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D3.1: eMBB Development and Test Plan

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Abstract

The focus of this document is to provide a tentative test plan for evaluation of the performance of enhanced Mobile Broadband (eMBB), in particular for the spectrum band at 3.5 GHz. The general trial setup requirements are given to harmonize between various trial sites. The detailed trial sites descriptions follow to explain the capability of each site to conduct different tests. The methodology and selected key performance indicators (KPIs) are also given, together with specific test plans of the eMBB trials in WP3.

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[1] http://creativecommons.org/licenses/by-nc-nd/3.0/deed.en_US

Executive Summary

This Deliverable D3.1 describes a tentative test plan for evaluating the performance of enhanced Mobile Broadband (eMBB), in particular for the spectrum band at 3.5 GHz, in WP3. The tests will be carried out at 5G-DRIVE trial sites and the general trial development setup is also given which helps to harmonize between the various trial sites.

The Deliverable is structured with the following distinct sections:

Section 1 gives an introduction of the WP3 trials with the objectives and the focus of this Deliverable.

Section 2 defines the general trial setup requirements with the considered test scenarios in WP3.

Section 3 descripts the 5G-DRIVE trial sites facilities in detail to help with an understanding of the capability of each site to conduct the different tests.

Section 4 discusses the methodology that will be employed in the WP3 tests, the considered KPIs, performance analysis, and specific test plan.

Section 5 summarises this Deliverable.

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Abbreviations

3GPP	The 3rd Generation Partnership Project
5G	The Fifth Generation of Mobile and Wireless Communications
5G PPP	5G Public Private Partnership
5GIC	5G Innovation Centre
5GTNF	5G Test Network of Finland
ADSL	Asymmetric Digital Subscriber Line
API	Application Programming Interface
ARM	Advanced RISC Machine
BAN	Body Area Network
BBU	Baseband Unit
BC	Boundary Clock
BNG	Broadband Network Gateway
BRA	Broadband Remote Access
BRAS	Broadband Remote Access Server
BS	Base Station
C-RAN	Cloud-RAN
CDF	Cumulative Distribution Function
CDR	Call Drop Rate
CEPT	European Conference of Postal and Telecommunications Administrations
CoMP	Coordinated Multi-Point
CP	Carrier Prefix
CP	Control Plane
CPE	Customer Premises Equipment
CPRI	Common Public Radio Interface
CPU	Central Processing Unit
CSCR	Call Setup Complete Rate
CU	Central Unit
DL	Download
DPI	Deep Packet Inspection
DRX	Discontinuous Reception
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DU	Distributed Unit
DWDM	Dense Wavelength Division Multiplexing

E2E	End-to-End
EC	European Commission
eCPRI	enhanced Common Public Radio Interface
EDGE	Enhanced Data rates for GSM Evolution
eMBB	enhanced Mobile Broadband
eNB	eNodeB
EPC	Evolved Packet Core
ETSI	European telecommunications Standards Institute
EU	European Union
FDD	Frequency Division Duplex
FRP	Filter Result Packet
FTP	File Transfer Protocol
FTTC	Fiber to the Cabinet
FW	FireWall
GA	Grant Agreement
GPS	Global Positioning System
GSM	Global System for Mobile Communications
IEEE	Institute of Electrical and Electronic Engineers
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
IoT	Internet of Things
IP	Internet Protocol
IPv6	IP version 6
IPTV	IP Television
iSCSI	Internet Small Computer System Interface
ISDN	Integrated Services Digital Network
ISP	Internet Service Provider
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union - Radiocommunications Sector
LoRa	Long Range
LoRaWAN	Long Range WAN
LTE	Long-Term Evolution
KPI	Key Performance Indicator
LAN	Local Area Network
LoS	Line-of-sight
LTE	Long Term Evolution

MANO	Management and Orchestration
MEC	Mobile Edge Computing
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
MPLS	Multiprotocol Label Switching
MPLS-TP	Multiprotocol Label Switching - Transport Profile
MTU	Max Transfer Unit
NB	NarrowBand
NB-IoT	NarrowBand-Internet of Things
NGA	Next Generation Access
NGC	Next Generation Core
NFV	Network Functions Virtualisation
NGMN	Next Generation Mobile Networks
NLoS	Non-Line-of-Sight
NOMA	Non-Orthogonal Multiple Access
NR	New Radio
NSA	Non-Standalone
OTE	Over-The-Air
OS	Open Source
OSM	Open Source MANO
OTDOA	Observed Time Difference of Arrival
PC	Personal Computer
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PHY	Physical Layer
PING	Packet Internet Groper
PIX	Private Internet eXchange
PoC	Proof of Concept
PON	Passive Optical Network
PoP	Point of Presence
POTP	Packet Optical Transport Platform
POTS	Plain Old Telephone Service
PTP	Precision Time Protocol
QoS	Quality of Service
R&D	Research and Development
RAM	Random Access Memory

RAN	Radio Access Network
RF	Radio Frequency
RIA	Research and Innovation Action
RISC	Reduced Instruction Set Computing
RRH	Remote Radio Head
RRC	Radio Resource Control
RRU	Remote Radio Unit
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RTT	Round Trip Time
RSL	Radio Spectrum Laboratory
RWin	Receive Window
Rx	Reception
SA	Standalone
SAS	Serial Attached SCSI
SC	Small Cell
SCSI	Small Computer System Interface
SDH	Synchronous Digital Hierarchy
SDN	Software Defined Networking
SDU	Service Data Unit
SINR	Signal-to-Interference-plus-Noise Ratio
SNR	Signal to Noise Ratio
STB	Set Top Box
TAI	International Atomic Time
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TEID	Tunnel Endpoint Identifier
TP	Time Plane
TP	Transport Profile
TR	Technical Report
TRxP	Transmission Reception Point
Tx	Transmission
UE	User Equipment
UL	Upload
UP	User Plane
URLLC	Ultra-Reliable Low-Latency Communications

USRP	Universal Software Radio Peripheral
UTC	Coordinated Universal Time
UTDOA	Uplink-Time Difference of Arrival
V2X	Vehicle-to-Everything
vBBU	virtualized Base Band Unit
VDSL	Very-high-bitrate DSL
VELA	Vehicle Emissions Laboratory
VLAN	Virtual LAN
VM	Virtual Machine
VoD	Video on Demand
VoIP	Voice over IP
VPLS	Virtual Private LAN Service
VPN	Virtual Private Network
WAN	Wide Area Network
Wi-Fi, WiFi	Wireless Fidelity
WiMax	Worldwide Interoperability for Microwave Access
WP	Work Package
WWW, www	World Wide Web

1 Introduction

Although the fifth generation (5G) of mobile and wireless communications is intended to support a wide range of services, enhanced mobile broadband (eMBB) is expected to be the first commercial use of the technology [1]. In the 5G-DRIVE project, the aim of work package (WP) 3 is to build pre-commercial end-to-end (E2E) testbeds with sufficient coverage to evaluate the performance of eMBB, particularly for the spectrum band at 3.5 GHz. With the considered very high data-rate use cases and architectures, which are defined in Deliverable D2.2 of WP2, the objectives of WP3 in 5G-DRIVE are listed as below:

1) setup 5G-DRIVE trials with focus on eMBB in various trial sites,
2) integrate several 5G radio access and network technologies into trials subject to equipment availability in various trial sites,
3) test and validate the communication systems developed in 5G-DRIVE in various trial sites,
4) analyse the spectrum usage of eMBB services at 3.5 GHz,
5) implement and evaluate the proposed research outcomes from WP5 subject to equipment availability in various trial sites,
6) define and perform eMBB joint trial with the twin Chinese project,
7) jointly analyse the various trials in the two regions and "conduct" recommendations and prepare the final report.

In Deliverable D3.1, the aim is to provide a tentative eMBB trial plan to cover the objectives 1) to 5), listed as above. Objectives 6) and 7) relate to the joint trial specification and will be reported in the forthcoming Deliverable D3.2 ("Joint specification for eMBB trials"). To approach this goal, the Deliverable D3.1 is organized to cover the following parts for eMBB trials in WP3:

- trial setup requirement with focus on eMBB,
- trial sites descriptions for harmonizing different partners conducting trials in various locations,
- a methodology for the trials activities to help to improve efficiency and success of the different trials activities,
- selected key performance indicators (KPIs),
- performance analysis strategy,
- tentative eMBB test plans for 5G New Radio (NR), as developed by the 3rd Generation Partnership Project (3GPP), with the consideration of facility availability in various trial sites.

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.). Detailed KPIs and use cases will also be defined and discussed in the respective Deliverable D2.2 in WP2. Subject to the availability of trial sites, the non-standalone (NSA) version of 5G NR (delivered by 3GPP in December 2017) or the standalone (SA) version of 5G NR (delivered by 3GPP in July 2018) will be chosen accordingly.

The collected data of tests will be compared with the targeted requirements and expected performance defined in 3GPP release 15, or release 16,or ITU-RM.2410-0-[5], subject to the individual requirement of each trial. The PASS/FAIL threshold definition for each test could be discussed and published through a 5G-DRIVE white paper or through other publication.

2 Trial setup requirements

In this section, the trial setup requirement considered in the 5G-DRIVE WP3 will be specified, with all the practical considerations.

2.1 General requirements

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. Moreover, in the 5G-DRIVE project, the collected test data from the two regions will be analysed and compared for interoperability purposes. Therefore, some general trial setup requirements should be listed so as that to harmonise the trial development facilities at the various trial sites. In the 5G-DRIVE framework, WP3 will employ the 5G trial and testing pre-commercial network trials framework provided by NGMN [2] for our tests as listed below.

2.1.1 Deployment setup

The trials planned in WP3 will cover several deployment scenarios, which include dense urban deployment, indoor hotspot and macro cells deployment. The minimum number of cells/site will vary depending on the deployment scenario, trial sites capability described in Section 3, and the nature of the planned test described in Section 4. In order to achieve important results, there would have to be enough sites to fulfil the following:

- areas with excellent signal to noise ratio (SNR) and negligible interference for peak performance measurements,
- areas with poor SNR for minimum performance measurements,
- 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.

The trials conducted in the 5G-DRIVE project will be in either the SA or the NSA architecture subject to trial availability. In the NSA architecture, the trials need to consider collocated and non-collocated NR and long-term evolution (LTE) radio suites to test the dual connectivity between both technologies.

Inter-network element distances should be close to real operational distances (i.e., radio -- core network -- servers). Notably the backhaul distances (over several km) should be indicated in the trial reports for ensuring a fair assessment of various latencies.

2.1.2 Traffic requirement

Generating a realistic traffic load in the trial is important for meaningful results. However, the number of available test user equipment (UE) is always a limiting factor. Therefore, generating artificial load and interference transmission can be used to limit the number of UEs.

2.1.3 Trial network setup and IP configuration for TCP

A typical 5G pre-commercial trial networks consists of the following parts:

- access domain, the aggregation domain (this is where the multi-access edge computing (MEC) option and the virtualized base band unit (vBBU) are located),
- the core network (evolved packet core (EPC) or next generation core (NGCore)),
- the application server.

The IP configuration for the trial network can be left for each trial site to set up according to their local or remote IP network configuration. However, in order to ensure comparable test results in terms of throughput and latency between various trials, some common IP configuration for the applications used in the trial must be utilized. Therefore, the IP configuration between the UE (and the host operating system running the application) and the application server is common. The following guidelines can be used to ensure a common setup.

- Main IP configuration parameters for TCP are shown in Table 1.
- The assumed operating system for the host application used in the trial setup at the UE side is *Windows 7* or according to the trial facility.
- The optimum TCP receive window (RWin) depends on the latency and the bandwidth of the underlying connection between the connection between the application server and the UE.
- In a trial there are varying expectations for the latency and bandwidth, depending on the service types and the deployment scenario.

The target latency and bandwidth for each of the deployment scenarios are as follows:

- E2E latency for the eMBB use case is less than 15ms,
- expected data rate for wide area deployment at operating frequency below 6 GHz with channel bandwidth of 100 MHz is 3Gbps/1.5GBps for DL/UL.

In varying E2E latency conditions, there is no fixed optimum value for setting the RWin parameter. As such, it is therefore recommended that the RWin is estimated according to the formula in [2]

$$Bandwidth\ (kbps)/8 * Average\ Latency\ (msec) = RWIN\ Size\ (Bytes), \quad (1)$$

and it should be reported with the test result in order to allow comparison and analysis of the test results. The optimum RWin is best setup based on the latency in the network employing the formula (1).Using packet Internet groper (PING) tool to find the optimal RWin Size, the ISP can be pinged with the max transfer unit (MTU) size. The average latency can be obtained using the PING function. The E2E latency parameters are given in Table 1 provided in [2]. If the 5G-DRIVE trial sites need to modify them according to the equipment facility, the new setup needs to be provided in the final Deliverable D3.3 for calibration of results.

Parameters	Value setup at application server	Value set at the UE PC
Operating system		***Windows 7***
TCP receiving windows (RWin)		**Using the formula (1)**
Default sent window		**Consistent with RWin**
MTU size	**1446**	**1446**
Selective Acks		**Yes**
Max duplicate Acks		**2**

Table 1: E2E latency parameters for TCP

Once the RWin is estimated, the following settings are recommended:

- Use the same MTU value at both sides to limit the impact of fragmentation and defragmentation processes on latency.

- At server side, the sending window should be set at a value above the RWin.
- When available, at the FTP server side:
    - Ensure Tx socket size is >= RWin (of the receiving side).
- Ensure internal buffet size is set to a low value (around 10% of Tx socket size).

2.1.4 Reporting requirement

The conducted WP3 eMBB trial results will be analysed within the 5G-DRIVE consortium and also together with the Chinese project, to validate the interoperability. Therefore, the trial reporting is a critical step and should contain sufficient detail such that each trial will provide a meaningful benchmark and comparison of the results. To approach this important goal, WP3 partners are encouraged to report as many details are possible about their tests. The following aspects are recommended by NGMN in their framework definition in [2], which could be used as a “template” for the case of 5G-DRIVE WP3.

- Trial setup information

  Following deployment parameters need to be reported for each trial:
    - carrier frequency
    - operating bandwidth
    - duplex mode (e.g., FDD TDD)
    - sub-carrier spacing
    - carrier prefix
    - slot length
    - number of sites and test UEs
    - type of environment (dense urban, urban, rural…)
    - site locations including coordinates and height information and a map with the site layout
    - test UEs location and height information
    - base station (BS) and UE transmit power and antenna gain
    - BS and UE antenna configuration (number of antenna, layout)
    - BS and UE number of supported MIMO layers
    - traffic type used for the trial.
- Trial result information
    - The counters to be logged at the BS and UE sides are specified for each test case.
- Trial result benchmarking
    - Choosing a baseline for benchmarking the performance of 5G NR is crucial. Depending on our trial sites facilities and individual test design, 3GPP Rel.15 or Rel. 16 is chosen accordingly as benchmark to help quantify the gains of NR as compared to LTE of the same release with the focus on eMBB aspects in WP3.

Moreover, the benchmark is ideally based on trial results with the same setup. However, a different trial setup could be acceptable as long as the differences between the two systems are well described and accounted for, e.g., the different operating frequency setup between EU and China. Finally, simulation results may also be used as a benchmark if trial results are not available in some cases.

2.2 Deployment scenarios

Three deployment scenarios are addressed here for WP3 eMBB trial consideration in the 5G-DRIVE project, which are indoor hotspot, dense urban and urban macro. Below, are the descriptions of the three scenarios, as also provided by NGMN [2], which will be employed as reference setups for our trial sites in WP3.

- Indoor hotspot

  This scenario focuses on high user density and high capacity/throughput in indoor small coverage areas. Scenario specific deployment attributes and expected values are listed in Table 2.

Attributes	Expected values
Carrier Frequency	Sub 6 GHz (around 3.5 GHz)
Aggregated system bandwidth	100 MHz for sub 6 GHz
Sub-carrier spacing	30 kHz for sub 6 GHz
Carrier prefix (CP) length	2.3 us
Slot length	0.5 ms (14 symbols), 0.25 ms (7 symbols) for sub 6 GHz
Number of Layers	1
BS antenna elements	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
User location and speed	100 % indoor, 3km/h
Traffic type	Full buffer traffic or non-full buffer traffic depends on the scenario
Inter site distance	20 m

Table 2: Indoor hotspot deployment attributes

- Dense Urban

  This section focuses on high use density and high traffic loads in city centres with outdoor coverage scenario. Scenario specific deployment attributes and expected values are listed as below in Table 3.

Attributes	Expected values
Carrier Frequency	Sub 6 GHz (around 3.5 GHz)
Aggregated system bandwidth	100 MHz for sub 6 GHz
Sub-carrier spacing	30 kHz for sub 6 GHz
Carrier prefix (CP) length	2.3 us

Slot length	0.5 ms (14 symbols), 0.25 ms (7 symbols) for sub6 GHz
Number of Layers	2
BS antenna elements	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
User location and speed	100 % outdoor, 3km/h
Traffic type	Full buffer traffic or non-full buffer traffic depends on the scenario
Inter site distance	200 m

Table 3: Dense urban deployment attributes

- Urban macro

  This section focuses on continuous coverage in urban areas. Scenario Specific deployment attributed and expected values are listed in Table 4.

Attributes	Expected values
Carrier Frequency	Sub 6 GHz (around 3.5 GHz)
Aggregated system bandwidth	100 MHz for sub 6 GHz
Sub-carrier spacing	30 kHz for sub 6 GHz
Carrier prefix (CP) length	2.3 us
Slot length	0.5 ms (14 symbols), 0.25 ms (7 symbols) for sub6 GHz
Number of Layers	1
BS antenna elements	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
User location and speed	80% indoor (3km/h) and 20% outdoor (30km/h)
Traffic type	Full buffer traffic or non-full buffer traffic depends on the scenario
Inter site distance	500 m

Table 4: Urban macro deployment attributes

2.3 Equipment availability

In our pre-commercial trials there will only be a few testbed based UE available be used for tests, which lack standard certification and testing. It is noticed that this factor will introduce some bias into our trial tests. However, since the goal of WP3 trial is to test the 5G network rather than the UE, we will not setup a calibration baseline to determine which contribution is coming from the UE, or network as recommended by NGMN in same situation.

3 Trial Sites Description

This section describes the four trial sites involved in the eMBB trial activities in the context of the 5G-DRIVE EU development and test plan.

3.1 Joint Research Centre (Ispra, Italy)

The JRC Ispra site is a fully fenced, 167-hectare research campus for hands-on experimentation, testing and demonstration purposes. It features 36 km of roads under real-life driving conditions, 9 Vehicle Emissions Laboratories[2] (VELA 1-9) for calibration and electromagnetic compatibility/interference testing, and several anechoic chambers of various sizes for conducting radio frequency (RF) measurements in a clean channel environment.

The JRC is also host to the Radio Spectrum Laboratory[3] (RSL), a research facility focusing on experimental RF activities both at the laboratory and field test levels. The goal of the RSL is to provide scientific and technical support to the European Commission (EC) in policy matters related to the efficient use of the radio spectrum across all EU Member States. In addition, RSL staff contributes to various technical groups in Standards Development Organisations (e.g., ETSI) and international coordinating bodies (e.g., the CEPT, the EU Radio Spectrum Committee, etc.).

