Enhanced Mobile Broadband as Enabler for 5G: Actions from the Framework of the 5G-DRIVE Project

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Abstract. In the new fascinating era of 5G, new communication requirements set diverse challenges upon existing networks, both in terms of technologies and business models. One among the essential categories of the innovative 5G mobile network services is the enhanced Mobile Broadband (eMBB), mainly aiming to fulfill users' demand for an increasingly digital lifestyle and focusing upon facilities that implicate high requirements for bandwidth. In this paper we have discussed eMBB as the first commercial use of the 5G technology. Then, we have focused upon the original context of the 5G-DRIVE research project between the EU and China, and we have identified essential features of the respective eMBB trials, constituting one of the corresponding core activities. In addition, we have discussed proposed scenarios and KPIs for assessing the scheduled experimental work, based on similar findings from other research and/or standardization activities.

Keywords: The Third Generation Partnership Project (3GPP) · 5G · 5G New Radio (5G NR) · enhanced Mobile Broadband (eMBB) · massive Machine Type Communication (mMTC) · Ultra-Reliable and Low-Latency Communication (URLLC)

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1 Introduction

Both the European and the global economy have faced multiple challenges for growth due to the immense evolution of the Internet and the expansion of the broader electronic communications sector in a fully converged environment, promoting competition and wider service offerings for the involved market players [1]. 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.

In order to "face" these major challenges, such innovative aspects not only necessitate but also imply for the proper establishment and the effective operation and management of a relevant novel kind of infrastructure being able to deliver network attributes and performance characteristics to assure progress and growth in all corresponding domains (i.e., technical, business, financial, regulatory, social, etc.). Major network operators are 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 following years [2]; in particular, 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 as well as a proper ecosystem for technical and business innovation [3, 4]. 5G has the potential to deliver substantial performance and capacity improvements for personal, public and enterprise communications. It has also the ability 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 [5]. 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.

The 5G system is expected to be able to deliver optimized support for a diversity of services, traffic loads and end-user communities [6]. To this aim, several industrial approaches [7] have proposed the conceptual framework of a system concurrently supporting various combinations of reliability, latency, throughput, positioning and availability. This sort of growth and development can be realised via the inclusion of modern technologies, both in access and the core network concept, offering flexibility and scalability of involved network resources. However, apart from increased flexibility and optimization, a 5G system has to support strict KPIs (Key Performance Indicators) for latency, reliability, throughput, etc. Furthermore, a modern 5G system is also expected to support innovative business models such as those for IoT (Internet of Things) and enterprise managed networks. Flexible network operations are essential features of the 5G system. Offering the intended degree of flexibility implicates the usage of features such as network slicing, network capability exposure, scalability, and diverse mobility. The 5G system will handle the great variability of all potential scenarios of use in a resource efficient manner. The corresponding use cases introduce new deployment requirements for indoor and outdoor, local area connectivity, high user density, wide area connectivity, and User Equipments (UEs) travelling at high speeds. Other 5G aspects may implicate requirements for various combinations of latency and reliability, as well as higher accuracy for positioning.

The work in the present paper is as follows: Sect. 2 discusses the critical role of the enhanced Mobile Broadband (eMBB) as a promoter of the first phase of the 5G implementation, within the scope of the New Radio (NR) actions, as originally performed by the Third Generation Partnership project (3GPP). Then Sect. 3 emphasizes on context of the specific eMBB trials within the framework of the 5G-DRIVE project; in particular, we identify several scenarios which include indoor hotspot, dense urban deployment and macro cells deployment and we propose related attributes. In order to promote the project actions for the scheduled trials, we also identify and briefly discuss corresponding KPIs, coming from similar research and/or standardization actions. Finally, Sect. 4 provides several concluding remarks.

