dynamically adjust data loads and routing and to control the latency and its deviation. The shared location information is therefore a valuable asset for both mobile end users and eMBB service providers to maintain and operate their devices. The latency trials can be carried out at three levels: E2E latency between User Equipment (UE) and application server, RAN latency and core network latency. The indoor hotspot trial in Espoo focuses on high user density and high capacity/throughput in indoor small coverage areas. The test environment for the indoor coverage measurements is in an office building, where the used radio network technologies are TD-5G (3.5 GHz) and FD-LTE (2.6 GHz). VTT's 3D model allows taking the shadowing effects of buildings and terrain into account. In fact, Fig. 6(a) "depicts the expected measurement route for providing reference location and indoor maps. Research on indoor communication quality and positioning is supported by a mobile robot shown in Fig. 6(b). The robot has two main tasks. It simultaneously constructs a map from its surroundings and localizes itself within it. This mobile robot is used to carry multiple measurement devices and to provide a reference location and timestamp for each measurement sample. In a typical setup, the robot is equipped with NEMO Outdoor laptop and six to nine terminals measuring different radio access technologies and different mobile operators.

Fig. 6. (a) Floor map including measured strength values; (b) mobile robot used for the IPS platform

The floor maps generated by the robot and existing 3D Otaniemi model are used for developing highly localised propagation models and positioning algorithms to capture the effects of LoS and NLoS regions shown in Fig. 6(a). The indoor positioning focuses on network based positioning techniques covering signal strength based, time based Uplink-Time Difference of Arrival (UTDOA) and Observed Time Difference of Arrival (OTDOA), and learning / data correlation based algorithms. The location information is used in several use cases e.g. for remote control and monitoring in industrial spaces, for location-aware traffic offloading using SDN, and location-aware access-control and network services in enterprise and public Wi-Fi deployments. The configuration has been used also for testing movable Wi-Fi APs, Wirepas sensors and Raspberry beacons in ad-hoc networks. Measurements can be real-time or offline network performance measurements. Measurements are used for: (i) optimisation of indoor LTE-WiFi pico-cell installations for positioning and latency reduction, and (ii) fine-tuning indoor or outdoor coverage prediction models. Coverage predictions can be used for: (i) estimating the coverage of licensed and unlicensed wireless networks, and; (ii) planning locations for new base stations to improve coverage and/or increase positioning accuracy. The stars in Fig. 7 depict placement of the installed picocells. All test measurements are carried out with a mobile robot, which obtains reference location. For sake of verification, the measurements are repeated twice along the measurement routes both clockwise and counter-clockwise at the height of 1.5 meters. As shown in that figure, the measurement route has been selected to include both LoS and NLoS regions. A smartphone and a modem/CPE are the user devices for the measurements. The indoor positioning platform has been further enhanced and tested for support of autonomous systems connectivity and navigation. In the actual measurement setup, we have equipped the mobile robot with four UE devices that have been used to increase the sampling rate; that is, a fourfold amount of data samples is collected as training and testing data for positioning and handover algorithms. The mobile robot uses LIDAR and SLAM (simultaneous localization and mapping) algorithm to provide a reference location for each measurement sample, and the timestamp for each measurement sample is taken from the robot's central clock.

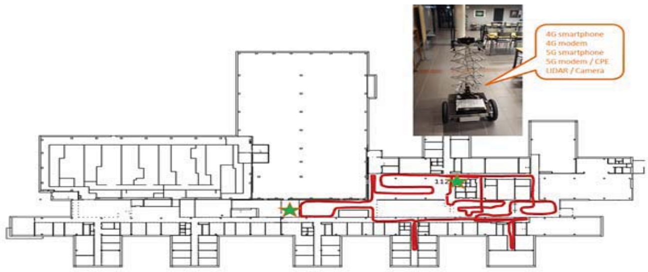

Fig. 7. Measurement route in the VTT site

Relevant KPIs for this use case are described as follows: (i) Peak data rate: this metric denotes the maximum physical-layer throughput achievable between the 5G gNB and the UE, in Gbps; (ii) Jitter: this KPI denotes the variation in the delay experienced by received packets (in ms); (iii) Latency: radio latency is the radio access network contribution to the total delay between the transmitter and the receiver, given in ms.