Figure 1: Map of the JRC Ispra site

[2] For more details also see: *https://ec.europa.eu/jrc/en/research-facility/vehicle-emissions-laboratory-vela*

[3] Also see, *inter-alia*: *https://ec.europa.eu/jrc/en/research-facility/radio-spectrum-laboratory-rsl*

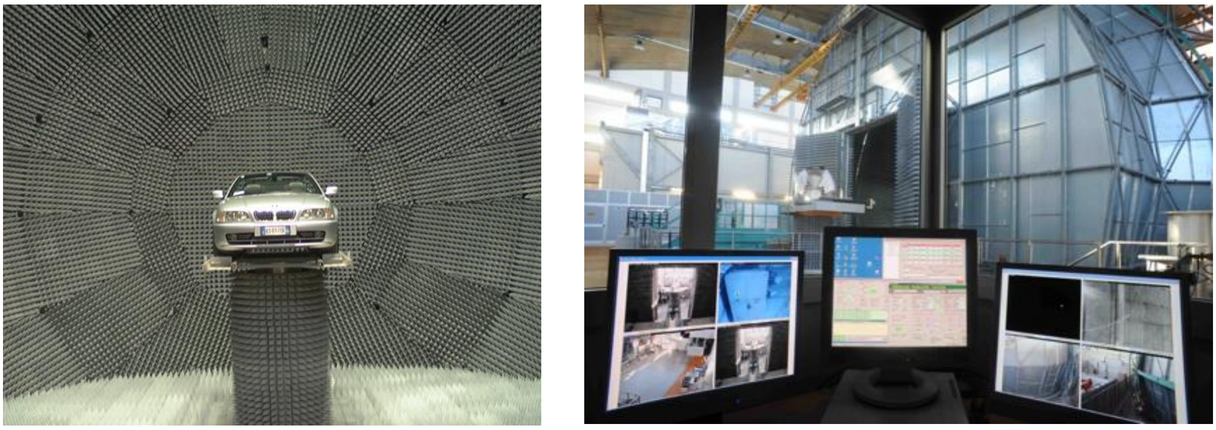

Figure 2: The large anechoic chamber at the Joint Research Centre Ispra campus

Figure 3: The small shielded anechoic chamber at the Joint Research Centre Ispra campus

In the context of 5G-DRIVE's eMBB trials, the JRC plans to focus on the performance characterisation of commercial 5G NR base stations delivering eMBB services in the 3.5 GHz band. In practice, this will entail conducting RF measurements (such as duty cycle, adjacent channel interference, coverage maps, etc.) using IQ data captured in the 5GIC testbed at the University of Surrey (see Section 3.3).

3.2 VTT (Espoo, Finland)

VTT's current infrastructure of integrated 5G testbeds is illustrated in Figure 4. The testbeds are distributed between premises located in Espoo and Oulu and connected by an optical fibre backbone. The infrastructure forms a dynamic and heterogeneous platform for developing and testing new applications, services, algorithms, technologies, cognitive management functionalities and system testing tools. In order to facilitate collaboration with other parallel research and industry projects and test infrastructures, this flexible and evolving 5G platform is already offered with standardized interfaces for third party equipment and service integration.

The Espoo trial site provides 5G testing facilities built in several national projects under the 5GTNF[4] (5G Test Network of Finland) framework. In the context of the 5G-DRIVE project effort, it will focus on the development and evaluation of both eMBB and V2X scenarios. The current network

[4] For more details, see: *http://5gtnf.fi/*

infrastructure is built on top of Nokia's NetLeap LTE test network[5]. It will be gradually upgraded to 5G networks when 5G NR and 5G core network components are available.

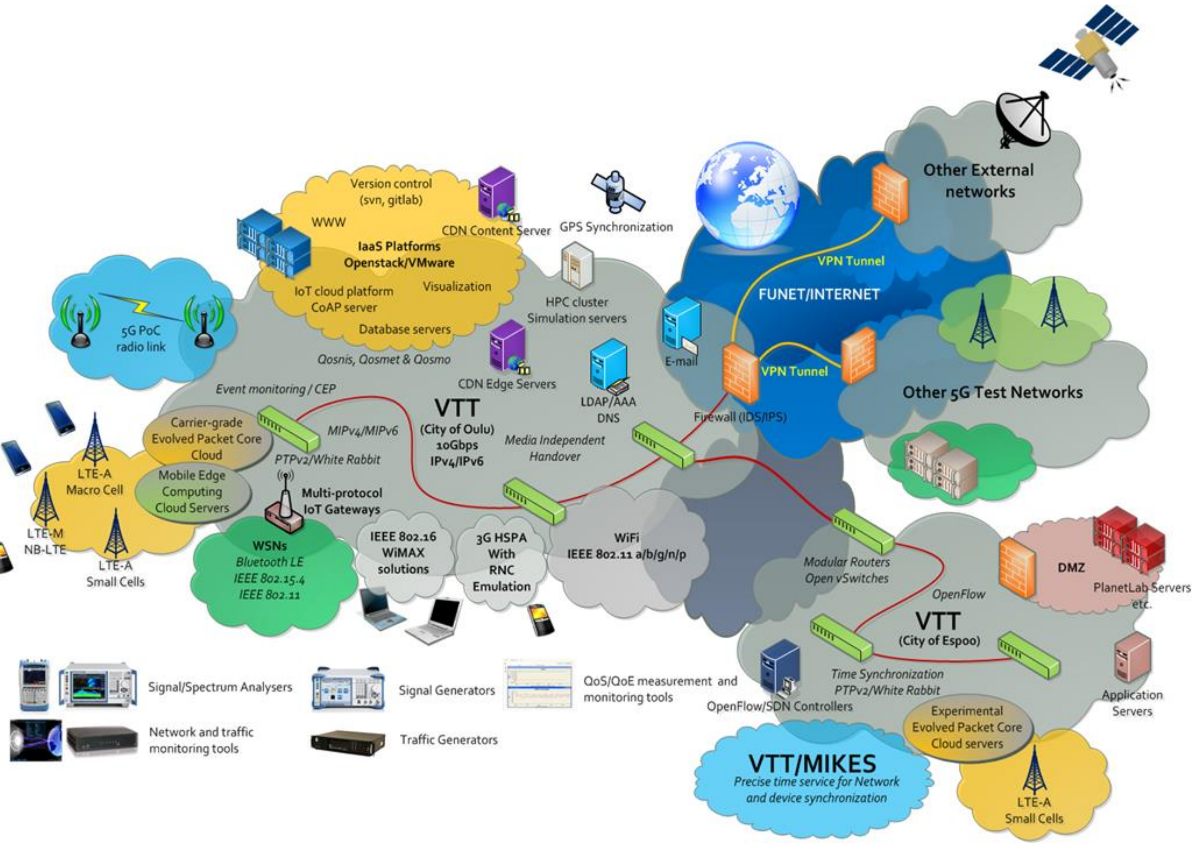

Figure 4: VTT's integrated testbed infrastructure

The current infrastructure supports research areas ranging from the programmable core network infrastructures, including the utilization of the software defined networking (SDN) and network functions virtualization (NFV) concepts, to dense and heterogeneous access network configurations with various short-range technologies, small cells, and Internet of Things (IoT) use cases. The core network comprises of a carrier grade telco cloud part that can be utilised for research and development requiring high capacity and limited amount of re-configurability, and of an open source core network implementation[6] (OpenEPC) that provides additional flexibility with more limited capacity. The radio access network contains a cellular component based on technologies in the LTE evolution path, as well as 5G prototype radios using new frequency ranges and air interface configurations not currently found in standardised technologies. In addition, various short-range radio technologies can be used to access the network. The existing infrastructure consists of several commercial indoor LTE pico cells, programmable OpenFlow software switches[7] running on commodity x86 servers[8], and a small-scale OpenStack installation for applications and services deployment. There is also a testbed for mm-wave backhaul development that consists of a group of interconnected network processor platforms emulating a wireless mesh backhaul. Finally, Nemo tools[9] are used for measuring the coverage and quality of wireless networks such as cellular and WiFi.

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5 For more details also see, *among others*: *https://www.aalto.fi/aalto-digi-platform*

6 Related information can also be found, *inter-alia*, at: *https://www.openepc.com/*

7 For further details see, *for example*: *http://yuba.stanford.edu/~casado/of-sw.html*

8 For further clarification also see, *among others*: *https://www.oracle.com/servers/x86/*

9 See, *for example*: *https://www.keysight.com/en/pc-2767981/nemo-wireless-network-solutions?pm=LB&nid=-32102.0&c=206738.i.1&no=0&to=79830.g.0&cc=FR&lc=fre*

The network contains both indoor and outdoor eNodeBs operating at 2.6 GHz, lamppost integrated small cell networks operating at 3.5 GHz and mm-wave bands at 26 GHz, as well as Wi-Fi networks operating at unlicensed 2.4 GHz and 5 GHz. This site enables creating a virtual mobile network with its own evolved packet core (EPC) and can utilize the edge computing platform for developing localized services. The design of the test network is such that it is open for experimental EPCs. This enables multi-operator scenarios and testing of network slicing in the project. MEC platforms are currently being installed at the Otaniemi site. With the aid of an artificial delay element (network emulator), the performance of MEC for URLLC use cases can be tested in different latency scenarios. eNodeBs are connected to a 10Gbps SDN-enabled backhaul and to an OpenStack[10] cloud environment. The Espoo testbed provides facilities and test environments for SDN/MEC, indoor positioning, latency reduction, reliability and other technology topics targeted by the 5G-DRIVE.

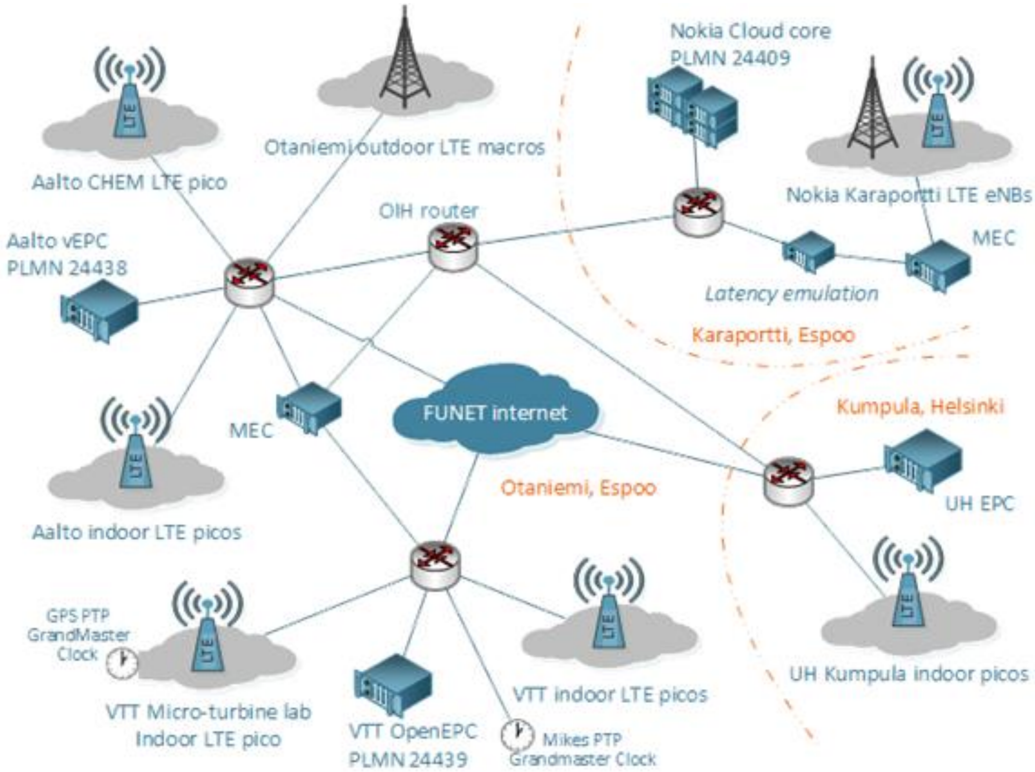

Figure 5: 5G testbed connections at the Espoo site.

The testbed exploits also a timing signal from VTT MIKES Metrology[11] as shown in Figure 5. The timing signal is generated from atomic clocks and is delivered over fibre network using Precision Time Protocol (PTP) based synchronization technology. This timing information is used for high accuracy one-way latency measurements, time based positioning, and synchronization of sensors, actuators, and other timing dependent devices.

10 See: *https://www.openstack.org/*

11 For more details see: *https://www.mikes.fi/en*

3.3 5GIC (Surrey, United Kingdom)

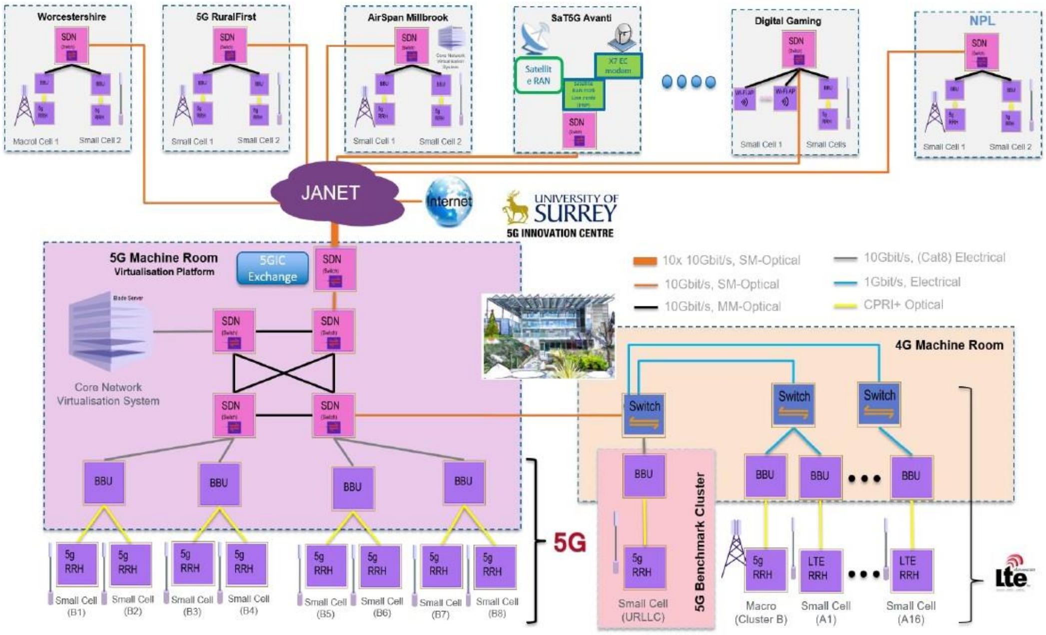

Figure 6: 5GIC Ultra dense campus testbed

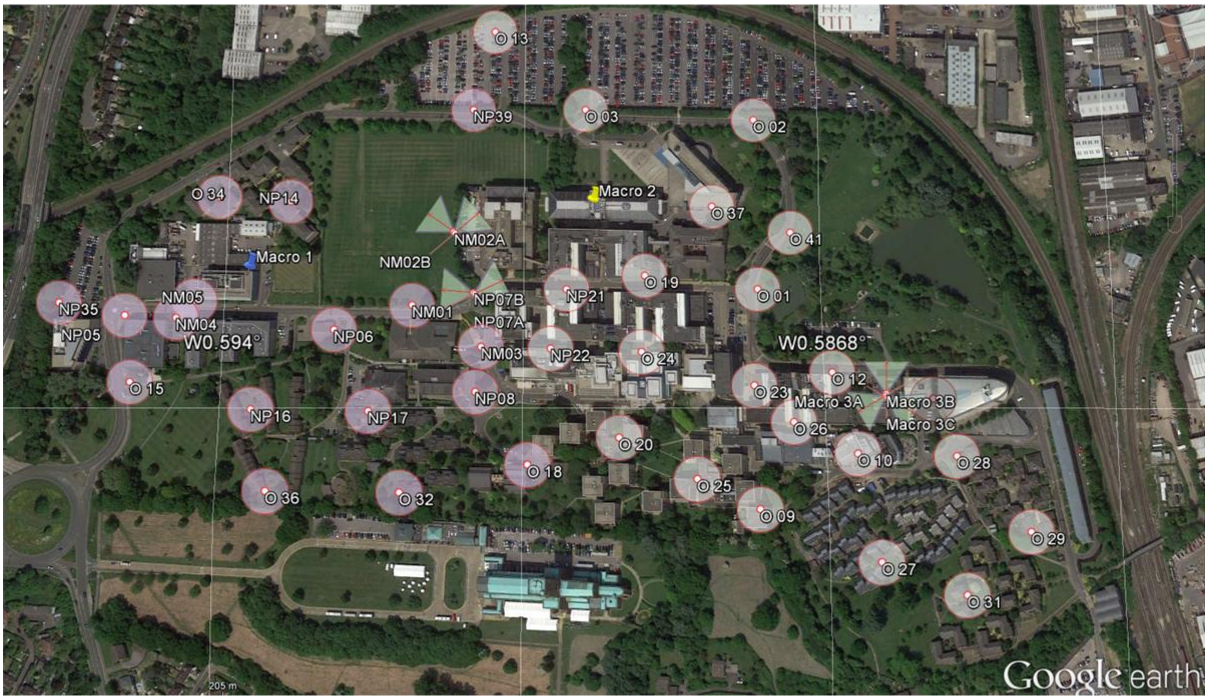

Figure 7: Aerial view of the 5GIC testbed

5G Innovation Centre[12] (5GIC) targets on providing state-of-the-art 5G test and demonstration platforms, which include a Cloud-RAN (C-RAN) test platform to supports clusters of remote radio heads (RRH) supported by high performance core processing facilities for experimental research on advanced techniques such as joint transmission coordinated multi-point transmission and reception (CoMP) schemes. In addition, the test network provides a unique environment to test operation of

[12] For more details also see: *https://www.surrey.ac.uk/5gic*

heterogeneous access networks in a real life environment. In the context of the 5G-DRIVE, it will focus on the development and evaluation of the eMBB scenario.

As shown in Figure 6, the testbed is connected to the Vodafone Core Network, and covers a 4 km^2 area for the testing of 5G technologies. The coverage area encompasses a stretch of motorway, dense urban radio environments. The outdoor deployment consists of 44 sites and 65 cells (of which 3 are macro cells, the remainder are small and ultra-dense cells as shown in Figure 7). This end-to-end testbed incorporates a different range of frequency bands (3.5 GHz, 28 GHz, and 60 GHz) and allows the testing and trialling of new air-interface solutions. Supported by a mix of wireless and fibre optic backhaul connectivity, trials can be matched to meet industry requirements.

3.4 OTE (Athens, Greece)

OTE’s Research & Development Department, Fixed & Mobile, is involved in almost all technological and infrastructural issues that pertain to OTE’s operations, in cooperation with other OTE Functional Units depending on the nature and/or the requirements of each specific R&D activity. OTE’s current R&D activities span a wide range of topics, including, *inter alia*, broadband technologies and services, next generation network architectures, infrastructure development etc., following the actual challenges for the development of a fully competitive network infrastructure & a portfolio of innovative services/facilities.