2 Enhanced Mobile Broadband as Fundamental Enabler of the "First Phase of 5G"

The eMBB is one of three primary 5G New Radio use cases [8] defined by the 3GPP as part of its SMARTER ("Study on New Services and Markets Technology Enablers") project [9, 10]. The 3GPP qualifies ultra-fast mobile broadband as mobile systems capable of delivering speeds of 20 gigabits per second, at least uni-directionally, and without specific latency requirements [11]. The eMBB will initially be an extension to existing 4G services and will be among the first 5G services, which could be commercially available as early as 2019. The objective behind SMARTER [12] was to develop high level use cases and identify what features and functionality 5G would need to deliver to enable them. This specific project 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 characterised by the performance attributes the particular use cases will require, although there is some overlap. The three fundamental sets of use cases are as follows:

- ***Enhanced Mobile Broadband (eMBB):*** This "addresses" the human-centric use cases for access to multi-media content, services and data. Based on the original scope of the SMARTER approach, related requirements have been defined on high data rates, higher traffic or connection density, high user mobility, and those relevant to various deployment and coverage scenarios. The scenarios have addressed different service areas (e.g., indoor/outdoor, urban and rural areas, office and home, local and wide areas connectivity), and special deployments (e.g., massive gatherings, broadcast, residential, and high-speed vehicles). Actual technology trends purely "demonstrate" that the demand for mobile broadband will continue to increase, thus 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. We can distinguish the following: (i) For a hotspot case, that is for an area with high user density, very high traffic capacity is needed, while the requirement for mobility is low and user data rate is higher than that of wide area coverage; (ii) For the wide area coverage case, seamless coverage and medium to high mobility are desired, with much improved user data rate compared to existing data rates. However, the data rate requirement may be relaxed compared to hotspot. The eMBB traffic can be considered to be a direct extension of the 4G broadband service. It is characterized by large payloads and by a device activation pattern that remains stable over an extended time interval. This allows the network to schedule wireless resources to the eMBB devices such that no two eMBB devices access the same resource simultaneously. The objective of the eMBB service is to maximize the data rate, while guaranteeing a moderate reliability, with packet error rate (PER) on the order of 10^{-3}.

- ***Ultra-Reliable Low Latency Communications (URLLC):*** This set has stringent requirements for capabilities such as throughput, latency and availability. In particular, it implicates for strict requirements on latency and reliability for mission critical communications, such as remote surgery, autonomous vehicles or the Tactile Internet; the latter can be defined by extremely low latency in combination with high availability, reliability and security and it will have a marked impact on business and society, introducing numerous new opportunities for emerging technology markets and the delivery of essential public services. Some other examples include wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid, transportation safety, etc. URLLC transmissions are also intermittent, but the set of potential URLLC transmitters is much smaller than for mMTC. Supporting intermittent URLLC transmissions requires a combination of scheduling, so as to ensure a certain amount of predictability in the available resources and thus support high reliability; as well as random access, in order to avoid that too many resources being idle due to the intermittent traffic. Due to the low latency requirements, a URLLC transmission should be localized in time. Diversity, which is critical to achieve high reliability, can hence be achieved only using multiple frequency or spatial resources. The rate of a URLLC transmission is relatively low, and the main requirement is ensuring a high reliability level, with a PER typically lower than 10^{-5}, despite the small blocklengths.
- ***Massive Machine Type Communications (mMTC):*** This set is characterised by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. These devices are usually located in a small area, which may only send data sporadically, such as Internet of Things (IoT) use cases. Devices are required to be low cost, and have a very long battery life. The mMTC has been already developed as part of 3GPP Release 13/ Release 14 [13, 14] low power wide area (LPWA) technologies [15], which includes Narrowband Internet of Things (NB-IoT). These are expected to "meet" most 5G mMTC requirements, while others that require more bandwidth with ultra-reliable low latency (full URLLC) will require the 5G Core deployment for full end-to-end latency reduction. Mission critical applications that are especially latency-*sensitive* will also

require wide coverage, which is highly unlikely in early 5G deployments, so this development is expected to come later. An mMTC device is active intermittently and uses a fixed, typically low, transmission rate in the uplink. A huge number of mMTC devices may be connected to a given base station (BS), but at a given time only an unknown (random) subset of them become active and attempt to send their data. The large number of potentially active mMTC devices makes it infeasible to allocate a priori resources to individual mMTC devices. Instead, it is necessary to provide resources that can be shared through random access. The size of the active subset of mMTC devices is a random variable, whose average value measures the mMTC traffic arrival rate. The objective in the design of mMTC is to maximize the arrival rate that can be supported in a given radio resource. The targeted PER of an individual mMTC transmission is typically low, e.g., on the order of 10^{-1}.