IV. KPIs FOR THE eMBB JOINT ASSESSMENT BETWEEN EU AND CHINA

Within the EU, the 5G Infrastructure Association (5GIA) and the projects funded through the 5G Public-Private Partnership (5G-PPP) have been the major drivers for 5G research and development, testing and trials. The sources of the KPI definitions come from ITU-R M.2410-0 [31], NGMN 5G Trial and Testing Initiative Pre-commercial Network Trials Framework Definition [32], 5G-PPP Phase-II KPI definitions [33] and 3GPP [34]. Note that the KPIs defined in these documents are used to provide a throughout performance evaluation of 5G systems. However, considering the capability and availability of the trial facilities in the project, only a selected set of KPIs will be evaluated. For this reason, in the following subsections we only list the KPIs relevant to the project trials and provide the test procedure. By applying a common test procedure, the trial results from different trial sites can be compared. A selected set of KPIs are to be measured in both the 5G-DRIVE and the Chinese twin project and results will be reported in the joint trial reports. In the following, we first provide the definition of the selected KPIs, and describe the test setup, test procedure, evaluation criteria and reporting process of each of the KPIs listed as follows:

Data rate: It is the number of bits transmitted through the system per unit of time. (There are different terms to represent the data rate. Some documents use the term "data rate", while others use the term "throughput"). We can distinguish the following: (i) *Peak data rate* in bit/s is the maximum achievable data rate under ideal conditions to a single mobile station, to which all assignable radio resources for the corresponding link direction are assigned, except the radio resources used for PHY layer synchronization, reference and pilot signals, guard bands and guard times. In some documents, it is referred to the peak user throughput. (ii) *User experienced data rate* is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput is defined as the number of correctly received bits, i.e. the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time. (iii) *Cell edge user data rate:* In 3GPP, the cell edge user data rate is defined as the 5% point of the CDF of user's average data rate. The user's average data rate is linked to the average spectral efficiency, used bandwidth, and the number of TRxP (transmission reception points) used in the system.

Latency: In communications, the latency is the time interval for a bit of data, usually a data packet, to travel across the network from one node or endpoint to another. According to the purpose of evaluation, there are two types of latencies, that is user plane latency and control plane latency. More specifically, we have: (i) *User plane latency*: At the application level, the most important latency is the end-to-end latency, which is the maximum tolerable elapsed time from the instant a data packet is generated at the source application to the instant it is received by the destination application. If direct mode is used, this is essentially the maximum tolerable air interface latency. If infrastructure mode is used, this includes the time needed for uplink, any necessary routing in the infrastructure, and downlink. (ii) *Control plane latency* refers to the transition time at the UE side from the idle or inactive RRC (radio resource control) state to the start of continuous data transfer (e.g., Active state).

Cell capacity is the KPI to evaluate the aggregate capacity of multiple users served by a cell. It can be measured by the cell peak throughput and cell average throughput. In the measurement, multiple UEs are placed in the different locations to represent different propagation environments. The results of cell capacity can be explained as the spectrum efficiency.

Spectral efficiency: Spectrum efficiency refers to the data rate that can be transmitted over a given bandwidth in a communication system. In the 5G-DRIVE project, it is the data rate per UE at given condition divided by the bandwidth used by UE for corresponding data rate. It is an important performance KPI of 5G system. The spectrum efficiency is also a good indicator to show the performance difference between 4G and 5G systems.

Coverage: The coverage area of a mobile system is the geographic area where the base station and the user device can communicate. Coverage is evaluated by the communication availability, in which the signal strength of a cell needs to exceed a defined minimum threshold and the achieved service quality, in which a minimum data rate in case of mobile data services or a minimum speech quality in case of voice services is required. The coverage depends on several factors, including the environment, buildings, technology, and radio frequency and most importantly for two-way telecommunications the sensitivity and transmit efficiency including maximum output power of the base station and the end-user device.

Mobility is the maximum mobile station speed at which a defined QoS can be achieved (in km/h). There are four identified classes of mobility, each one implicating up to a certain "threshold" of speed, as follows: (i) Stationary: 0 km/h; (ii) Pedestrian: 0 km/h to 10 km/h; (iii) Vehicular: 10

km/h to 120 km/h, and; (iv) High speed vehicular: 120 km/h to 500 km/h.