OTE’s R&D activities are also supported by four research laboratories of the Labs and New Technologies Division, Fixed

- *Wireless/Satellite Communications Lab;*
- *Core Network Lab;*
- *Access Network Lab, and;*
- *Voice/VoIP/IMS Lab.*

The Labs are fully equipped with an immense variety of modern equipment, able to perform tests/trials and several validation processes and thus to support modern research activities.

OTE provides reliable and quality communication to all people in Greece, even in the most remote and inaccessible areas of the country, utilizing more than 35.000 km of optical fibres, numerous satellite, underwater and terrestrial international links. Infrastructure is also continuously upgraded, following the latest technological developments. In the Figure 8 the Urban High level Network Architecture is depicted.

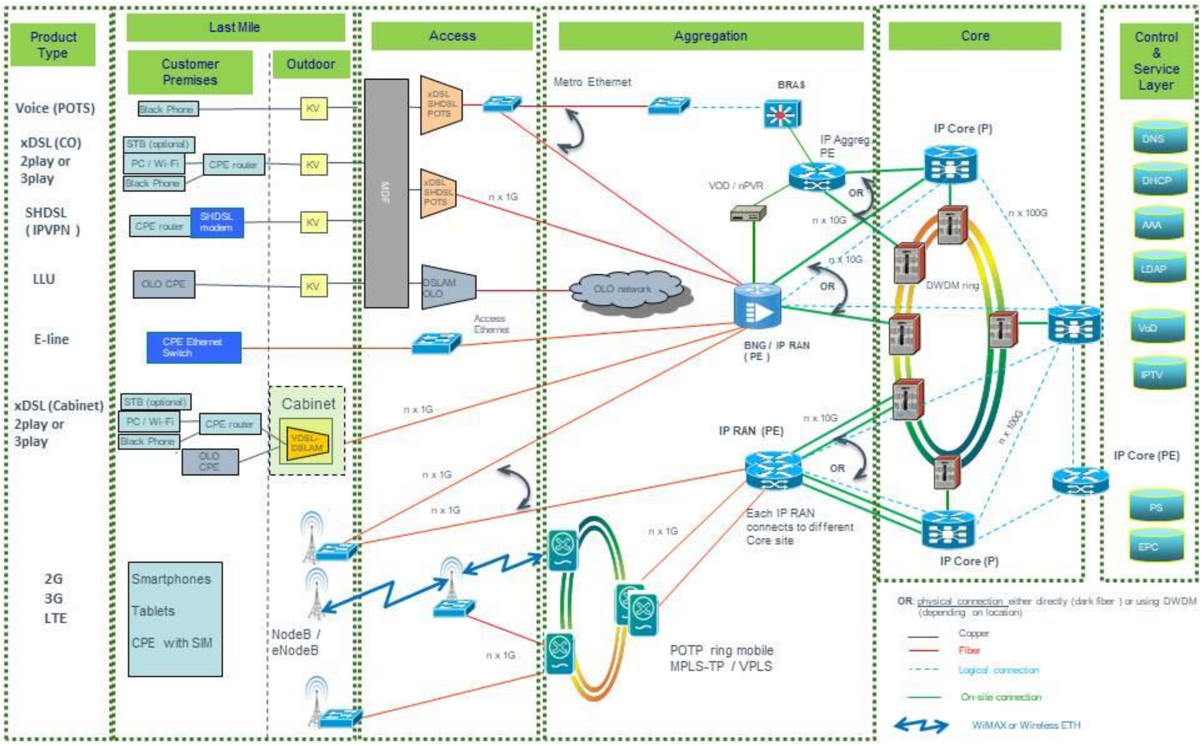

Figure 8: Urban high level network architecture

OTE's Network is configured in aggregation, access and core network. The core is routing traffic from cells sites (or points of presence - PoPs) into the core network. It has higher speed to transfer large information sent from various terminal equipment. Backhaul parts as well as access parts can be via wired or wireless solutions. It should also be noted that mesh connectivity is used among many nodes in order to avoid congestion, provide load balancing and avoid single points of failure.

All services provided by OTE are located in the control and service layers. These services could be telephony services and IMS, users' authentication, address assignment, IPTV etc.

Core network is the platform that serves all the services offered by OTE Group and aims to connect all kinds of circuits from the access network to the aggregation and Core network (and vice versa). The core network of OTE Group includes Next-Generation Synchronous Digital Hierarchy (NG-SDH) rings, Metro Ethernet nodes and mobile links and Dense Wavelength Division Multiplexing (DWDM) optical rings. The IP/MPLS-based network consists of 7 (dual) core nodes. Three core nodes are also interconnected (in a resilient way) with our upstream provider (i.e., OTE's subsidiary company OTEGlobe[13]) in order to provide global Internet connectivity.

100 Gbps links have been introduced between core nodes, as well as between IP core & OTEGlobe. OTE's IP network is topologically very close to the TeraStream concept (only 2 IP nodes between customers and services, IPv6 support end-to-end) which the target architecture is for all national companies (NatCos) in the DT (Deutsche Telekom) Group of Companies (where OTE is an active member). OTE is also in the process of consolidating the IP core networks of OTE & Cosmote[14] (Cosmote is OTE's subsidiary company offering mobile services), further enhancing the footprint of IP network and creating economies of scale.

[13] For further details about OTEGlobe also see: *http://www.oteglobe.gr/el*

[14] See: https://www.cosmote.gr/

In OTE's aggregation network, there are more than 100 BNGs/BRASs that aggregate the broadband traffic and several other big routers dedicated to business services (i.e.: SYZEFXIS[15], VPNs, LL, etc). All BNGs/BRASs are connected to diverse core nodes with at least 2x10 Gbps links. The core nodes themselves are interconnected by Nx10 Gbps links to ensure the maximum possible quality of service & reliability.

Transport network is part of aggregation, and serves all the services offered by OTE Group and aims to connect all kinds of circuits from the access network to the aggregation and core network (and *vice versa*). The transport Network of OTE Group includes Next-Generation Synchronous Digital Hierarchy (NG-SDH) rings and Metro Ethernet nodes, new OTE transmission network, which is being developed is based on the MPLS-TP protocol and on the POTP platform (Packet Optical Transport Platform). This new platform is flexible enough to serve all the Packet-based broadband services with flexibility and expandability in the necessary bandwidth.

The access network refers to the network segment that connects the subscriber to the Central Office (CO). It is based on copper cables which are gradually being replaced by optical fiber cables due to investment in NGA (Next Generation Access) network. Specifically, OTE deploys a modern NGA network based on Fiber to the Cabinet – FTTC architecture, which brings optical fiber cables and active VDSL2 equipment on outdoor cabinets and offers broadband access services of up to 50 Mbps bandwidth.

The basic available access technologies are:

- Copper: Ethernet is the most commonly installed wired LAN (local area network) technology. Ethernet LAN typically uses coaxial cable or special grades of twisted pair wires, xDSL POTS, ADSL, VDSL, ISDN, Metro Ethernet.
- Wireless Transmission: Cellular (2G/3G/4G), WiFi (802.11x), WiMax (802.16).
- Optical Fiber: PON, SDH. Metro Ethernet.

The last mile network is the final connectivity leg between the telecommunication service provider and an individual customer. Here signals are carried via any kind of digital medium from the broad along the relatively short distance (hence, the "last mile") to and from the home or business. Last-mile technologies include:

- Plain old telephone systems (POTS),
- ISDN,
- Digital Subscriber Line (DSL) over existing telephone twisted pair lines,
- Cable and the cable modem for data,
- Wireless, Cellular,
- Optical fiber and its transmission technologies.

Last but not least, OTE has a cloud testbed including the following:

- An Openstack-based cloud infrastructure (>220 CPU cores, >30 TB HDD, >340 GB RAM), consisting of 1 gateway, 5 controllers, 4 x86 + 2 ARM-based compute nodes, a VPN Server, a CISCO PIX FW[16], switches/routers, while being interconnected to OTE's Labs, providing thus additional capabilities for testing new technologies either for PoC or for field trials.
- Eight Nokia 4G/4G+/Wi-Fi Small Cells[17] (SCs) distributed in two floors.

[15] More details about this infrastructure and set of facilities can be found at: *http://www.syzefxis.gov.gr/*

[16] Also see: *https://www.cisco.com/en/US/docs/security/pix/pix30/user/guide/pixugint.html*

[17] For more details also see: *https://networks.nokia.com/products/small-cells*

- A flexible, scalable, E2E IoT platform –developed from scratch exclusively by OTE– including:
  - A wide range of end-devices/sensors such as, air-quality, temperature, humidity, pressure, activity, luminance, fire as well as power/energy ones, communicate with the backend (cloud) infrastructure over a wide range of short/long range technologies (Ethernet, Wi-Fi, z-wave, BLE, LoRaWAN[18], NB-IoT).
  - IoT hubs/gateways (local and remote – based on LoRaWAN) for facility automation and energy management/control (based on events/rules) supporting multiple HAN/BAN/LAN/WAN technologies/interfaces; over 150 Techs/protocols are currently supported.
  - A (common) backend infrastructure (including storage, monitoring/data visualization, command exchange, etc.).

[18] For further informative details also see: *https://www.thethingsnetwork.org/docs/lorawan/*

4 eMBB Trial Measurements and Plan

The purpose of this section is to describe both the partners' support for network performance evaluation and the initial plan for the target eMBB trials. Also described are some network performance evaluation criteria for different use cases, the required test equipment and their respective setups.

4.1 Methodology

This subsection provides a high-level view of the steps to carry out the target eMBB trials. The technical requirements and respective system functionality to support the eMBB use cases are initially identified and specified. The KPIs needed to measure success criteria for overall system functionality is then defined and these KPIs are used as basis to determine the test network setups for validating the eMBB use cases. Since each test network setup will require specific equipment, the test network setups are implemented by different partners based on their available facilities. The actual test measurements and results analysis for each of the test network setups will be executed in accordance to 3GPP recommendations, e.g. as referenced by the NGMN testing framework document [2]. The measurements and analysis results from each of the test network setups as well as the respective shared results from the Chinese twin Project are gathered for synthesis and conformance verification. Thereafter, a joint trial report on overall performance evaluation results will be generated. The following figure depicts the overall high-level view of these steps to carry out the target eMBB trials.

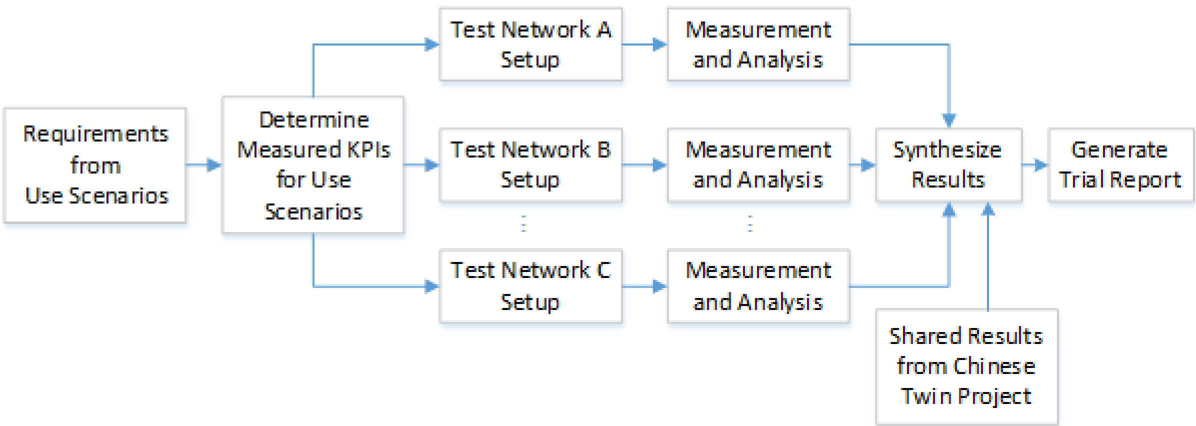

Figure 9: Methodology

4.2 KPIs relevant to eMBB trial in the project

The KPIs relevant to the 5G-DRIVE use scenarios are identified in the WP2. In this document, we list the relevant 5G KPIs related to the radio access network (RAN) and use as a reference for different trial sites to conduct trials under the same baseline. The sources of the KPI definitions come from ITU-R M.2410-0 [3], NGMN 5G Trial and Testing Initiative Pre-commercial Network Trials Framework Definition [2], 5G PPP Phase II KPI definitions [4, 14-18], and 3GPP [19]. 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 in the project. For this reason, we only list the KPIs relevant to the project 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. The 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 in the following subsection.

4.2.1 Data rate

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.

4.2.1.1 Peak data rate

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. 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/UL 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:

$$R_P = W \times SE_p \tag{2}$$

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

$$R = \sum_{i=1}^{Q} W_i \times SEp_i \tag{3}$$

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 ITU-R M.2410-0 [5], the minimum requirements for peak data rate are as follows[19]:

- Downlink peak data rate is 20 Gbit/s.
- 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.

4.2.1.2 User experienced data rate

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 5th percentile user spectral efficiency through the

[19] The baseline selection is subject to individual test and trial requirement.

following equation. Let W denote the channel bandwidth and SE_{user} denote the 5th percentile user spectral efficiency. Then the user experienced data rate, R_{user} is given by:

$$R_{user} = W \times SE_{user} \tag{4}$$

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:

- Downlink user experienced data rate is 100 Mbit/s.
- Uplink user experienced data rate is 50 Mbit/s.

These values are defined assuming supportable bandwidth as described in Report ITU-R M.2412-0 [5] for each test environment. In the project, the measurement results will depend on the availability of the bandwidth.

4.2.1.3 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 NGMN trial framework document [2], 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). In this document, we follow the NGMN definition in the trials.

4.2.2 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. 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 document, we only give the brief definition of these two latencies. For the more detailed information of control plane and user plane latency, please refer to NGMN trial framework document [2].

4.2.2.1 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 (SDU) 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 ITU M.2410-0) for the RAN latency are 8 ms for eMBB assuming unloaded conditions (i.e. a single user) for small IP packets (e.g. 0 byte payload + IP header), for both downlink and uplink.

The latency can be one direction or round trip time (RTT). In this project, for the user plane latency between the user terminal to Evolved Packet Core (EPC) in NSA case and Next Generation Core (NGC) in the SA case, the RTT for both RAN and end-to-end latency is considered.

4.2.2.2 Control plane latency

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). Referring to the 3GPP TR 38.913 [6], the RRC states related to the measurement of control plane latency are shown in Figure 10:

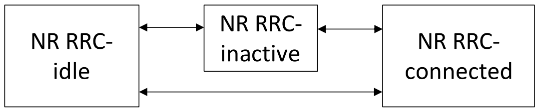

Figure 10: NR UE RRC stated and transitions

The minimum requirement for control plane latency is 20 ms.

4.2.3 Cell capacity

The 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.

4.2.4 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. 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 projects will three spectrum efficiency KPIs:

- Peak spectral efficiency, derived from peak user rate test results.
- Average spectral efficiency, derived from cell average throughput test results.
- Cell edge spectrum efficiency, derived from Cell-edge user data rate test results.

4.2.5 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, 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 continues 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.

In outdoor single-cell coverage test, the coverage performance will be tested in uplink and downlink, in control and data channels, in terms of both the maximum distances in line-of-sight (LoS) and non-LOS (NLOS) conditions and the corresponding data rates at cell edge.

In indoor coverage test, the test area will be the office building where the indoor 5G gNBs are installed. Both LOS and NLOS will be taken into account in the test.

4.2.6 Mobility

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:

– Stationary: 0 km/h
– Pedestrian: 0 km/h to 10 km/h
– Vehicular: 10 km/h to 120 km/h
– High speed vehicular: 120 km/h to 500 km/h.

Table 5 defines the mobility classes that shall be supported in the respective test environments.

Test environments for eMBB			
	Indoor Hotspot – eMBB	**Dense Urban – eMBB**	**Rural – eMBB**
Mobility classes supported	Stationary, Pedestrian	Stationary, Pedestrian, Vehicular (up to 30 km/h)	Pedestrian, Vehicular, High speed vehicular

Table 5: Mobility classes

A mobility class is supported if the traffic channel link data rate on the uplink, normalized by bandwidth, is as shown in Table 6. This assumes the user is moving at the maximum speed in that mobility class in each of the test environments.

Test environment	Normalized traffic channel link data rate (bit/s/Hz)	Mobility (km/h)
Indoor Hotspot – eMBB	1.5	10
Dense Urban – eMBB	1.12	30
Rural – eMBB	0.8	120
	0.45	500

Table 6: Traffic channel link data rates normalized by bandwidth

These values were defined assuming an antenna configuration as described in Report ITU-R M.2412-0 [5].

4.2.7 Reliability

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 $1\text{-}10^{-5}$ 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.

4.2.8 Area traffic capacity

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,

$$C_{area} = \rho \times W \times SE_{avg}. \tag{5}$$

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 including supportable bandwidth are described in Report ITU-R M.2412-0 [5] for the test environment.

4.3 Test procedure and reporting

In this subsection, we describe the test procedure and evaluation criteria for the KPIs listed in the previous section. To make the results comparable, it is important to use the same test procedure under the similar trial setting. This is particular important in order to also compare the results from the Chinese twin project. We use the KPI test methodology from the NGMN trial framework document [2] as the reference test methodology for 5G-DRIVE trials. The NGMN trial framework document [2] is jointly defined by mobile operators and is therefore an important methodology document for 5G pre-commercial trials. Depending on the trial settings in the project, which are limited by the availability of network equipment and deployment scenario, the test setup and procedure may be modified during the trials. The actual test setup and procedure will be reported in the trial result report.

4.3.1 Data rate

4.3.1.1 Peak data rate

<table>
<tr><td>Test ID:</td><td colspan="3">TST_DR_1</td></tr>
<tr><td>Test item:</td><td>Data Rate</td><td>Sub-item:</td><td>Peak data rate</td></tr>
<tr><td>Refer document:</td><td colspan="3">NGMN trial framework document [2]</td></tr>
<tr><td colspan="4">Test setup and conditions:
One UE will be placed in the tested gNB under the ideal channel condition. No other UEs should be placed in the surrounding cells. The test will be executed under the stationary scenario.
The reference configuration for the eMBB test under 3.5GHz include: 30KHz sub-carrier spacing, 2.3us CP length, 500us slot length for 14 symbols at 30kHz, 100 MHz bandwidth, for DL rate test by DL/UL ratio or minimum UL configuration if dynamic UL/DL switching not supported, and for UL peak rate test by DL/UL ratio or minimum DL configuration if dynamic UL/DL switching not supported.</td></tr>
<tr><td colspan="4">Test procedure:
1. Coverage of the test area defined as Received RSRP > -60 dBm and SINR > 22dBas measured with measurement tool.
2. Identify a location(s) where combination of highest MIMO rank modulation and coding rate can be attained with stability.
3. Ensure that there are no UEs connected in any of the surrounding cells.
4. Repeat steps 5-6 at each location with the UE static in that location.
5. Connect 1 UE to the sector and ensure there is only this UE connected to the sector.
6. Measure L1 and PDCP layer throughput
a. If dynamic UL/DL ratio is not supported, reconfigure the system for minimum UL DL/UL ratio
b. Download to the UE using UDP or TCP for DL peak test
c. Measure PDCP layer throughput (PDCP throughput is payload bits divided by the aggregated time) and L1 throughput using measurement tool; session duration should be at least 2 minutes; max./min./avg. value should be reported
If dynamic UL/DL ratio is not supported, reconfigure the system for minimum DL DL/UL ratio
d. Upload to the test server using UDP or TCP for UL peak test
e. Measure PDCP layer throughput (PDCP throughput is payload bits divided by the aggregated time) and L1 throughput using measurement tool; session duration should be at least 2 minutes; max./min./avg. value should be reported.</td></tr>
</table>

Evaluation criteria [2]:

1. For 3.5GHz, 100 MHz bandwidth, the peak data rate for DL should be at least 6Gbps, for UL should be at least 1.5Gbps.
2. Theoretical peak rate derived from the peak spectral efficiency requirement [5]: 3Gbps/1.5Gbps for DL/UL.