The grand objective of 5G wireless technology is to support the above three generic services with vastly heterogeneous requirements, that is eMBB, mMTC and URLLC. Service heterogeneity can be accommodated by network slicing, through which each service is allocated resources to provide performance guarantees and isolation from the other services [16]. Under a broader concept, the Mobile Broadband (MBB) enhancements aim to fulfil a number of innovative KPIs. These pertain to high data rates, high user density, high user mobility, highly variable data rates, deployment, and coverage. High data rates are driven by the increasing use of data for services such as streaming (e.g., video, music, and user generated content), interactive services (e.g., Augmented Reality (AR)), and IoT.

More specifically, to support the initial rollout of eMBB services, since March 2017 the 3GPP's RAN (Radio Access Network) Group committed to finalise the Non-Standalone (NSA) 5G NR variant by March 2018. In fact, the standard was approved in December 2017 [17]. The NSA mode considers the current 4G network, as supplemented by 5G NR carriers to boost data rates and decrease latency. The NSA 5G NR will utilize the existing LTE (Long Term Evolution) radio and core network as an "anchor" for mobility management and coverage, while adding a new 5G carrier. This is the configuration that will be the target of early 2019 deployments (in 3GPP terminology, this is NSA 5G NR deployment scenario Option 3). The Standalone (SA) variant was to be completed by September 2018 but was also finished early, in June 2018. The SA 5G NR implies full user and control plane capability for 5G NR, utilizing the 5G next-generation core network architecture (5G NGC) also being done in 3GPP. SA 5G NR technical specifications have been completed in June 2018 as part of 3GPP Release 15. Thus, eMBB can be assessed as "the first phase of 5G", which will be encompassed in the 3GPP Release 15 standard [18]. The 5G Phase 2 will go beyond the eMBB services to more transformational URLLC and mMTC applications and will be included in Release 16, which is due to be completed at the end of 2019. By considering the case of connected cars as a characteristic example, the first phase of eMBB services will include 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 involve autonomous vehicles on a mass scale capable of connecting to and interacting with other vehicles and/or with the nearby road infrastructure [19].

Following to the above context, the eMBB can be seen as a natural development of current 4G networks that will deliver faster data rates and, *consequently*, a better user experience than present mobile broadband services [20]. Nevertheless, it is expected that eMBB will evolve further and assure faster downloads to offer a progressively more seamless user experience that will conceal the quality of service we now experience from fixed broadband technologies. In the long run, it will also allow the provision of 360^{o} video streaming, rightly immersive Virtual Reality (VR) and Augmented Reality applications and a variety of modern solutions. In fact, if we assess the framework of potential eMBB use cases, there are three separate features that 5G has to guarantee: (i) Higher capacity, which implicates that broadband access has to be offered in densely populated areas, both indoors and outdoors (including, for example: city centres, office buildings or public venues such as malls, stadiums, conference centres, concerts sites, etc.); (ii) enhanced connectivity, implicating that broadband access has to be obtainable everywhere with the aim of offering a reliable user experience, and; (iii) higher user mobility that will allow for the provision of mobile broadband services in moving vehicles (including cars, buses, trains and planes). These categories of use cases will implicate for diverse requirements. In fact, as of the case of a "hotspot" scenario where there are many end-users (such as viewers at a sporting event), there will be a prerequisite for very high traffic capacity to satisfy the needs of all the participating end-users, but these will be static -or moving slowly- so the request for mobility will be assessed as low. However, when offering eMBB services/facilities to travellers in a high-speed train this by default necessitates for a high degree of mobility although the traffic capacity shall be lower than if compared to that of a hotspot scenario. Being somewhere between the above two essential use cases, the coverage of a wide area may implicate for a kind of "medium" level of mobility and although data throughput can be higher than the actual experience, it cannot be as high as in a hotspot.