Reliability relates to the capability of transmitting a given amount of traffic within a predetermined time duration with high success probability. Reliability is the success probability of transmitting a layer 2/3 packet within a required maximum time, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface at a certain channel quality.

Area traffic capacity is the total traffic throughput served per geographic area (in Mbit/s/m2). The throughput is the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time.

Depending on the trial settings in the project, which may be potentially limited by the availability of network equipment and the deployment scenario, *per case*, the test setup and procedure may be modified during the trials, *if and when necessary*. Within the context of the 5G-DRIVE project [35], the consortium has analytically described the corresponding test procedure(s) together with the evaluation criteria for the KPIs that have been presented above. In the context of the performed trials, as the reference test methodology it has been selected the KPI test methodology from the NGMN trial framework document in [32]. This is an important methodology approach for 5G pre-commercial trials.

The technical objectives for the 5G-DRIVE eMBB joint trials with the "twin" Chinese project involve: (i) Developing joint test specifications through collaborative agreement for testbeds and trials for eMBB in multiple cities; (ii) developing and trialing "key" 5G technologies, including, but not limited to, mMIMO, E2E network slicing, SDN; (iii) developing and trialing cross-domain network slicing across the two regions, and; (iv) analysis of system interoperability issues (provided through joint reports, recommendations, white papers, etc.). Thus, a possible means for cooperation is to identify and define the common KPIs that would be measured by both projects, following similar, agreed test procedures, and then jointly comparing results.

The use of eMBB in the 3.5 GHz band will be developed and demonstrated with the 5G technologies in EU, while the use of eMBB in the 2.6 GHz band will be employed to develop and demonstrate in China (due to the spectrum allocated to China Mobile). This is a "key difference" which needs to be accounted for in the results analysis. To approach the cooperation goal, three main joint trials have been identified, which are:

- Basic performance of the 5G NR in both SA and NSA modes, that is with the 5G RAN equipment attached to a 5G CN (core network) or a 4G (LTE) CN, *respectively*.
- Indoor coverage performance tests, for example, using small/pico-cells and/or distributed antenna systems, and examining localization techniques.
- Multi-antenna or mMIMO array antenna subsystem tests, which will examine the enhanced performance possible from such beamforming systems, and different beamforming operational methodologies.

The first phase of the trial activities on both EU and China sides have focused very much on the performance of the 5G NR. The objective is to carry out extensive eMBB tests in the two regions with pre-commercial equipment and sufficient cellular coverage. The next objective of the joint trial activities is to validate basic network performance on agreed eMBB KPIs with both the NSA and SA architectures, and the agreed KPIs for indoor performance and for multi-antenna (mMIMO) performance. The planned tests include outdoor coverage performance, access performance, single user speed and Control Plane (CP) / User Plane (UP) latency, cell average and peak throughput, indoor performance from outdoor radio units, indoor coverage and throughput, beamforming.

V. Discussion

The work is further expected to be extended following to the progress of the related use cases in the respective trials. Regarding the current state-of-the-art about the eMBB trials, we can summarize as follows:

- Basic performance of the 5G NR in NSA mode have been measuring in both Surrey site and Espoo site. Single UE peak data rate has been measured for both uplink and downlink with TCP (transmission control protocol) and UDP (user datagram protocol). Control Plane (CP) latency measurement is also under progressing and initial results have been achieved. More measurements will be carried upon achieving stable measurement performance.
- Indoor coverage provided by outdoor gNB measurements are progressing. A 3D model is also under investigation to be employed for comparing the measurement results.
- MIMO beamforming techniques have been tested and studied and, *moreover*, results are progressing to collaborate with the SA trial data provided by the Chinese "twin" project.
- Joint AR demo has been tested with the Chinese "twin" project. However, measured performance cannot achieve the requirement of the use case due to the network firewall security issue in China. Therefore, a joint AR demo has been conducted between Surrey trial site and Espoo trial site. The partners from the Chinese 'twin" project also participate to this joint demo from the Surrey site.
- Joint trials have been conducted in both China and UK four times, and joint publications are either under review or preparing to be submitted.

Based on the appearing outcome(s) and the currently performed progress of the trials, we can confirm that the eMBB can act as a real "5G promoter" upon the basis of the selected uses cases for early introduction of very high rate services in both regions.

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