Reporting:

On UE side, the following metrics should be available for performance assessment:

- DL throughput (L1 and PDCP throughput)
- UL throughput (L1 and PDCP throughput)
- RSRP (Reference Signal Received Power)
- RSRQ (Reference Signal Received Quality)
- SINR
- DL BLER (at first retransmission)
- MIMO mode used (incl. MIMO rank)

4.3.1.2 User experienced data rate

Test ID:	TST_DR_2		
Test item:	Data Rate	**Sub-item:**	User experienced data rate
Refer document:	NGMN trial framework document [2]		

Test setup and conditions:

There should be one UE under test. Static locations and/or drive route should be identified to cover the whole range of SINR. The drive route should cover different environments such as open areas, close to reflecting buildings, LOS and NLOS. Additionally, different relevant inter-cell relations depending on used beam management features, such as direction in extension of neighbor cell BS to UE direction. There should be multiple static UEs (depending on availability of UEs but 10 is recommended) in all cells (evenly distributed in the cell/coverage area). Several loading load scenarios should be considered: no load, full load.

The reference configuration for the eMBB test under 3.5GHz include: 30KHz sub-carrier spacing, 2.3us CP length, 500us slot length for 14 symbols at 30kHz, 100 Mhz bandwidth, for DL rate test by DL/UL ratio or minimum UL configuration if dynamic UL/DL switching not supported, and for UL peak rate test by DL/UL ratio or minimum DL configuration if dynamic UL/DL switching not supported.

Test procedure:

1. Select cells pointing to the trial area and providing continuous coverage.
2. Select drive route and/or static locations to cover the whole range of SINR
   a. Cell edge should represent interference limited positions with SINR < 0dB.
   b. Average conditions should be represented by SINR (5dB to 10dB).
   c. Good conditions should be represented by SINR (15dB to 20dB)
   d. Excellent conditions should be represented by SINR > 22dB
3. Load surrounding cells by deploying the loading UEs or by activating load feature.
4. Connect UE to the cell and perform download/upload to/from the UE using UDP or TCP.
5. Measure PDCP layer throughput (PDCP throughput is payload bits divided by the aggregated time) and L1 throughput using measurement tool; session duration should be at least 2 minutes; max./min./avg. value should be reported.

Evaluation criteria: For dense-urban environment at 3.5GHz and 100 MHz bandwidth, by NGMN • 2.6 bits/s/Hz (Cat. 11/12) average DL spectral efficiency is assumed, 5G should deliver 260 Mbps average data rate. • 2.0 bits/s/Hz (Cat. 11/12) average UL spectral efficiency is defined, 5G should deliver 200 Mbps average data rate. For dense-urban environment at 3.5GHz and 100 MHz bandwidth, by ITU-R • 7.8 bits/s/Hz DL average spectral efficiency is assumed, 5G should deliver 780 Mbps average data rate. • 5.4 bits/s/Hz UL average spectral efficiency is assumed, 5G should deliver 540 Mbps average data rate. For indoor hotspot at 3.5GHz and 100 MHz bandwidth, by ITU-R • 9.0 bits/s/Hz DL average spectral efficiency is assumed, 5G should deliver 7.2 Gbps average data rate. • 6.75 bits/s/Hz UL average spectral efficiency is assumed, 5G should deliver 5.4 Gbps average data rate.
Reporting: The drive test results could be presented as a curve of throughput versus SINR. The bandwidth and the UL/DL ratio for TDD need to be reported along with the results. Calculate the average data rate for each static measurement points. On UE side, the following metrics should be available for performance assessment: • DL throughput (L1 and PDCP throughput) • UL throughput (L1 and PDCP throughput) • RSRP • RSRQ • SINR • DL BLER (at first retransmission) • MIMO mode used (incl. MIMO rank)

4.3.1.3 Cell-edge user data rate

Test ID:	TST_DR_3		
Test item:	Data Rate	**Sub-item:**	Cell-edge user data rate
Refer document:	NGMN trial framework document [2]		
Test setup and conditions: One UE will be placed in the cell under test, positioned in the coverage limited cell edge location. No other UEs should be placed in the surrounding cells. Test should be executed in stationary scenario. The UE should be placed in different positions with respect to expected beam forming gain. The reference configuration for the eMBB test under 3.5GHz include: 30KHz sub-carrier spacing, 2.3us CP length, 500us slot length for 14 symbols at 30kHz, 100 Mhz bandwidth, for DL rate test by DL/UL ratio or minimum UL configuration if dynamic UL/DL switching not supported, and for UL peak rate test by DL/UL ratio or minimum DL configuration if dynamic UL/DL switching not supported.			
Test procedure:			

1. Select sector pointing out of the trial area 2. Identify coverage limited location: 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. 3. Repeat steps 4-6 at each location with the UE static in that location. 4. Connect one UE to the sector and ensure there is only this UE connected to the sector. 5. Perform a. Download to the UE using UDP or TCP for DL peak test b. Upload to the test server using UDP or TCP for UL peak test 6. Measure PDCP layer throughput (PDCP throughput is payload bits divided by the aggregated time) and L1 throughput using measurement tool; session duration should be at least 2 minutes; max./min./avg. value should be reported.
Evaluation criteria [2]: 1. 3GPP: 3x IMT-A (0.18 bits/s/Hz or 18Mbps on DL and 0.09 bits/s/Hz or 9Mbps on UL) 2. ITU-R: The minimum requirements for average spectral efficiency for various test environments are: a. 0.225 bits/s/Hz DL cell edge spectral efficiency is assumed, 5G should deliver 22.5 Mbps cell edge data rate. b. 0.15 bits/s/Hz UL cell edge spectral efficiency is assumed, 5G should deliver 15 Mbps cell edge data rate.
Reporting: On UE side, the following metrics should be available for performance assessment: • DL throughput (L1 and PDCP throughput) • UL throughput (L1 and PDCP throughput) • RSRP • RSRQ • SINR • DL BLER (at first retransmission) • MIMO mode used (incl. MIMO rank)

4.3.2 Latency

4.3.2.1 User plane latency

Test ID:	TST_LTC_1		
Test item:	Latency	**Sub-item:**	User plane latency
Refer document:	NGMN trial framework document [2]		
Test setup and conditions: The architecture between RAN, core and application server will affect the latency. In this measurement, two architectures between RAN and application server are taken into account: one is to deploy the application server behind the core network as the normal case in 4G network; the second is to deploy the application sever at multi-access edge computing server so the data is steered to the local server to reduce the end-to-end latency. The test will report which architecture is used in the measurement. The reference configuration for the eMBB test under 3.5GHz include: 30KHz sub-carrier spacing, 2.3us CP length, 500us slot length for 14 symbols at 30kHz, FDD mode, or TDD mode with (75% /			

25%) and/or (50% / 50%) typical DL/UL ratio.
Test procedure: 1. Select a location in that cell (good, average and cell conditions) based on the cell grid: a. Good conditions should be represented by -90 dBm < RSRP b. Average conditions should be represented by -100 dBm < RSRP < -90 dBm; c. Cell edge conditions should be represented by RSRP < -100 dBm 2. Start traces on protocol analyser 3. Measurement performed for both unloaded and loaded scenario. 70% network resource usage in all cells is recommended for the "Loaded scenario". 4. Perform multiple (100) DL/UL standard size (32, 1500B) pings over the UE under test to a local test server, and record Max, Min and Average ping times. 5. Derive the RAN Latencies on 5 (chosen around the average End to End Latency) of these 100 measurements: • Calculate the DL/UL RAN Latency as the subtraction of the two previous values: RAN latency = E2E latency - Core latency.
Evaluation criteria: The 5G system should be able to provide 10 ms E2E latency in general and 1 ms E2E latency for the use cases which require extremely low latency. Note these latency targets assume the application layer processing time is negligible to the delay introduced by transport and switching. For eMBB use case: • RAN Latency ≤ 8 ms • E2E latency with 200 km distance between NR node and EPC/NGCore + Application server ≤ 10-15ms
Reporting: On the UE side, the following metrics should be available for performance assessment: • RSRP • RSRQ • RAN Latency (when possible) • E2E (End to End) Latency • Ping Success Rate • Packet Loss Rate At the gNB side: • Latency from gNB to EPC/NGC

4.3.2.2 Control plane latency

Test ID:	TST_LTC_2		
Test item:	Latency	**Sub-item:**	Control plane latency
Refer document:	NGMN trial framework document [2]		
Test setup and conditions: Latency will be tested in two scenarios: a single user in the cell, and multiple users in the same cell. The NSA and SA architecture will take different procedure to measure the control plane latency. Latency testing should be performed at several locations across the considered cell for ensuring different radio conditions. Measurements should be performed in a loaded scenario. 70% network resource usage in all cells is recommended for the "Loaded scenario".			

The reference configuration for the eMBB test under 3.5GHz include: 30KHz sub-carrier spacing, 2.3us CP length, 500us slot length for 14 symbols at 30kHz, FDD mode, or TDD mode with (75% / 25%) and/or (50% / 50%) typical DL/UL ratio.

Test procedure:

NR RRC Idle to NR RRC Connected latency in NSA configuration

1. In the serving cell, start UE trace and UE power cycle.
2. 4G Core Network initiates UE Context Release Command messages, and then UE transmits Idle state.
3. Ping a server on the 4G Core Network to trigger a service request from UE.
4. Stop UE trace.
5. Based on UE log, evaluate the transition time: Transition time at UE side = Time of last “RRC reconfiguration complete” – Time of “RACH preamble transmission”
6. Repeat steps 1-5 20 times.

NR RRC Idle to NR RRC Connected latency in SA configuration

1. In the serving cell, start UE trace and UE power cycle.
2. 5G Core Network initiates UE Context Release Command messages, and then UE transmits Idle state.
3. Ping a server on the 5G Core Network to trigger a service request from UE.
4. Stop UE trace.
5. Based on UE log, evaluate the transition time: Transition time at UE side = Time of last “RRC reconfiguration complete” – Time of “RRC Setup Request”.
6. Repeat steps 1-5 20 times.

NR RRC Inactive to NR RRC Connected latency in SA configuration

UE Triggered Transition

1. In the serving cell, ensure UE is in Inactive State and moved from its last Serving g-NodeB to under the coverage of another g-NodeB (actual).
2. Start UE and g-NodeB traces.
3. Ping a server on the 5G Core Network to trigger a service request from UE.
4. Stop traces.
5. Based on UE and g-NodeB logs, evaluate the transition time: Transition time = “Path Switch Request Response” at g-NodeB – Time of “RRC Connection Resume Request” at UE side.
6. Repeat steps 1-5 20 times.

Network Triggered Transition

1. In the serving cell, ensure UE is in Inactive State.
2. Start UE and g-NodeB traces.
3. Trigger a RAN paging event (e.g. in initiating an incoming DL user plane)
4. Observe that the UE switches to Connected mode.
5. Stop UE trace.
6. Based on UE and g-NodeB logs, evaluate the transition time: Transition time = Time of “Resuming from RRC Inactive” – “Paging UE Message”
7. Repeat steps 1-6 20 times.

Evaluation criteria:

The metric to validate the tests shall be the transition times between states. Trial initiatives shall report on used trigger points to evaluate the state transitions times. Minimum 20 valid samples are required for result evaluation. The result will be calculated and reported as an average from these

20 samples. Expected target value in SA configuration: • NGMN recommendations = Idle <-> Connected transition time ≤ 10 ms • NGMN recommendations = Inactive <-> Connected transition time ≤ 10 ms (pending 3GPP definition).
Reporting: Record the state transition latency from the RRC state idle to active, and from inactive to connected. Record the min, max and median values of the latency.

4.3.3 Cell capacity

Test ID:	TST_CPC_1		
Test item:	Cell capacity	**Sub-item:**	Cell peak throughput
Refer document:	NGMN trial framework document [2]		
Test setup and conditions: Configure the test cell BS system parameters depending on the deployment scenario, such as the frame structure, bandwidth, duplex mode, output power etc. Single cell without inter-cell interference and the other cells around the test cell should be configured no power output. 10 test points with high RS-SINR in the test cell and at least one UE should be placed in one test point. Use at least 10 UE devices in the network. The reference configuration for the eMBB test under 3.5GHz include: 30KHz sub-carrier spacing, 2.3us CP length, 500us slot length for 14 symbols at 30kHz, 100 Mhz bandwidth, minimum UL configuration for DL peak rate test, and minimum DL configuration for UL peak rate test.			
Test procedure: 1. Downlink Cell Capacity Test All of UEs are configured to receive downlink full-buffer UDP services. The downlink L3 PDCP throughput should be recorded as the indicator of the downlink cell capacity. The L3 PDCP throughput is data received in the receiver PDCP layer per second. The time for test is at least 5 minutes until the L3 throughput is stable. The stable throughput should be record as the final throughput in each test point. 2. Uplink Cell Capacity Test. All of UEs are configured to transmit uplink full-buffer UDP services. The L3 PDCP throughput is data received in the receiver PDCP layer per second. The time for test is at least 5 minutes until the L3 throughput is stable. The stable throughput should be record as the final throughput in each test point.			
Evaluation criteria: Based on the test results, the cell peak capacity can be obtained by aggregating the throughput of all the UEs. For the test results comparison, the recalculated cell peak capacity should be given based on the 100% corresponding link (100% downlink or 100% uplink) frame structure. The throughput is calculated using the following formulas: Throughput(TP) = Σ test point_TP (both for DL and UL) DL_Recalculate_TP = DL_Throughput/ DL_percentage UL_Recalculate_TP = UL_Throughput/ UL_percentage			
Reporting:			

The following metrics should be available for performance assessment:

- RSRP
- RS-SINR
- PDCP throughput
- MCS
- layer numbers of transmission data
- UE uplink power
- transmission mode
- BLER

The test results should be record for both downlink and uplink.

<table>
<tr><td>Test ID:</td><td colspan="3">TST_CPC_2</td></tr>
<tr><td>Test item:</td><td>Cell capacity</td><td>Sub-item:</td><td>Cell average throughput</td></tr>
<tr><td>Refer document:</td><td colspan="3">NGMN trial framework document [2]</td></tr>
<tr><td colspan="4">Test setup and conditions:

Configure the test cell BS system parameters depending on the deployment scenario, such as the frame structure, bandwidth, duplex mode, output power etc. Single cell without inter-cell interference and the other cells around the test cell should be configured no power output. Chose 10 test points in the cell and the ratio of transmission condition is excellent: good: medium: bad=1:2:4:3. At least one UE should be placed in one test point. Use at least 10 UE devices in the network.

If the trial sites can support multiple-cell deployment, cell capacity under inter-cell interference will be tested. The following configuration is considered. The surrounding cells of the test cell should be configured as:
Downlink: 50% interference level from neighbour cell both for control channel and data channel. The definition of 50% interference level is that 50% downlink transmission PRB are randomly chosen to transmit interference signal.
Uplink: lead to 5dB uplink Interference over Thermal rise for test cell. The definition of 5dB Interference over Thermal rise is that the received interference noise from the UEs of neighbour cell uplink transmission should lead to 5dB rise of the receivers’ noise power
The reference configuration for the eMBB test under 3.5GHz include: 30KHz sub-carrier spacing, 2.3us CP length, 500us slot length for 14 symbols at 30kHz, 100 MHz bandwidth, minimum UL configuration for DL peak rate test, and minimum DL configuration for UL peak rate test.</td></tr>
<tr><td colspan="4">Test procedure:

1. Setup the test environment as the test configuration respectively for single cell configuration and multiple-cell test configuration

2. Downlink Cell Capacity Test

All of UEs are configured to receive downlink full-buffer UDP services. The downlink L3 PDCP throughput should be recorded as the indicator of the downlink cell capacity. The L3 PDCP throughput is data received in the receiver PDCP layer per second. The time for test is at least 5 minutes until the L3 throughput is stable. The stable throughput should be record as the final throughput in each test point.

3. Uplink Cell Capacity Test

All of UEs are configured to transmit uplink full-buffer UDP services. The uplink L3 PDCP throughput should be recorded as the indicator of the uplink cell capacity. The L3 PDCP</td></tr>
</table>

throughput is data received in the receiver PDCP layer per second. The time for test is at least 5 minutes until the L3 throughput is stable. The stable throughput should be record as the final throughput in each test point.
Evaluation criteria: Based on the test results, the cell peak capacity can be obtained by aggregating the throughput of all the UEs. For the test results comparison, the recalculated cell peak capacity should be given based on the 100% corresponding link (100% downlink or 100% uplink) frame structure. The throughput is calculated using the following formulas: Throughput (TP) = Σ excellent_TP + Σ Good_TP + Σ Medium_TP +Σ Bad_TP (both for DL and UL) DL_Recalculate_TP = DL_Throughput/ DL_percentage UL_Recalculate_TP = UL_Throughput/ UL_percentage
Reporting: The following metrics should be available for performance assessment: • RSRP • RS-SINR • PDCP throughput • MCS • layer numbers of transmission data • UE uplink power • transmission mode • BLER The test results should be record for both downlink and uplink.