3 eMBB Within the Context of the 5G-DRIVE Project

The 5G-DRIVE project [21] as it is actually funded by the European Commission within the framework of the 5G-PPP Phase 3 [22], aims to perform a "close" collaboration between EU and China to synchronise 5G technologies and spectrum issues before the final roll-out of 5G in order to "address" two most promising 5G deployment scenarios, namely enhanced Mobile Broadband (eMBB) and Vehicle-to-Everything (V2X) communications.

The main scope of the 5G-DRIVE's effort is to conduct 5G trials addressing two specific scenarios of prime importance in modern 5G-oriented applications, as follows: (i) Scenario no 1 - enhanced Mobile Broadband (eMBB) on the 3.5 GHz band, which is a priority band in the two regions for early introduction of very high rate services; *and*; (ii) Scenario no 2 - Internet of Vehicles (IoV) based on LTE-V2X using the 5.9 GHz band for Vehicle-to-Vehicle (V2V) and the 3.5 GHz band for Vehicle-to-Network (V2N). The overall goal is to evaluate in real setup innovative end-to-end 5G systems built on the outcomes of the previous phases of the 5G Research and

Innovation (R&I). Both scenarios shall be implemented in both regions through test-beds with interoperability forming the core of the R&I work.

The underlying trials' testing facilities shall implement the latest mature and broadly commonly agreed 5G systems, network architectures and technologies spanning from the core/transport networks, the radio access, up to the service, orchestration, management and security components. The trial facility shall not be restricted to innovative 5G radio access technology, but should include and enable the evolution of 5G networks innovations in network slicing, virtualisation, cross-domain orchestration, in view of supporting resource control from multiple tenants.

The focus of the testing will be upon the radio interface except for some KPIs, features and use cases selected for eMBB scenarios considered in the 5G-DRIVE, which need to be quantified in an end-to-end configuration, (e.g., various latency measurements, network slicing, etc.). Subject to the availability of trial sites, the non-standalone version or the standalone version of 5G NR will be chosen accordingly. In the NSA architecture, the trials need to consider collocated and non-collocated NR and LTE radio suites to test the dual connectivity between both technologies.

3.1 eMBB Trials Scenarios in the 5G-DRIVE Framework

The collected data of tests will be compared with the targeted requirements and expected performance defined in 3GPP release 15 or release 16 or in the ITU-RM.2410-0 [23], subject to the individual requirement of each trial. The primary aim of building pre-commercial end-to-end testbeds is to test 5G NR with a focus on eMBB using close-to-commercial equipment in realistic settings, which can "reflect" near real-life network performance.

Table 1. Deployment attributes for the eMBB trials scenarios within the 5G-DRIVE framework (i.e.: indoor hotspot, dense urban and urban macro, *accordingly*).

Attributes	Indoor hotspot scenario	Dense urban scenario	Urban macro scenario
Carrier Frequency	Sub 6 GHz (around 3.5 GHz)	Sub 6 GHz (around 3.5 GHz)	Sub 6 GHz (around 3.5 GHz)
Aggregated system bandwidth	100 MHz for sub 6 GHz	100 MHz for sub 6 GHz	100 MHz for sub 6 GHz
Sub-carrier spacing	30 kHz for sub 6 GHz	30 kHz for sub 6 GHz	30 kHz for sub 6 GHz
Carrier prefix (CP) length	2.3 us	2.3 us	2.3 us
Slot length	0.5 ms (14 symbols), 0.25 ms (7 symbols) for sub 6 GHz	0.5 ms (14 symbols), 0.25 ms (7 symbols) for sub6 GHz	0.5 ms (14 symbols), 0.25 ms (7 symbols) for sub6 GHz
Number of layers	1	2	1