4.3.4 Spectrum efficiency

Test ID:	TST_SE_1		
Test item:	Spectrum efficiency	**Sub-item:**	
Refer document:	NGMN trial framework document [2]		
Test setup and conditions: For spectrum efficiency calculation, the test setup and procedure in Section 4.3.1.1, 4.3.1.2, 4.3.1.3 will be used to obtain the throughput and thus get the spectrum efficiency for peak spectrum efficiency, medium spectrum efficiency, and cell edge spectrum efficiency, respectively.			
Test procedure: Refer to Section 4.3.1.1, 4.3.1.2, 4.3.1.3			
Evaluation criteria: • 3GPP peak spectral efficiency targets (eMBB use case): 30 Bit/s/Hz for DL, 15 Bit/s/Hz for UL • ITU-R medium spectral efficiency targets (eMBB use case): 7.8 Bit/s/Hz for DL, 5.4 Bit/s/Hz for UL • ITU-R cell edge spectral efficiency targets (eMBB use case): 0.225 Bit/s/Hz for DL, 0.15 Bit/s/Hz for UL			
Reporting: • Peak spectral efficiency • Medium spectral efficiency			

- Cell edge spectral efficiency

4.3.5 Coverage

<table>
<tr><td>Test ID:</td><td colspan="3">TST_CVR_1</td></tr>
<tr><td>Test item:</td><td>Coverage</td><td>Sub-item:</td><td>Outdoor single-cell coverage</td></tr>
<tr><td>Refer document:</td><td colspan="3">NGMN trial framework document [2]</td></tr>
<tr><td colspan="4">Test setup and conditions:
The coverage performance will be tested in UL and DL, in control and data channels, in terms of both the maximum distances in LOS and NLOS conditions, and the corresponding data rates at cell edge. Frequency reuse factor is 1. Three test cases are considered.
In stand-alone cell test case, neighbouring 4G and 5G cells are turned off, leaving the centre 5G cell on. Prior to the trials, the noise floor of the 5G band (e.g. BW=100MHz) should be measured and recorded with the 5G base stations turned off and on respectively.
In interference on control channel only test case, the interference from neighbouring cells impacts on the control channel only, by turning on the 6 cells (broadcasting channel and synchronization channel are on) without any users or traffic, i.e. no interference on the data channel. Tests should be carried out on UL and DL separately.
In interference on control and data channel test case, the interference from neighbouring cells impacts both the control and data channels, to create interference across the operating bandwidth. The level of the interference can be controlled by the allowed traffic in neighbour cells. Tests should be carried out on UL and DL separately.
The reference configuration for the eMBB test under 3.5GHz include: 30KHz sub-carrier spacing, 2.3us CP length, 500us slot length for 14 symbols at 30kHz, 100 MHz bandwidth.</td></tr>
<tr><td colspan="4">Test procedure:
1. Activate cell under test
2. Activate surrounding cells
3. Configure cells according to test configuration (stand alone, interference on control channel only, interference on control and data channel)
4. Place end user devices in the cell under test and establish data connections
5. Move end user devices throughout the cell area and log data</td></tr>
<tr><td colspan="4">Evaluation criteria :
The achieved data rate in a geographical area.</td></tr>
<tr><td colspan="4">Reporting:
• Record channels’ maximum path losses and coverage distances for PDSCH, PUSCH, PDCCH, PUCCH, PBCH.
    • RSRP
    • RSRQ
    • RS-SINR
    • Location
    • Distance to BS
    • Throughput
    • LOS/NLOS condition
• The coverage distances that correspond to the following low data rates: UL: 512kbps, 1Mbps; DL, 1Mbps, 2Mbps.</td></tr>
</table>

Test ID:	TST_CVR_2		
Test item:	Coverage	**Sub-item:**	Indoor coverage
Refer document:	NGMN trial framework document [2]		

Test setup and conditions:

The test environment is the office building under LOS or NLOS conditions. The BS is placed on ceiling or wall mounted. The UL and DL coverage should be balanced. That means measurement result should be able to tell whether loss of connection is caused by UL or DL, and by which channel. Tests may be carried out in a single cell deployment

The reference configuration for the eMBB test under 3.5GHz include: 30kHz sub-carrier spacing, 2.3us CP length, 500us slot length for 14 symbols at 30kHz, 100 MHz bandwidth.

Test procedure:

1. Activate cell under test
2. Place 5G end user devices
3. Activate data connection of the devices
4. Measure parameters for data and control channels when moving within the indoor location

Evaluation criteria :

The coverage area achieving the data rates defined below in the reporting section of this form.

Reporting:

- Record channels' maximum path losses and coverage distances for PDSCH, PUSCH, PDCCH, PUCCH, PBCH.
    - RSRP
    - RSRQ
    - RS-SINR
    - Location
    - Distance to BS
    - Throughput
    - LOS/NLOS condition
- The coverage distances that correspond to the following low data rates: UL: 512kbps, 1Mbps; DL, 1Mbps, 2Mbps.

4.3.6 Mobility

Test ID:	TST_MB_1		
Test item:	Mobility	**Sub-item:**	NSA inter-cell mobility
Refer document:	NGMN trial framework document [2]		

Test setup and conditions:

Depending on the availability of gNB and LTE eNodeB in the trial sites, the project takes this mobility test as an optional. The UE is attached to master LTE cell and secondary 5G NR cell is added during connected mode. At least 2 Master LTE eNB and 3 Secondary 5G NR gNB is needed for the test.

Test procedure:

1. LTE and 5G NR Base Stations are powered on and configured with handover related parameters (neighbor cells, thresholds etc…)
2. All the UE's are under Master LTE eNB and Secondary 5G NR gNB coverage.

3. UE's are powered on and complete initialization process.
4. UE's are successfully attached to the LTE/5G network and are able to upload/download data.
5. All UE's start uploading/downloading data
6. UE moves from according to the test scenario
7. Be sure that handover procedure is successfully performed for all UE's.

Evaluation criteria:

Minimum 20 valid samples are required for result evaluation. For Intra Master eNodeB handover user plane handover interruption time should be 0 ms. For Inter Master eNodeB handover user plane handover interruption time should be similar to LTE.

Reporting:

- DL and UL Throughput
- Packet loss
- Interruption time

Test ID:	TST_MB_2		
Test item:	Mobility	**Sub-item:**	SA inter-cell mobility
Refer document:	NGMN trial framework document [2]		

Test setup and conditions:

Depending on the availability of gNB in the trial sites, the project takes this mobility test as an optional. In the test, the Number of 5G NR cells should be at least two in order to trigger Handover during drive test.

The below KPIs should be focused on during test.

- Handover interruption time which is defined in the NGMN 5G Whitepaper as a time during which the user is not able to receive any user plane data, including inter-system authentication time, should be evaluated in different scenarios and configurations.
- DL and UL throughput variations and minimum DL/UL Throughput should be measured and verified during the handover
- Packets loss rate due to the handover procedure at different OSI layers should be measured during the trial.

Test procedure:

1. 5G NR Base Stations are powered on and configured with handover related parameters (neighbor cells, thresholds etc…)
2. All the UEs are under Cell1 coverage.
3. UE's are powered on and complete initialization process.
4. UE's are successfully attached to the 5G network and are able to upload/download data.
5. All UE's star uploading/downloading data
6. For all scenarios above (scenario 1 to 5), UE should move from Cell 1 to Cell 2 with given velocities (refer to NGMN trial framework document [2]).
7. The handover procedure should be successfully performed for all UE's.

Evaluation criteria:

Minimum 20 valid samples are required for result evaluation. The user plane handover interruption time should be 0 ms.

Reporting:

- DL and UL Throughput
- Packet loss
- Interruption time

4.3.7 Reliability

Test ID:	TST_RL_1		
Test item:	Reliability	**Sub-item:**	
Refer document:	NGMN trial framework document [2]		

Test setup and conditions:

Test scenario 1: One UE and one BS - test the UL and DL reliability as the UE moves from good coverage to worse coverage (until the UE is out of coverage).

Test scenario 2: Multiple UEs and 1 BS and test the UL and DL reliability as the test UE moves from good coverage to worse coverage while other UE's are connected to the same BS and have UL or DL traffic.

Test scenario 3 (Optional test in the project): One UE and multiple BSs and test the DL reliability in different interference scenarios (starting with minimum interference to the worst-case interference where all interfering BSs are pointing their main beam towards the UE.

Test scenario 4 (Optional test in the project): Multiple UEs and multiple BSs and test the UL reliability in different interference scenarios.

Test procedure:

1. Select sector pointing into the trial area and make sure that only one test UE is connected to this sector.
2.
    a. For scenario 1: make sure that all interfering cells are either not transmitting or are not pointing their main beam to the test UE.
    b. For scenario 2: Have all interfering BSs transmit towards the coverage area of the serving cell of the test UE.
    c. For scenario 3: Have all interfering UEs transmit in the UL to generate interference to the test UE.
    d. For scenario 4: Make sure that all interfering cells are either not transmitting or are not pointing their main beam to the test UE. Make sure all background UE's are connected to the same BS as test UE and have some UL or DL traffic.
3. Start moving the test UE from the cell centre towards the cell edge in scenario 1 and from low interference to high interference conditions in scenarios 2 and 3.
4. Perform a download/upload from/to UE using UDP or TCP.
5. Log the measurements.
6. Repeat steps 3-5 several times with different locations and traffic load.
7. Repeat test for different UE speeds.

Evaluation criteria:

For eMBB, the requirement on reliability for one transmission of a packet of 32 bytes with a user plane latency of 8ms is recommended to be at least 10^{-2}.

For mobility use cases, the requirements for communication availability, resilience and user plane latency of delivery of a packet of size 300 bytes are as follows: • Reliability = 1-10^{-5}, and user plane latency = 3-10 ms, for direct communication via sidelink and communication range of (e.g., a few meters) • Reliability = 1-10^{-5}, and user plane latency = 3-10 ms, when the packet is relayed via BS.	
Reporting: • Reliablity = the success probability of transmitting a set number of bytes within a certain delay • CDR (Call drop rate) • CSCR (Call setup complete rate) • DCDR(Dual connectivity drop rate) in case of NSA	

4.4 Initial trial plan and measured KPIs at 5G-DRIVE trial sites

In this subsection, an initial trial plan will be presented to describe how the network performance will be tested as well as the evaluation KPIs covered by the partners setup. The selected KPIs subject to various trial sites availability will be described as well as the needed equipment as shown in Table 7. [20]

KPIs	Trial sites(s)	Involved Partner(s)
Latency	Surrey site, Espoo site	UoS, UKent, JRC, VTT
Cell Capacity	Surrey site	UoS
Coverage	Espoo site	VTT
Mobility	Espoo site	VTT
Reliability	Espoo site	VTT
Peak Data Rate	Surrey site, Espoo site	JRC, VTT, UKent (for transport arch.)
User-experienced Data Rate	Surrey site, Espoo site	JRC, VTT, UKent (for transport arch.)

Table 7: KPI evaluation per trial site and partner

4.4.1 VTT

To support trial measurements, VTT's testbed has been extended with latency measurement capabilities to support one-way and two-way delay measurements. The two-way delays (round-trip time (RTT)) are measured with Nemo Outdoor and one-way delays with Qosium. The latter one is a real-time passive measurement tool that monitors and computes key QoS parameters from ongoing network traffic.

[20] Actual measured KPIs also need to subject to availability of various trial sites.

For the latency measurements, specific measurement sites can be and have been selected based on signal strength measurements. Currently, there are already three buildings in Espoo Otaniemi where the latency measurements are planned to be performed. The reason for having different measurement sites is to be able to perform measurements in good, medium, and bad propagation conditions.

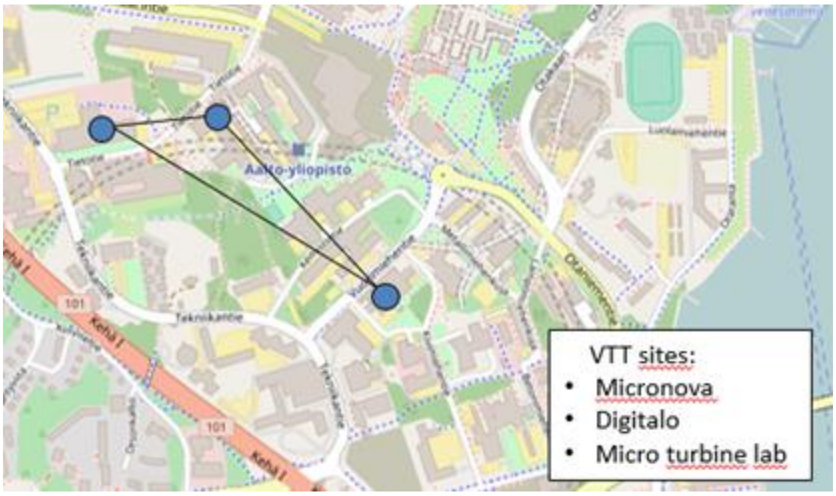

Figure 11: Current latency measurement sites at VTT's premises in Espoo Otaniemi.

An example of an existing latency measurement setup is presented in Figure 11. There are two different synchronisation and timing options to be used: an own time server using GPS (can be extended with GPS repeaters) and MIKES’s time server. The time (UTC or TAI) is provided to endpoints using Precision Time Protocol (PTP). The measurement setup can also be modified for other use cases. Varying network conditions can be emulated, with a network emulator by adding additional delay or dropped packets between network components.

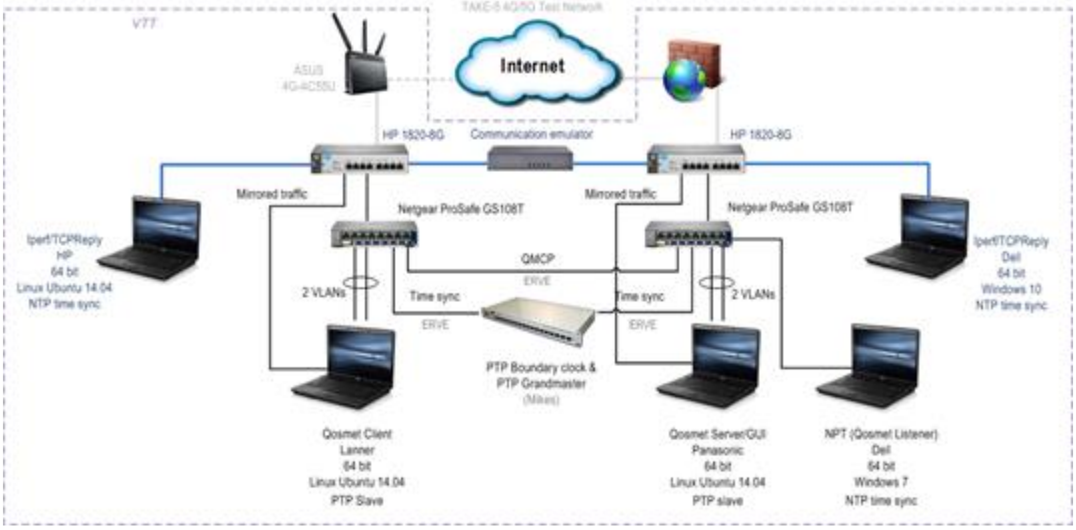

Figure 12: The latency measurement setup at VTT.

Utilizing VTT’s network planning tools for support of network coverage and QoS measurements as well as performance analysis for heterogeneous network planning, we will carry out the joint eMBB trials according to the Section 2 trial setup requirements, which define also how the deployment parameters will be reported for each trial.

The latency trials will be carried out at three levels: E2E latency between UE and application server, RAN latency, and core network latency. The 3GPP target latency and bandwidth for each of the deployment scenarios are as follows.

- E2E Latency for the eMBB use case is less than 15 ms.
- RAN Latency ≤ 8ms.
- The expected data rate bandwidth for wide area deployment at carrier frequency in below 6 GHz with Channel bandwidth of 100 MHz is 3G bps/1.5 Gbps for DL/UL.

The latency trials will include testing to validate different mobility state transitions (control plane) and their transition times, i.e. these tests aim to quantify “Idle to Connected”/ “Connected to Idle”, and “Inactive to Connected”/ “Connected to Inactive” state transition times, as well as to verify the associated process for each type of state transition. The latency testing will be performed at several locations across the considered cell for ensuring different radio conditions. Measurements will also be performed in a scenario with loaded network resource usage in the cells. This will be achieved using traffic generators. VTT’s comprehensive set of network planning tools can be utilized also for testing both intra-cell mobility and inter-cell mobility (handover) scenarios. On the UE side, at least the following metrics will be available for performance assessment:

- RSRP (Reference Signal Received Power)
- RSRQ (Reference Signal Received Quality)
- RAN Latency (when possible)
- E2E (End- to- End) Latency
- Ping Success Rate
- Packet Loss Rate

At the gNB side:

- Latency from gNB to EPC/NGC

VTT has developed a measurement and analysis platform to support both mobile network planning and performance assessment. One of the main components is Network Planning Tool (NPT) implemented to support R&D of different communication solutions in multi-operator and multi-RAN environments. The tool supports indoor and outdoor, real-time and offline measurements. Offline measurements are mainly used for coverage optimisation and positioning research. The real-time measurements are used for QoS assessment and latency reduction research. The tool contains interfaces to different measurement devices e.g. Nemo Outdoor[21], Viola Systems’[22] Arctic modules[23], NPT client with Qosium[24], and to dedicated monitoring apps on Android phones. Qosium is a real-time passive measurement tool that monitors and computes key QoS parameters from ongoing network traffic.

The following Figure 13 shows the network coverage in the Espoo Otaniemi campus[25], which is practically the whole campus area and thus gives a good opportunity to test radio access and core network solutions in different environments both indoors and outdoors.

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[21] For details also see: *https://www.keysight.com/en/pd-2765544-pn-NTA00000A/nemo-outdoor?&cc=GR&lc=eng*

[22] See: *http://www.protocolindia.com/associates/principals/viola-systems/*

[23] Also see: *http://protocolindia.com/pdf/arcticviola/VU-10-1-Arctic_GPRS_Gateway_Users_Manual-1.6.pdf*

[24] For more relevant information also see: *https://www.kaitotek.com/qosium*

[25] See: *https://www.aalto.fi/campus*

Figure 13: Outdoor coverage of existing test network in the Espoo site.

Research on indoor communication quality and positioning is supported by a mobile robot shown in the left picture below. 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.

Figure 14: Measurement devices used for indoor and outdoor measurements.

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 Figure 15. 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[26], and Raspberry beacons[27] in ad-hoc networks.

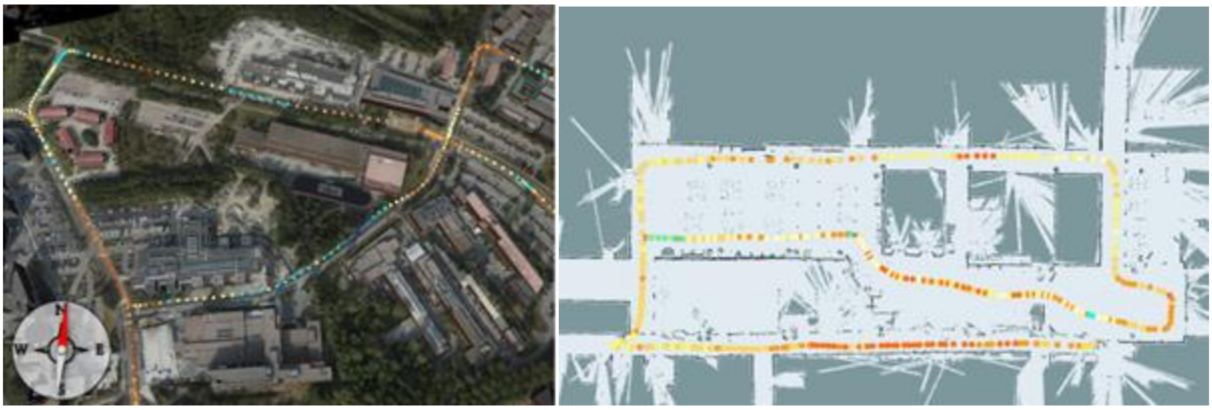

Figure 15: 3D model of Otaniemi and floor map including the measured signal strength values.

For the trials, tests will be carried out to measure user throughput including peak throughput, throughput at interference limited cell edge, cell edge coverage throughput, and throughput in different interference/coverage conditions. Peak user throughput is the maximum DL/UL data rate achievable for a single user located at the best location within a cell. On UE side, the following metrics and the derived link budget will be available for performance assessment.

- DL throughput
- UL throughput
- RSRP (Reference Signal Received Power)
- RSRQ (Reference Signal Received Quality)
- SINR
- DL BLER (at first retransmission)
- MIMO mode used (incl. MIMO rank)
- UE & gNB Tx power
- Channel utilization or scheduling/activity factor

Finally, the same set of network planning tools will be utilized to carry out coverage measurements including available signal strength and service quality both outdoors and indoors. Reliability can be expressed by the success probability of transmitting a set number of bytes within a certain delay. It 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.

To support overall performance assessment, all above KPI measurement results will be recorded with location stamps by utilizing VTT's positioning platform as described above.

4.4.2 JRC

As part of the eMBB trials, the JRC will conduct an RF characterisation and performance evaluation of the 3.5 GHz eMBB radio signals transmitted by 5G gNBs in the Surrey trial site. This is subject to

[26] See: *https://wirepas.com/products-and-services/sensors/*

[27] Also see: *https://www.hackster.io/nickfloyd/raspberry-beacon-5ccb2f*

equipment availability and deployment progress. The objective of this measurement campaign is to experimentally validate a subset of the eMBB KPIs defined in [3] against their theoretical/expected values. In particular, the JRC will measure the following metrics:

- **Peak data rate**: the maximum achievable data rate under ideal conditions per device (in Gbps);
- **User experienced data rate**: the achievable data rate that is available ubiquitously across the coverage area to a mobile device (in Mbps or Gbps);
- **Latency**: the RAN contribution to the total elapsed time, measured from the instant the source sends a packet to the moment when the destination receives it (in ms);

To measure these subset of KPIs, the JRC will collaborate with the 5GIC testbed team at the University of Surrey to capture (e)CPRI frames carrying IQ data between the 5G Baseband Units (BBUs) located in the University of Surrey's 5G/4G Machine Rooms and the 5G Remote Radio Heads (RRHs) deployed throughout the campus, subject to the availability of equipment, as depicted in Figure 16.

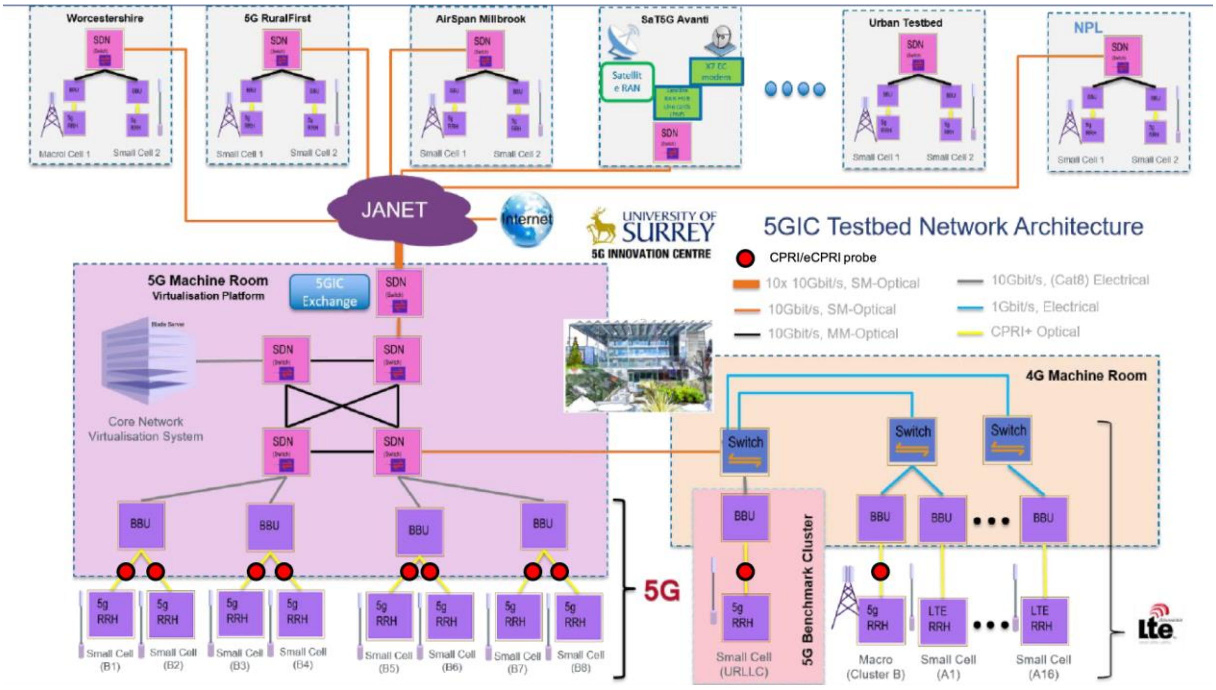

Figure 16: Capturing IQ data via (e)CPRI probes in the 5GIC testbed (logical architecture).

Protocol data contained in the user- and control-plane messages exchanged between the 5G gNB and the UE can later be extracted by post-processing the IQ data encapsulated in the (e)CPRI frames. In addition, since IQ data is just a digitised version of an analogue 5G NR waveform, both the uplink and downlink 5G NR waveforms from probed 5G gNBs could also be synthesised and played back in the anechoic chambers of the JRC Ispra site using a vector signal generator or a Universal Software Radio Peripheral (USRP). This procedure will enable a detailed RF characterisation and performance evaluation of 5G gNBs without the logistics complexity of conducting an exhaustive over-the-air RF measurements campaign at the Surrey trial site.

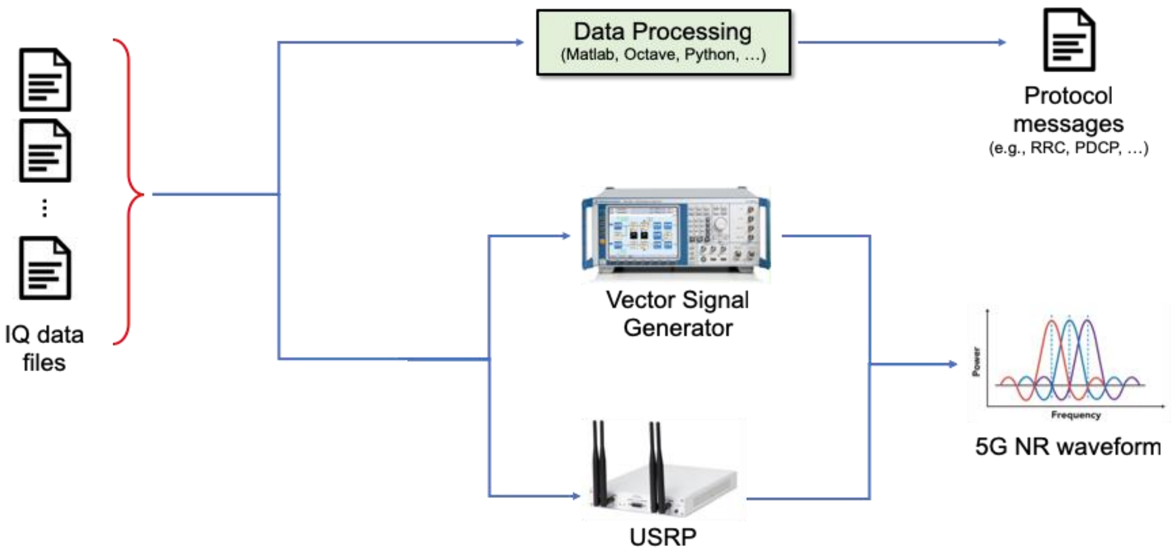

Figure 17: Extracting protocol messages and synthesising a 5G NR waveform from IQ data

4.4.3 UKent

To support the eMBB trials, UKent will use a measurement platform (shown in Figure 18) that combines Ethernet devices that include 10GbE connectivity and can act as precision-time protocol (PTP) transparent clocks (TCs), boundary clocks (BCs) and slave or master clocks. The platform includes hardware Ethernet probes that, according to appropriately defined filters (which instruct a probe to “capture” packets of a given traffic flow), will generate filter result packets (FRPs, these carry timestamps, sequence numbers and other metadata fields for the monitored packets) and forward them to a probing server. The server aggregates the FRPs (there can be multiple corresponding to any number of monitored flows) and employs a Python API[28], a listening socket and Key Performance Indicator extraction algorithms. KPIs include data rate (over different fronthaul segments), latency and inter-frame delays. Timing servers are used to condition the clock in the probing server (which then acts as a PTP grandmaster to the probes). Impairment generators and/or background traffic generators are used to inject impairments/background traffic for performance analysis. An SDN controller is used (integrated as a VM in the processing server) for layer-2 traffic steering and load balancing of flows.

The platform will be used for performance analysis in a number of “use cases”:

- For fronthaul/xhaul/backhaul links for eMBB. Initial definition of the measurements can be done with the 4G testbed at UKent, with technology then moved to 5GIC or Espoo for incorporation into the trial sites. The xhaul load/throughput and latency/latency variation measurements would then be taken under different network conditions, locations (for coverage analysis) and for different equipment (e.g. UEs).
- For Coordinated Multipoint (CoMP). Low-latency variation is needed for synchronization between the RRUs in CoMP scenarios; this may be performed without a problem with CPRI as long as there is an appropriate timing mechanism, but could be a problem for eCPRI if there are multiple RRUs with variable load, and some stat muxing efficiency gains are desired. The platform can be used to performing latency tests and time-information distribution tests using different combinations of PTP-aware Ethernet switches in CoMP scenarios.

[28] Also see: *https://realpython.com/api-integration-in-python/*

– For localization. Similarly, performance analysis for contention-induced latency variation will be very important for accurate localisation, e.g. indoor positioning.

– For Mobile Edge Computing (MEC) use cases. The platform can be used for performance analysis of Mobile Edge Computing (MEC) links (CP and UP latency over local tunnels).

For all use-cases described here (and depending on their availability in the trial networks), UKent will contribute to the measurement of latency metrics for adherence to the latency KPIs definitions as stated in Section 4.2.2 and within the test procedures defined in Section 4.3.2. The contribution will aim to breakdown transport-induced contributions to UP and CP latencies and offer solutions to meet the target KPIs.

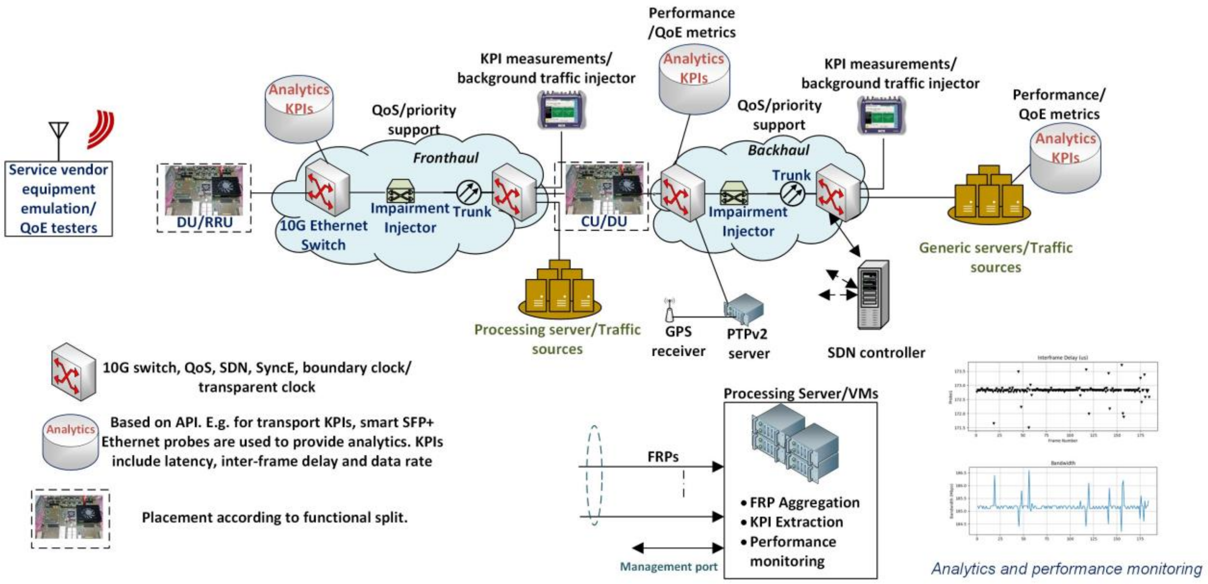

Figure 18: High-level view of UKent test network.

UKent will perform two broad sets of experiments within the trial testbeds. The test domains are depicted in Figure 18. These tests will be used within the test and evaluations procedures as described in Section 4.3.1 and Section 4.3.2 focusing on the latency KPIs listed in Section 4.2.2. A high-level view of the UKent testbed, its features and the planned contribution to the evaluation procedures was provided in Section 4.4.3. In this section a more detailed description of “use case” tests and the tools that will be used is provided. The test will be conducted using in-line small factor pluggable (SFP) hardware probes in appropriate locations within the trial network. The locations will be determined by the path that monitored packets (derived from CP, UP and time plane flows) will flow through the network (as derived from the evaluations procedures described in Section 4.3.1 and Section 4.3.2. The probes will detect monitored packets, and will send timestamps (of the time a packet was detected at a specific location within the trial network) and a number of other metadata fields to an analytics engine as shown in Figure 19. The analytics engine will then process the metadata and generate the relative KPI estimates (latency, latency-variation, data rate). Note that additional estimates can be used to better refine contributors to latency, for example inter-frame latency that includes latency contributions from higher processing layers and/or the framing/packetization system at the physical layer. Figure 20 shows a screen capture for an example dynamic monitoring session while Figure 21 shows the corresponding inter-frame delay trace of a flow transporting encapsulated LTE traffic. Similar sessions will be set-up at different locations of the trial network for KPI monitoring and analysis.

a) Control and user plane monitoring

Assuming flows are differentiated (e.g. through standard UDP, VLAN headers or TEIDs), the tests will monitor control and user plane traffic and will measure effects of impairments and/or background traffic on CP and UP flows. Note that these experiments can be applied to CU/DU, DU/RRU and backhaul interfaces. The aim being to assess UP and CP impairments separately and in unison. CoMP tests, depending on whether an evolved fronthaul network is available, will concentrate on latency/latency variation performance tests across different x-haul links to cooperating end-nodes. For MEC links tests will be carried out over local tunnels while latency/latency variation performance over such links can be related to application level KPIs.

In general, the aim of these tests are two-fold:

First, employed interfaces (e.g. eCPRI) will have vendor specific absolute requirements/specifications in terms of latency and latency variation. Provided that such flows are differentiated (for example by standard UDP or VLAN headers), the set-up will be used to verify such requirements.

Second, performance monitoring of control plane (CP) and user plane (UP) performance, when absolute flow requirements/specifications are met. The aim here being to measure effects of impairments and/or background traffic on CP and UP flows. Contention over the transport network can cause the DU/RRU (e.g. eCPRI RRU) to transmit nulls in place of late-arriving UP and CP data. Therefore, provided that User Equipment (UE) are available, an interesting aspect of performance monitoring will be to associate over-the-air (OTA) KPIs and transport network KPIs (for example latency variation and OTA HARQ retransmissions). For CoMP deployments, latency/latency variation performance tests across x-haul links will be very important, while for MEC latency over local tunnels (to the MEC) are important.

These tests can be combined with different Ethernet scheduler regimes and/or SDN functionality.

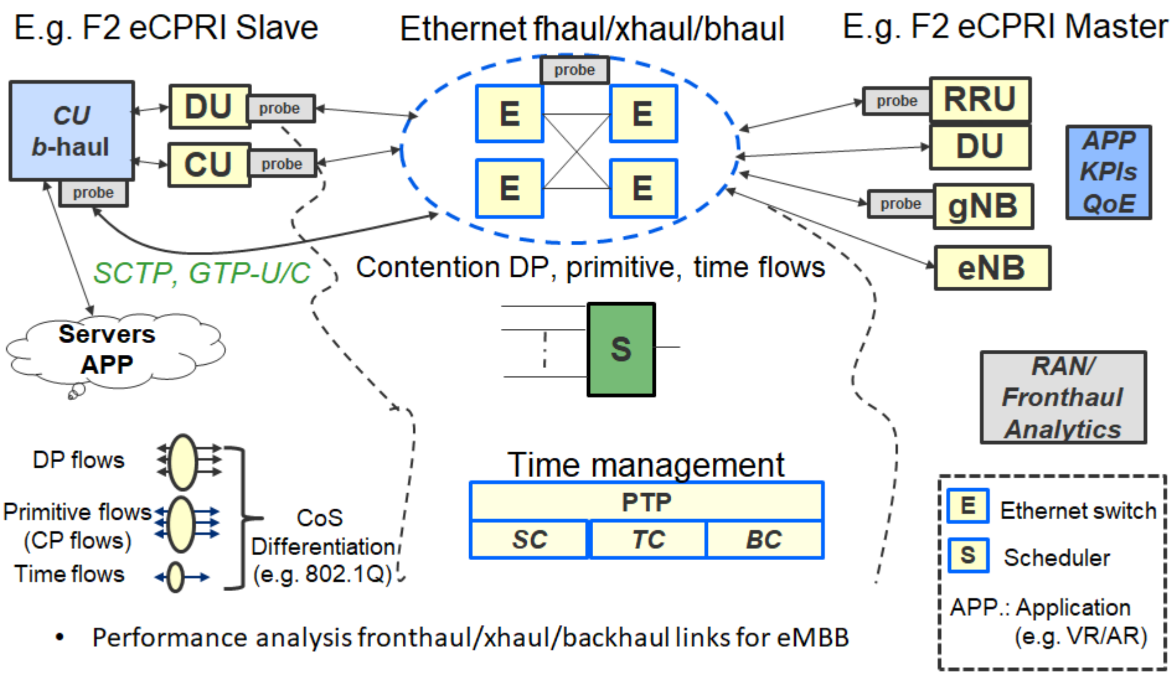

Figure 19: Overview of test domains within the fronthaul, x-haul and/or backhaul links. PTP, Precision Time Protocol; SC, Slave Clock; TC;, Transport Clock; BC, Boundary Clock; APP., Applocation; DP, Data Plane. DU, Distributed Unit; CU, Central Unit; RRU, Remote Radio Unit.

Figure 20: Screen capture of live performance monitoring with generated inter-frame delay and data rate KPIs. (Bottom) Monitoring with a source generating traffic with a throughput of 0.2 Gbps (approx). Annotations show the probing metadata and the generated KPIs.