(*continued*)

Table 1. (*continued*)

Attributes	Indoor hotspot scenario	Dense urban scenario	Urban macro scenario
BS antenna elements	Up to 256 Tx and Rx antenna elements (64 or 128 is recommended)	Up to 256 Tx and Rx antenna elements (64 or 128 is recommended)	Up to 256 Tx and Rx antenna elements (64 or 128 is recommended)
UE antenna elements	Up to 8 Tx and Rx antenna elements (4 is recommended) for sub 6 GHz	Up to 8 Tx and Rx antenna elements (4 is recommended) for sub 6 GHz	Up to 8 Tx and Rx antenna elements (4 is recommended) for sub 6 GHz
User location and speed	100% indoor, 3 km/h	100% outdoor, 3 km/h	80% indoor (3 km/h) and 20% outdoor (30 km/h)
Traffic type	Full buffer traffic or non-full buffer traffic depends on the scenario	Full buffer traffic or non-full buffer traffic depends on the scenario	Full buffer traffic or non-full buffer traffic depends on the scenario
Inter site distance	20 m	200 m	500 m

In the 5G-DRIVE project, the collected test data from the two regions (EU and China) will be analysed and compared for interoperability purposes. Therefore, some general trial setup requirements should be listed so that to harmonize the trial development facilities at the various trial sites. The trials planned will cover several deployment scenarios, which include indoor hotspot, dense urban deployment and macro cells deployment. In order to achieve important results, there would have to be enough sites to fulfil the following: (i) Areas with excellent signal to noise ratio (SNR) and negligible interference for peak performance measurements; (ii) areas with poor SNR for minimum performance measurements, and; (iii) areas with low to very high interference for realistic interference measurements. For a dense urban macro deployment, the minimum number of sites would be different to that in an indoor or rural environment in order to achieve the above.

Table 1 illustrates descriptions of the three scenarios, as also provided by NGMN in [24], which will be employed as reference setups for the 5G-DRIVE trial sites, together with the relevant attributes. The indoor hotspot scenario focuses on high user density and high capacity/throughput in indoor small coverage areas. The dense urban scenario focuses on high use density and high traffic loads in city centres with outdoor coverage scenario. Finally, the urban macro scenario focuses on continuous coverage in urban areas.

3.2 KPIs for the Assessment of the eMBB Trials

In the following subsections we list the relevant 5G KPIs related to the radio access network and use as a reference for different trial sites to conduct trials under the same baseline. The sources of the KPI definitions come from various prior works such as: (i) the ITU-R M.2410-0 [23]; (ii) the NGMN 5G Trial and Testing Initiative Pre-commercial Network Trials Framework Definition [24]; (iii) 5G-PPP KPI definitions [25–30], *and*; (iv) the framework proposed by 3GPP in TS 28.554 [31]. Note that the KPIs defined in the above documents are used to provide a throughout performance evaluation of 5G systems, within a broader scope. However, considering the capability and availability of the trial facilities in the 5G-DRIVE project, only a selected set of KPIs will be later evaluated in this project. For this reason, we only list the KPIs relevant to the 5G-DRIVE trials and provide the test procedure. By following the common test procedure, the trial results from different trial sites can be compared. A selected set of KPIs are planned 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 KPI.

Data rate 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". They have the same meaning in this document. Thus otherwise explicitly mentioned, they are used exchangeable. There are several data rate KPIs related to the performance of 5G systems. In the 5G-DRIVE project, we will "address" peak data rate, user experienced data rate, and cell-edge user data rate. The definitions of these are given below.