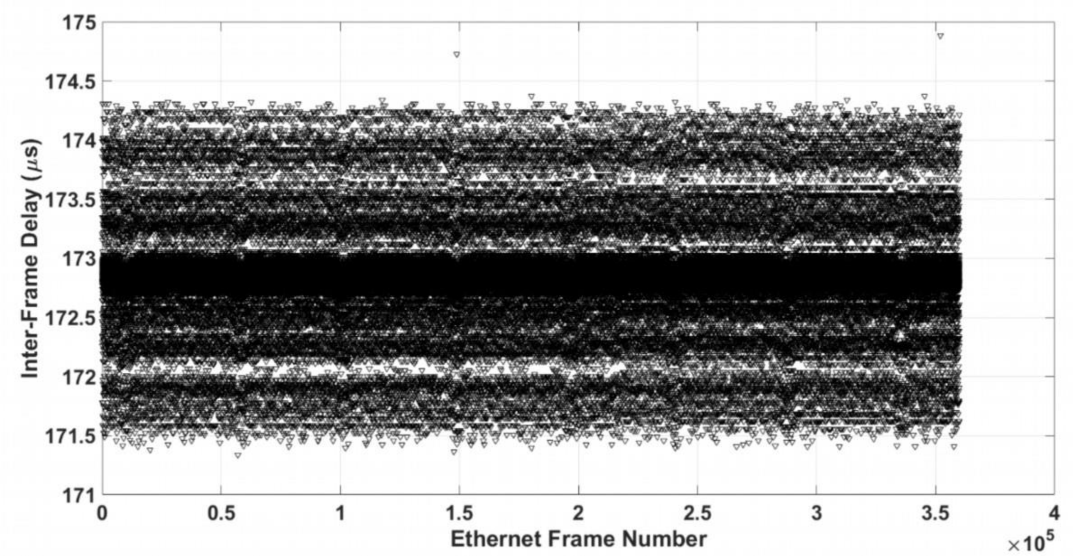

Figure 21: KPI dynamic monitoring example, in this case for inter-frame (Ethernet) delay with a source generating 0.2 Gbps of throughput.

b) Time information distribution

Contention can also affect time plane (TP) flows provided that such flows are in-band (i.e. transported through the network). Tests will be carried out by distributing different combinations of

PTP devices throughout the network, and measuring effects of contention. PTP devices will consist of different combinations of TCs, BCs, slave and master clocks.

These tests will be aimed at assessing the performance of transport networks with live traffic for eMBB applications, by analysing effects of contention/impairment on the “in-band” time plane (TP) flows and how resulting time-stamping errors affect the overall performance of the transmitted flows. Example applications include CoMP and localization services. These tests can be combined with different Ethernet scheduler regimes and/or SDN functionality.

c) Data rate

Tests will be carried out to measure transport architecture data rates per UP and CP flows. The aim of the tests is to identify limitations in data rate and user-experienced data rate that derive from the transport architecture.

4.4.4 UoS

As one of the 5G-DRIVE trial sites, UoS will cooperate with JRC to conduct an RF characterisation and network performance evaluation at 3.5 GHz, which eMBB signals will be transmitted and tested through 5G gNBs in 5GIC trial site. The proposed KPIs for measurement have been listed in Table 7 and the actual testing results will be subject to equipment availability and deployment progress. UoS will also host UKent to jointly measure the latency as explained in Section 4.4.3. Moreover, the evaluation of NOMA technologies in eMBB will be carried by UoS team.

4.4.5 ORION Innovations PC

ORION will contribute an adaptation of its in-house developed VNFs for eMBB use cases selected specifically for the functionalities required by WP3. Examples include multimedia services (caching, watermarking, transcoding, etc.) and security services (firewall, Deep Packet Inspection (DPI), etc.). Initial development and testing will be performed in the ORION cloud infrastructure, which is based on the OpenStack Cloud Operating System, comprising of 8 compute nodes and storage system supporting SAS (Serial Attached SCSI) and iSCSI (Internet Small Computer System Interface). The ORION testbed also features SDN-enabling network devices that support OpenFlow protocol (i.e., HP 3500yl-24G[29], Dell PowerConnect 5524[30]), as well as legacy devices including firewalling and routing equipment, i.e. a Cisco 2921 Integrated Router[31], a Cisco ASA 5510 Firewall[32] and a Cisco-based VPN facility for site-to-site interconnection as well as remote integration and testing. A variety of open source tools are also available (for traffic generation, stress testing, pen testing, traffic classification etc.). The main focus of ORION is to measure for any given service, the resource utilisation, the contribution to overall latency, the capacity to scale up and the durability of the service.

The ORION cloud infrastructure integrates tools for OpenStack resource monitoring. ORION focuses on collecting data on the utilisation of the physical and virtual resources available to cloud deployments. Data can be stored and analysed, and actions or alarms can be triggered according to

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[29] Also see, *for example*: *https://support.hpe.com/hpsc/doc/public/display?docId=emr_na-c01804513*

[30] Also see: *https://www.dell.com/en-us/work/shop/cty/powerconnect-5524-switch/spd/powerconnect-5524*

[31] See: *https://www.cisco.com/c/en/us/products/routers/2921-integrated-services-router-isr/index.html*

[32] See: *https://www.cisco.com/c/en/us/support/security/asa-5510-adaptive-security-appliance/model.html*

predefined conditions set by the user. The major components of OpenStack Telemetry[33] that are deployed include:

- Aodh [7]: the alarming service that allows the user to define alarms and actions based on programmable triggers,
- Ceilometer [8]: the data collection service that monitors resource usage (similar to Barometer),
- Gnocchi [9]: a time-series database and resource indexing service (similar to Prometheus[34]),
- Panko [10]: the event and metadata indexing service,

Ceilometer monitors resource usage in OpenStack environments for resource tracking, customer billing, or to trigger other programmable capabilities. The telemetry data collection [8] services provide the following functions:

- Efficient polling of metering data related to OpenStack services.
- Collection of events and metering data by monitoring notifications sent from services.
- Transmission of collected data to various targets (including data stores and message queues.)

Gnocchi's goal is to provide a time-series resource indexing, metric storage service which enables users to capture Ceilometer metrics. Using rolling aggregation set by user-defined archival policies, it provides scalable storage of short- and long-term data and provides a statistical view based on its input.

Aodh communicates with Ceilometer and Gnocchi through the OpenStack message bus to monitor the state of the resources. The user can define threshold-based, event-based or composite alarms, following a tri-state model (“ok”, “alarm”, “insufficient data”).

Panko provides metadata indexing and event storage service, thus capturing the state information of OpenStack resources at any given time. It provides a scalable means of storing both short- and long-term data for a variety of use cases, including auditing and system debugging.

These monitoring data from Ceilometer are integrated into the NFV Orchestrator via a Kafka bus[35]. Orion deploys the ETSI-supported OpenMANO[36] (OSM[37] orchestrator) to handle deployment and lifecycle management of the network services that will be essentially later deployed in an eMBB slice. Resource utilisation data can then be collected via OpenStack, or even directly through the VNFs via an exporter to a Prometheus time series database.

ORION plans to develop specific services for the eMBB trials and test them locally to optimise resource utilisation. The developed services will then be deployed on a trial site on separate slices to assess their contribution to overall latency. Depending on the functionality of the service, and whether it is necessary for the network traffic to traverse the VNF, the effects to latency may differ.

Another important aspect relates to the scaling of the network services. Ceilometer can be used to measure [11] CPU load (MHz), RAM consumption (Gb), the total amount of instances (max number of instances spawned) and total operation time (msec). These data can be used to program “trigger” events for automated resource re-provisioning, in cooperation with OpenStack Heat[38], which features autoscaling. Autoscaling refers to on-the-fly re-provisioning of the resources assigned to a VNF, without necessarily stopping and restarting it. Otherwise, downscaling and upscaling is

[33] For further details also see, *among others*: *https://wiki.openstack.org/wiki/Telemetry*

[34] More details can be found at: *https://prometheus.io/*

[35] For more details see: *https://kafka.apache.org/*

[36] For more informative details also see: *https://osm.etsi.org/wikipub/images/5/5a/OSM_Introduction_Francisco.pdf*

[37] For further reading see: *https://osm.etsi.org/*

[38] See: *https://wiki.openstack.org/wiki/Heat*

performed after the VNF has been stopped. In order for autoscaling to work, a load balancer should be in place, to monitor and distribute the loads across all the VMs on the scaling group. Hence, autoscaling can detect, increase, decrease, and replace instances without manual intervention even across thousands of instances. This should not be confused with scale-in and scale-out of the Network Service; NS scaling refers to the addition or removal of VNFs. Some orchestrators, e.g. OSM, support scale-out and scale-in operations on running services.

Upscaling the environment, on the other hand, may refer to adding new infrastructure nodes or adding new compute hosts [12]. OpenStack is responsible for managing the nodes in the network infrastructure, provides an OpenStack-Ansible repository [13] to facilitate scaling operations (e.g. to add, remove, recover a host after a failure etc.). Scale up can then be monitored in terms of performance with Ceilometer. However, Neutron[39] testing is also important in order to estimate control plane performance (networking) with the addition of multiple nodes. OpenStack has published a full list of test plans for this purpose. These OpenStack tests extend the number of compute nodes up to the scale of 103, the number of workloads (VMs) up to the scale of 104. For Neutron, performance issues might be expected in the scale of 102.

Finally, the availability and durability of the services need to be ascertained, as well as the effect of a failure in a running service. The goal is to provide a VNF that is easily deployable, that provides “5 nines” availability to be considered carrier grade. In cases where the traffic traverses the VNF, higher availability may be required and a failure might result in adverse effects. Network services will need to be started for long periods of time and their behaviour monitored (e.g. in 24 h, 48 h, a week or more of uptime, etc.).

[39] See: *https://wiki.openstack.org/wiki/Neutron*

5 Conclusion

In this Deliverable, the trial plan in WP3 for eMBB testing, in particular for the spectrum band at 3.5 GHz, in the 5G-DRIVE project has been defined. The scope and trial setup requirements based on NGMN recommendation [2] have been listed at the beginning of this Deliverable as reference for various trial sites. Moreover, this setup will help to harmonize the measurement results calibration, which will be conduct both within 5G-DRIVE and within two regions. Detailed trial sites descriptions are also discussed in Section3 to support trial plans. In Section 4, an overall methodology for eMBB trail has been proposed, and the selected KPI relevant to eMBB trail in the 5G-DRIVE are also provided. Based on this information, specific trial plans have been designed and provided from WP3 partners either individually or jointly in various trial sites.

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Appendix A Trial Site Facility, Test Plan and Selected KPIs

In this Appendix, the facilities at each trial site planned to be used for 5G-DRIVE will be given together with the planned tests and selected KPIs. Moreover, a detailed time plan for trial measurement from WP3 partners has also been provided.

A.1 Surrey 5GIC Site

This section presents the components of the Surrey 5GIC trial site platform, which will be used for the measurements for 5G-DRIVE. The main parts have been summarised in the *Table H* below.

Table H: Infrastructure layer components.

Component	**Product/Technology**	**Mode of Implementation**
5G UE	OAI-based UEs + commercial 5G UEs, expected to be released by 2019/2020 (Vendor 3, Vendor 5)	Single instance & SDR HW
5G NR (gNB)	Vendor 3/ Vendor 4	Single instance & SDR HW
5G Core	5GIC in-house developed	Platform Specific
Transport	SDN based (HW) NE	Multiple instances
4G EPC	– 5GIC in-house developed – OAI	Platform Specific
4G eNB/Small Cells	– Vendor 3 (outdoors/indoors) – Vendor 1 (outdoors) – IP Access (indoors) – Vendor 2 (SDR) – Lab. – OAI (SDR) – Lab.	Platform Specific
4G UEs	Various Devices - Commercial 4G mobile phones (Pixel XL2, Nokia 8 Siraco, Samsung 9) + those compatible with OAI (Nexus 5, Galaxy S6)	Platform Specific
Spectrum	OFCOM provides / license for 2.3GHz, 2.6GHz, 3.5GHz & 700 MHz	-
Traffic Generators for performance / benchmarking / monitoring	– TM500 (CobhamWireless) – Landslide (Spirent) – iPerf – Open-source traffic generators	COTS devices and SW
Probes	MONROE nodes	Multiple instances deployed across the network
WIFI AP/AC	Pre-installed indoor APs in 5GIC (for Cycle 1) and FON outdoor APs (Cycle 2/3)	Multiple instances

A.1.1 5GCore

As shown in *Figure V*, the Surrey platform 5GCore (5GC) developed in-house offers Flat Distributed Core (FDC)-based user-context awareness functionality compliant to 3GPP specifications. Specifically, the FDC architecture supports the 3GPP Release 15 for the core network functionality and Rel-16 context-aware network, to intelligently interwork with 5G New Radio, both Stand-alone (SA) and Non-Stand-alone (NSA).

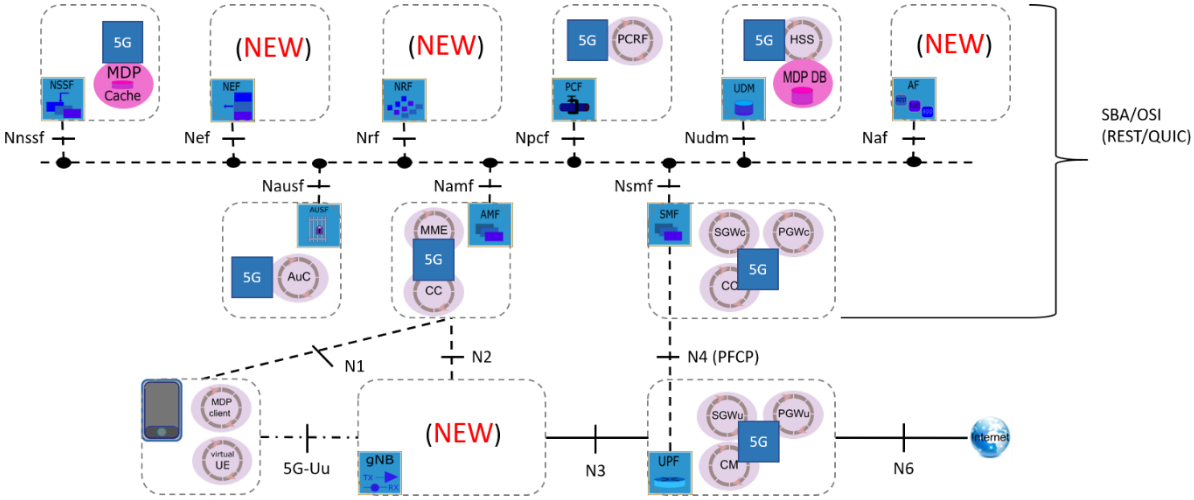

Figure V: The 3GPP Rel-15 5GC deployed at the Surrey platform.

The FDC-based architecture represents a world first 5G core network implementation addressing the needs of 5G testbeds for the project and for partners' activities. FDC-based user-context aware 5GC network includes a large level of newly implemented functions developed on top of an accelerated software platform:

• Integration with 5G New Radio: NSA [S1-MME, S1-U] and SA [N1, N2, N3],

• Implementation of control-user plane split – PFCP [N4],

• Implementation of Service-Based Architecture Features [HTTP/2, REST].

It integrates with 5G NR SA and NSA prototypes and off-the-shelf LTE access networks enabling immediate demonstration of different features and applications and supporting the current need to have a genuine 5G Core Network in addition to the evolved EPC one, and runs on top of common hardware platforms. NFs are deployed with K8S docker containers platform and virtual machines on top of a large number of virtualization environments. FDC-based architecture also supports microservices-based architectures.

A.1.2 Radio Network Domain

The radio network domain of Surrey platform includes both 3GPP and non-3GPP access technologies.

A.1.2.1 3GPP access technologies

(a) COTS 5G NR

COTS 5G NR solutions developed for 5G (once available) shall be integrated as part of larger flexible 5G network infrastructure and will allow support for a wide range of 5G use cases empowered by network slicing in the scope of 5G-DRIVE.

(b) 5G NR UE

OpenAirInterface RAN (OAI-RAN) solution is an open-source software and hardware platform providing a standard-aligned implementation (3GPP Rel. 10/14) for the LTE UE and eNB. Currently, OAI is being extended to support 5G-NR UE and gNB, as per Rel.15 standards.

The OAI software is freely distributed by the OpenAirInterface Software Alliance (OSA) and it can be deployed using standard off-the-shelf Linux-based computing equipment (Intel x86 PC architecture) and standard RF equipment (e.g., National Instruments/Ettus USRP). In this context, OAI offers a flexible framework for experimentation with prototype 4G/5G implementations of the UE and base station components.

The Surrey platform will integrate the OAI 5g-NR UE component which will be interoperable with the gNB provided from Vendor 4 to perform end-to-end experimentation and KPI measurement collection. In this context, the protocol stack extensions for 5g-NR UE will be made gradually available throughout the different phases of 5G-DRIVE, starting from the physical layer (cycle 1) and continuing with the rest of the RAN protocol stack (MAC, RRC, PDCP). The OAI UE can be launched and configured easily through a Command Line Interface (CLI). Based on this CLI the UE can also be controlled remotely through external software.

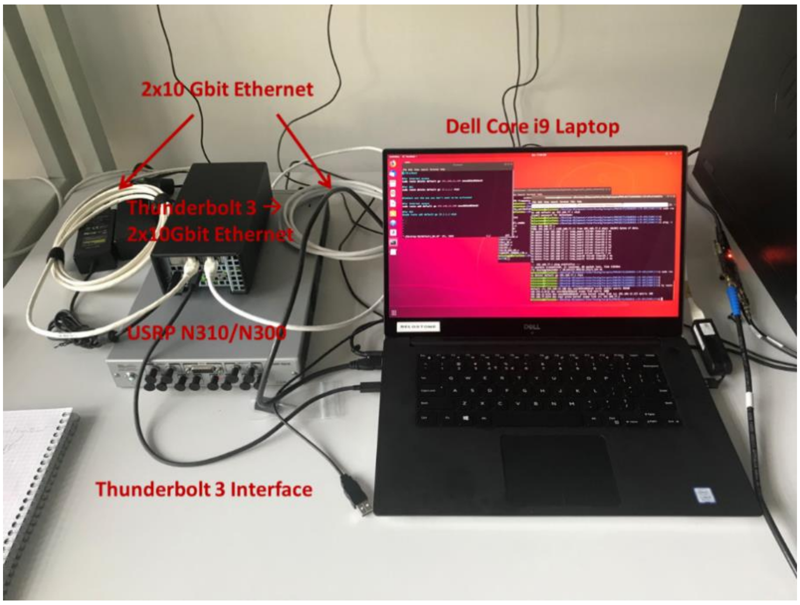

Figure W: 5G-NR UE platform running OpenAirInterface.

The hardware platform is going to use the ETTUS N310 boards together with a powerful laptop with a Core i7-7900 8 core processor. An adaptor will be used to connect the Thunderbolt 3 interface of the laptop with the 2x10Gbit Ethernet interface of the USRP. An additional RF frontend and antenna will provide enough output power and amplification to operate in an outdoor environment. A picture of the UE is given in *Figure W* and a table of hardware components in *Table I*. Given the fact that the UE is a simple software program, it can easily be launched and accessed remotely through SSH interface (provided that the Laptop is connected to the Internet through an additional connection). Performance measurements with iPerf or ping can be easily carried out directly or remotely.

Table I: Part list of 5G-NR platform.

USRP N310	ETTUS
Laptop with Intel Core i7-9700K or Core i9-9900K (8 cores) and Thunderbolt 3	Schenker, Dell, etc.
Tunderbolt3 (2x) 10Gbit Ethernet converter	Sonnettech Twin 10G or Solo 10G
3.5GHz RF frontend (PA/LNA/Switch)	Eurecom
3.5GHz Antenna	-

(c) 5G NR gNB

The 5G NR provided by Vendor 4 that will be installed at the Surrey platform consists of the Distributed Architecture with PHY layer split (ORAN[40] like) as depicted in the yellow marked area in

[40] https://www.o-ran.org/

Figure X.

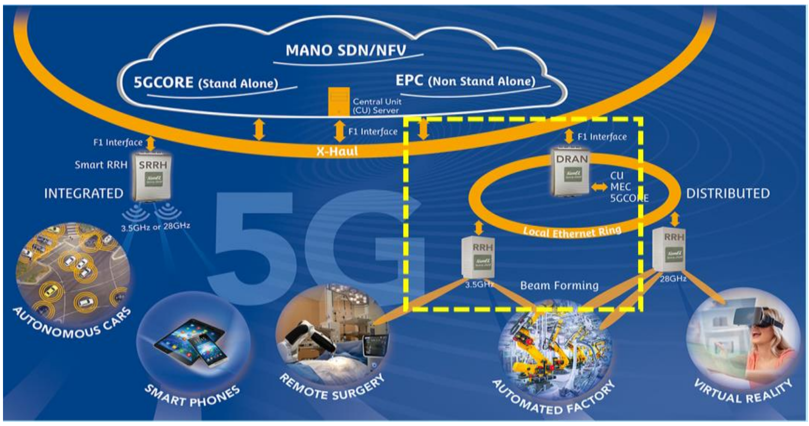

Figure X: 5G distributed Architecture from Vendor 4.

A.1.2.2 Non-3GPP access technologies

(a) WiFi

The non-3GPP access unlicensed spectrum technology WLAN integrated with 5GC will provide overlapping coverage (in addition to 4G, 5G and other non-3GPP access technologies) at the trial site and contribute to the maintenance of service continuity of the end users. A number of Access Points (APs) will be installed at the premises (site of use-case) to ensure good signal coverage.

At this stage of the project, FON has the technology to integrate WiFi interface following release 15. This release only considers NSA case for non-3GPP networks. This implies the use of 4G EPC as the core of the mobile network. Next 3GPP release will specify what to do in SA (Stand Alone) cases, but 3GPP Rel.16 specifications have not yet been released.

Non-3GPP networks are divided in the release, as either trusted or untrusted networks. In a real scenario, the operator that owns the mobile network will decide whether a network is trusted or untrusted. The deployment is a little different in each case. In this section, the integration of both kinds of networks will be described as they both are achievable.

The access points populate a specific SSID for the 5G non-3GPP network. All user traffic generated with that particular SSID will be tunnelled directly to the EPC, to the interface specified in Rel.15. In order to manage the access points, enterprise-scale deployments typically have a WiFi access controller (AC) that exposes via API and via a dashboard, the features and allows for configurations of the access points. Through the AC, the MANO is able to automatically configure APs.

Regarding the authentication, the Radius-based AAA server in the WiFi network finalizes the authentication performed in the HSS (of the mobile network). To enable this functionality, 3GPP Rel.15 defines two interfaces that are exposed by the 3GPP AAA server, acting as a proxy of the HSS.

A.1.3 Concept for Monitoring and Measurement

The Surrey platform will employ a variety of instruments/applications for conducting and reporting measurements

A.1.3.1 5GC Benchmarking Tools

The Landslide tool from Spirent, emulates network functions, control and, data plane traffic for millions of subscribers/devices as well as user activity at high scale to test mobile core, carrier Wi-Fi, IMS and Diameter networks, covering services in 5G, LTE, GSM, UMTS, and Wi-Fi networks. Spirent Landslide emulates 5G devices, user traffic and, network functions to test 5G mobile and core infrastructure, ensuring its readiness for successful 5G rollouts. Landslide's emulation and testing capabilities support 3GPP release 13 and onwards, making it ideal for validating the entire evolution path towards 5G. The Surrey platform will deploy the Landslide test server in the infrastructure to test for the functioning of packet core components/functions and to validate the KPIs.

A.1.4 Planned tests and selected KPIs at Surrey 5GIC trial site

As shown in *Table J*, the selected KPIs planned to be measured at Surrey 5GIC trial site has been summarized.

Table J: Measured KPIs at Surrey 5GIC trial site.

KPIs	At Surrey 5GIC Trial Sites
Latency	Radio latency is the radio access network contribution to the total delay between the transmitter and the receiver, expressed in ms.
Peak Data Rate	This metric denotes the maximum physical-layer throughput achievable between the 5G gNB and the UE, in Gbps.
User-experienced Data Rate	This metric denotes the average physical-layer throughput achieved between the 5G gNB and the UE during road test.
RSRP	This KPI is the received signal strength level measured by the terminal (used for coverage estimation).
SINR	This KPI presents the network quality measured by the terminal.

A.2 VTT Site

The main components of the VTT 5G trial site platform relevant for 5G-DRIVE test measurements are summarized in the *Table K* below.

Table K: Infrastructure layer components.

Component	Product/Technology	Notes
5G UE	Mediatek 5G modems	
5G NR (Macro)	Nokia Airscale (AEQD) • MAA (Massive Antenna Array) • 64T64R, 128 antenna elements • N78/B43 frequency band	
5G NR (Small Cell)	Nokia Airscale Indoor (AWHQB) • pRRH (pico RRH) • 4T4R • N78/B43	
Transport	10 Gbps SDN based backhaul using Pica8 switches	
4G EPC	Nokia EPC supporting NSA (version to be confirmed), Nokia EPC simulator	

4G eNB (Macro)	Nokia Airscale (AHHB) • RRH • 4T4R • B7	Anchor for 5G NR Macro (NSA option 3X)
4G eNB (Macro/NB-IoT)	Nokia Flexi Zone Mini-Macro Outdoor BTS (FW2PC) • 2T2R • B28	
4G eNB (Small Cell)	Nokia Airscale Indoor (AHGEHA) • pRRH (pico RRH) • 2T2R • B7 (+ B3)	Anchor for 5G NR Small Cells (NSA option 3X)
4G/5G Baseband	Nokia Airscale Subrack with • 5G Capacity module (ABIK) (for MAA) • 5G Capacity module (ABIK) (for Small cells) • 5G System module (ASIL) • 4G Capacity module (ABIA) • 4G System module (ASIA)	
Fronthaul HUB	Nokia Air Scale indoor Radio HUB (ASiR-HUB)	
Spectrum	Traficom license for 2.6GHz/10MHz (FDD-LTE) & 3.5GHz/60MHz (TDD), Operator permission/borrow 700MHz/10MHz (FDD-LTE) for NB-IoT	
Traffic Generators and performance monitoring	• iPerf • QoSmet tool • Monitor App • Nemo tool	
WIFI AP/AC	LW AP integrated to picocells	RUCKUS

A.2.1 VTT 5G trial site facilities used for 5G-DRIVE test measurements

This section presents which components of the VTT 5G trial site platform will be used for 5G-DRIVE. *Figure Y* first shows the actual radio network topology at the Espoo site for testing the NSA/SA network performance under the different 5G-DRIVE indoor hotspot and urban macro scenarios.

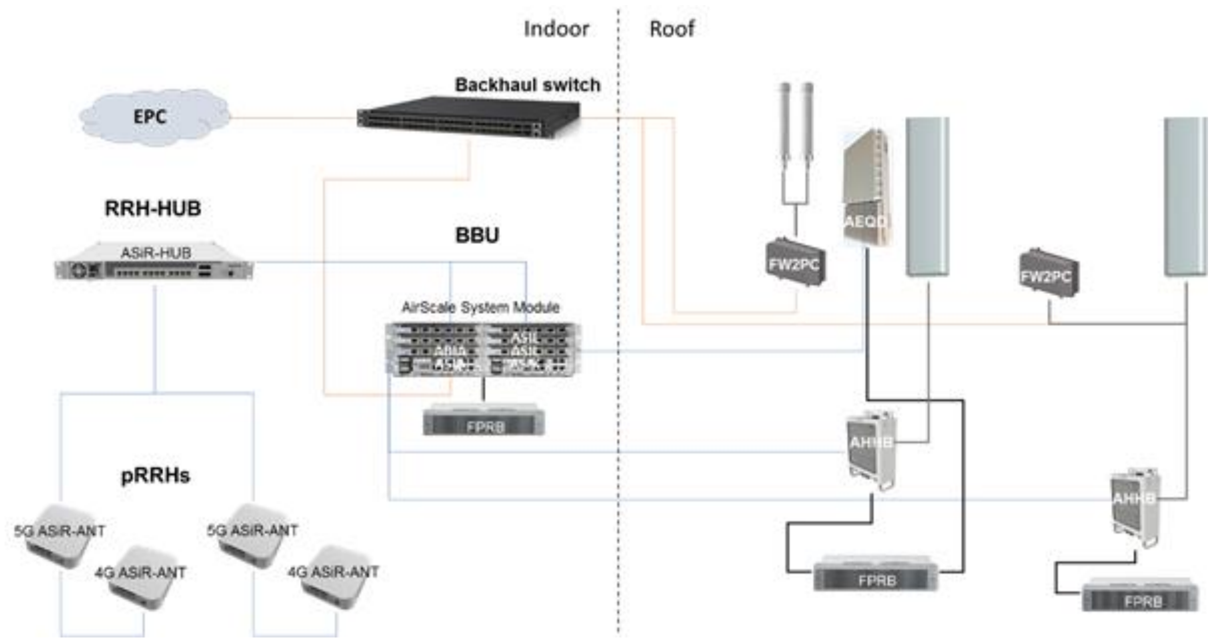

Figure Y: Network topology for 5G-DRIVE test measurements at Espoo site.

For testing the NSA/SA network performance under the different 5G-DRIVE indoor hotspot and urban macro scenarios, *Figure Z* respectively shows the actual radio network components and their interconnections at the Espoo site. The main components are detailed in the *Table K* above.

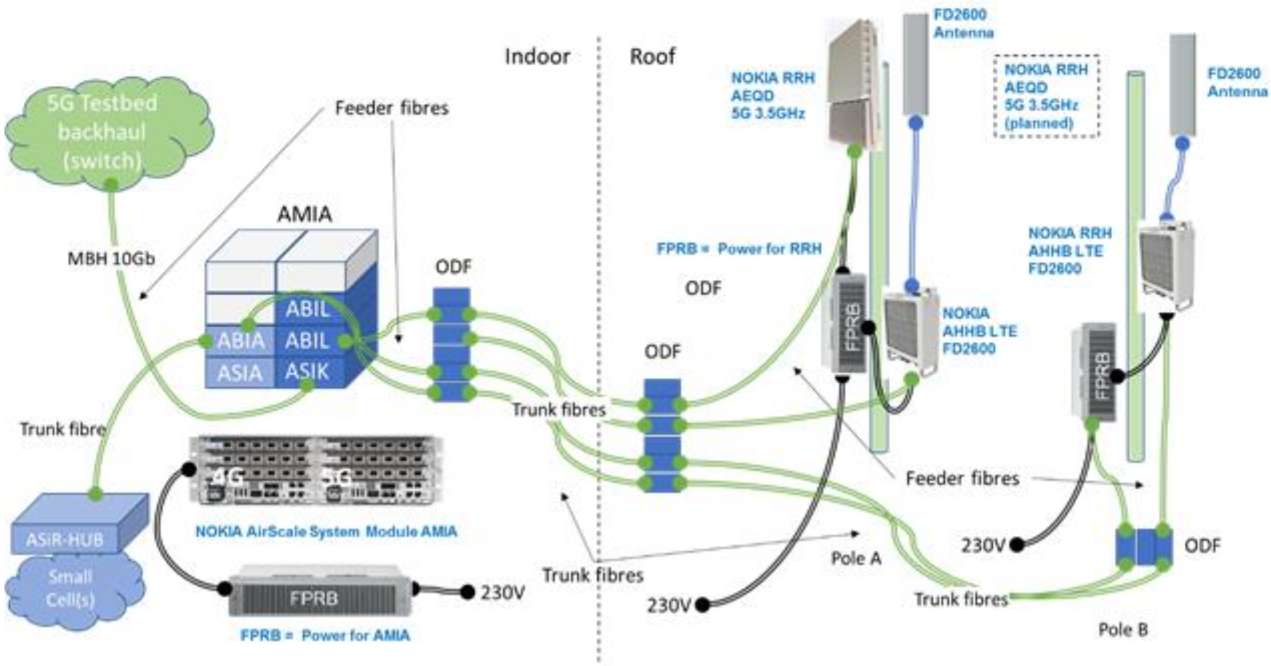

Figure Z: Network components for 5G-DRIVE test measurements at Espoo site.

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). The stars in the following *Figure AA* depict placement of the installed picocells. All test measurements are carried out with a mobile robot, which obtains reference location information with a LIDAR and SLAM algorithms. 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 *Figure AA*, 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.

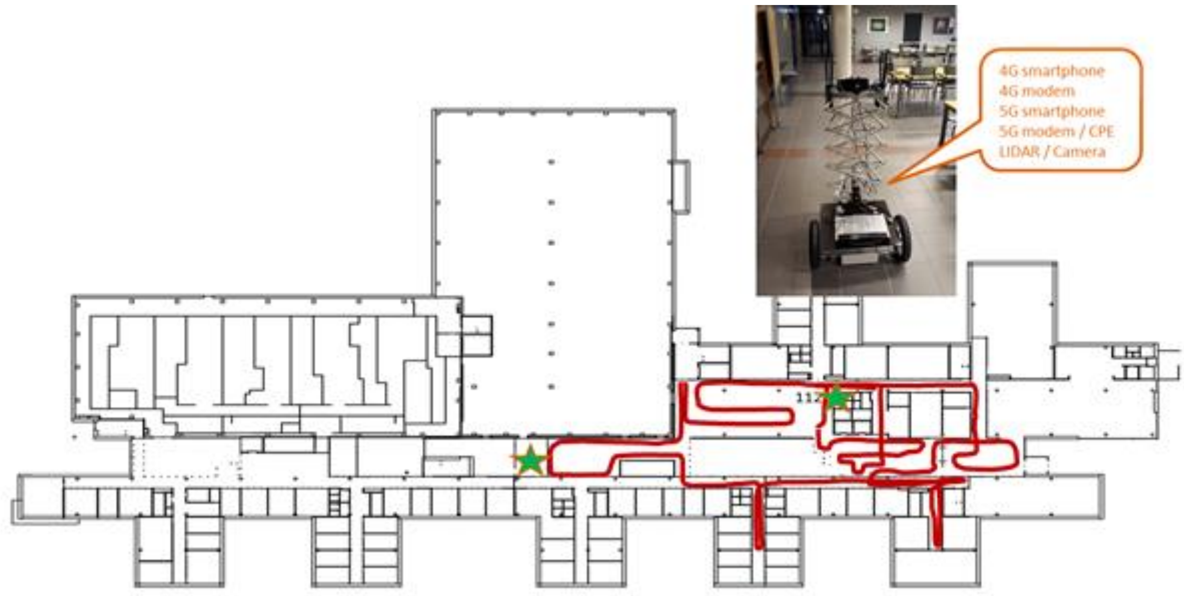

Figure AA: Measurement route in the Micronova building at Espoo site.

The urban macro trial in Espoo focuses on continuous coverage in urban areas. The measurement procedure in the urban macro trial is the same as in the indoor hotspot trial, except that the reference location information is obtained with RTK (Real Time Kinematics) devices.

A.2.2 5G-DRIVE test measurements conducted at VTT 5G trial site

This subsection describes the test setup and procedure for single/multiple pRRU UL/DL throughput and coverage, while the actual execution may be modified during the test subject to availability. The KPIs test methodology follows the NGMN trial framework document [1]. The main objectives include to test the coverage of single/multiple pRRUs under NR frequency band as well as to test the service capabilities of the single/multiple pRRUs.

Following are some example test conditions and example procedure steps to describe the testing. The base station configurations include single/multiple distributed pRRU coverage (3.5 GHz) without external antennas. The trial site also has single/multiple FD-LTE pRRU coverage (2.5 GHz). The BBU connects 1 RHUB, and the RHUB connects to the pRRU. A single cell configuration provides 100 MHz bandwidth connectivity, which is supported by the UE. The pRRU coverage is tested with TCP/UDP traffic service following a path from the cell center to the edge.

The first step is that the test UE (e.g. NEMO tool) connects to the pRRU cell. In case of a single pRRU condition, the NEMO test software is used to perform cell locking of the terminal. The test UE then runs FTP downlink service. An indoor robot is utilized to move the test UE along the predefined path to the edge of the cell, i.e. until throughput drops to near zero or until there is no ping to the network. For verification, this procedure step is carried out twice.

All data parameters are recorded including timestamps, location (x and y coordinates in a building's coordinate system), RSRP, SINR/RSRQ, CQI, UL and DL data rates with UDP and TCP/IP traffic (small packet size), and RTT (ping). As far as indoor coverage tests are concerned, the most important test parameters are throughput and RTT. The record data includes also the constellation and distance of the pRRUs.

A.2.3 KPIs measured in planned 5G-DRIVE tests at VTT 5G trial site

As shown in *Table L*, he following KPIs are the most relevant for the above planned 5G-DRIVE network coverage tests at the VTT 5G trial site.

Table L: Measured KPIs at VTT trial site.

KPIs measured	at VTT 5G trial site
Peak data rate	This metric denotes the maximum physical-layer throughput achievable between the 5G gNB and the UE, in Gbps.
Jitter	This KPI denotes the variation in the delay experienced by received packets (in ms).
Latency	Radio latency is the radio access network contribution to the total delay between the transmitter and the receiver, expressed in ms.
RSRP	This KPI is the received signal strength level measured by the terminal (used for coverage estimation).
SINR/RSRQ	This KPI presents the network quality measured by the terminal.
CQI	This KPI presents the channel quality measured by the terminal.

A.3 Trial Time plan

In this section, detailed time plan for all WP3 partners are summarised as below in *Table M*.

Table M: WP3 Trial time plan.

Tasks	Trial topic	Partners	Planned start time	Planned finish time	Trial sites
Task 3.1	NSA basic performance measurement	UoS	June 2019	January 2020	Surrey 5GIC trial site
	SA basic performance measurement	UoS	November 2019	June 2020	Surrey 5GIC trial site
	Indoor coverage performance measurement	VTT	October 2019	April 2020	VTT 5G trial site
	MIMO trial test	UKent, VTT	June 2019	August 2020	VTT 5G trial site
Task 3.2	Network Slicing test	VTT	November 2019	May 2020	VTT 5G trial site

	X-hual latency test	UKent, VTT	July 2019	April 2020	VTT 5G trial site
	VNF test	Orion	September 2019	June 2020	Orion test-bed

[end of document]