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 (Physical) layer synchronization, reference and pilot signals, guard bands and guard times. In some documents, it is referred to the peak user throughput. The peak data rate can be derived from the simulation and theoretical analysis. In this project, we will measure the data rate through the trials. In this context, it is the maximum DL (Downlink)/UL (Uplink) data rate achievable for a single user located at the best location within a cell. Peak data rate is defined for a single mobile station. In a single band, it is related to the peak spectral efficiency in that band. Let W denote the channel bandwidth and SE_p denote the peak spectral efficiency in that band. Then the user peak data rate R_p is given by:

$$R_P = W \times SE_p \tag{1}$$

Peak spectral efficiency and available bandwidth may have different values in different frequency ranges. In case bandwidth is aggregated across multiple bands, the peak data rate will be summed over the bands. Therefore, if bandwidth is aggregated across Q bands then the total peak data rate is

$$R = \sum\nolimits_{i=1}^{Q} W_i \times SEp_i \tag{2}$$

where W_i and SEp_i (i = 1,…Q) are the component bandwidths and spectral efficiencies respectively. The peak data rate is defined for the purpose of evaluation in the eMBB usage scenario. In [23], the minimum requirements for peak data rate are as follows:

(i) Downlink peak data rate is 20 Gbit/s; (ii) Uplink peak data rate is up to 10 Gbit/s. Note that these requirements make assumptions on the 5G spectrum used in the system. In the project, the measurement results will depend on the availability of the spectrum and the trial setting, which may result in lower peak data rate values.

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. In case of one frequency band and one layer of transmission reception points (TRxP), the user experienced data rate could be derived from the 5^{th} percentile user spectral efficiency through the following equation. Let W denote the channel bandwidth and SE_{user} denote the 5^{th} percentile user spectral efficiency. Then the user experienced data rate, R_{user} is given by:

$$R_{user} = W \times SE_{user} \tag{3}$$

In case bandwidth is aggregated across multiple bands (one or more TRxP layers), the user experienced data rate will be summed over the bands. The target values for the user experienced data rate are as follows in the Dense Urban – eMBB test environment: (i) Downlink user experienced data rate is 100 Mbit/s; (ii) Uplink user experienced data rate is 50 Mbit/s. These values are defined assuming supportable bandwidth as described in [23] for each test environment. In the project, the measurement results will depend on the availability of the bandwidth.

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 used in the system. The average spectral efficiency is the aggregate throughput of all users divided by the channel bandwidth of a specific band divided by the number of TRxPs and is measured in bit/s/Hz/TRxP. In the NGMN trial framework document [24], it refers to cell edge coverage throughput, which is defined as the user data rate at the location of the cell edge with 1–3 dB lower path loss compared to control channel coverage limit (path loss limit).

Latency: As 5G will support ultra-low latency services, the latency is an important parameter to be evaluated in trials. 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: user plane latency and control plane latency. Depending on which part of user plane is targeted, the user plane latency can be the end-to-end latency, RAN latency and core latency [24]. The control plane latency under the 5G context is tightly related to the radio resource control (RRC) state transitions in the control plane. In this work, we only give the brief definition of these two latencies.

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. The RAN latency refers to the delay occurring in the RAN. It includes the time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 service data unit ingress point to the radio protocol layer 2/3 SDU egress point via the radio interface in both uplink and downlink directions, where neither device nor base station reception is restricted by discontinuous reception mode (DRX). The core latency refers to the round trip time between gNB and the Application Server. The minimum requirements (recommended by [23]) for the RAN latency are 8 ms for eMBB assuming unloaded conditions (i.e. a single user) for small Internet protocol (IP) packets (e.g. 0 byte payload + IP header), for both downlink and uplink.

Control plane latency refers to the transition time at the UE side from the idle or inactive RRC state to the start of continuous data transfer (e.g. Active state) [32]. The minimum requirement for control plane latency is 20 ms.

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. The cell peak throughput represents the maximum transmission capability of a single cell, without inter-cell interference from other cells. In the measurement of this KPI, all UEs will be placed in the locations with good channel quality. The cell average throughput represents the average transmission capability of a single cell, with the inter-cell interference from neighbouring cells. The tested UEs will be placed in different locations with different level of channel qualities. Among the UEs, the channel qualities to the gNB will be divided to four types: excellent, good, medium, and poor. The average capacity test should consider both UL and DL interference from other cells. In the cell capacity measurement, both single cell and multi-cell should be considered to reflect the cell capacity in different inter-cell interference.

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. Since the spectrum efficiency is obtained from the data rate measurement under a certain bandwidth configuration, the results from user throughput and cell capacity measurement can be used to derive the spectrum efficiency. The project will take into account three spectrum efficiency KPIs: (i) Peak spectral efficiency, derived from peak user rate test results; (ii) average spectral efficiency, derived from cell average throughput test results, *and*; (iii) cell edge spectrum efficiency, derived from Cell-edge user data rate test results.

Coverage: The coverage area of a mobile system is the geographic area where the base station and the user device can communicate. The 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. To evaluate the coverage of 5G system, the following aspects need to be taken into account: coverage gap between 4G and 5G, beamforming capability of 5G gNB (next generation NodeB) [8], downlink data/control channel coverage difference, and uplink coverage enhancement at UE. Depending on the setting of the trial networks, the following coverage can be evaluated: outdoor single-cell coverage, outdoor multi-cell continued coverage, outdoor to indoor coverage, and indoor coverage. Considering the capability of the trial sites in the project, we will focus on the outdoor single-cell coverage and indoor coverage evaluation.

Mobility is the maximum mobile station speed at which a defined QoS can be achieved (in km/h).The following classes of mobility are defined: (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. While the reliability is one of the main KPIs to evaluate URLLC performance, we will evaluate this KPI under eMBB trials. The minimum requirement for the reliability is $1-10^{-5}$ success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1 ms in channel quality of coverage edge for the Urban Macro-URLLC test environment, assuming small application data (e.g. 20 bytes application data + protocol overhead). The larger packet sizes, e.g. layer 2 PDU size of up to 100 bytes, may be considered in the trials.

Area traffic capacity is the total traffic throughput served per geographic area (in Mbit/s/m^2). 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. This can be derived for a particular use case (or deployment scenario) of one frequency band and one TRxP layer, based on the achievable average spectral efficiency, network deployment (e.g. TRxP (site) density) and bandwidth. Let W denote the channel bandwidth and ρ the TRxP density (TRxP/m^2). The area traffic capacity C_{area} is related to average spectral efficiency SE_{avg} through equation,

$$C_{area} = \rho \times W \times SE_{avg}. \tag{4}$$

In case bandwidth is aggregated across multiple bands, the area traffic capacity will be summed over the bands. The target value for area traffic capacity in downlink is 10 Mbit/s/m^2 in the Indoor Hotspot – eMBB test environment. The conditions for evaluation for the test environment are described in [23].

4 Conclusion

In the present work we have first delineate the importance and the multiple benefits coming from the 5G evolution, affecting both market growth and innovation. In particular, within the context of the effort for the development of the 5G NR, we have identified and discussed the critical role that eMBB has to realize, as a "promoter" of the first phase of the 5G, in parallel with standardization actions coming from the 3GPP. Thus, we have discussed the three fundamental sets of use cases comprising of eMBB, URLLC and mMTC and then we have primarily focused upon the eMBB that can be initially assessed as an extension to existing 4G services and will be among the first 5G services, which could be commercially available as early as 2019. Then we have focused on the specific framework of the actual 5G-DRIVE project funded by the European Commission, which promotes a framework for international research and cooperation between the European Union and China. Among the two core scenarios of this project is the realization of eMBB trials on the 3.5 GHz band for the support of suitable services such as AR/VR. Based on the 5G-DRIVE proposed methodology as well as to approaches proposed by the actual trends and/or bibliography, we have initially distinguished three scenarios which include indoor hotspot, dense urban deployment and macro cells deployment and we have propose corresponding attributes. With the aim of creating a framework for the effective support of the scheduled trials we have then identified and briefly discussed several corresponding KPIs. The 5G-DRIVE trials for the eMBB validation will be aligned to existing practices in order to make results comparable and meaningful.

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